DECEMBER 2020 VOLUME 11

ASIAN RESEARCH POLICY

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VOLUME 11 ASIAN RESEARCH POLICY

KISTEP Korea Institute of S&T Evaluation and Planning

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A S T N

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R&D has never been more called upon: COVID-19 and related S&T policies

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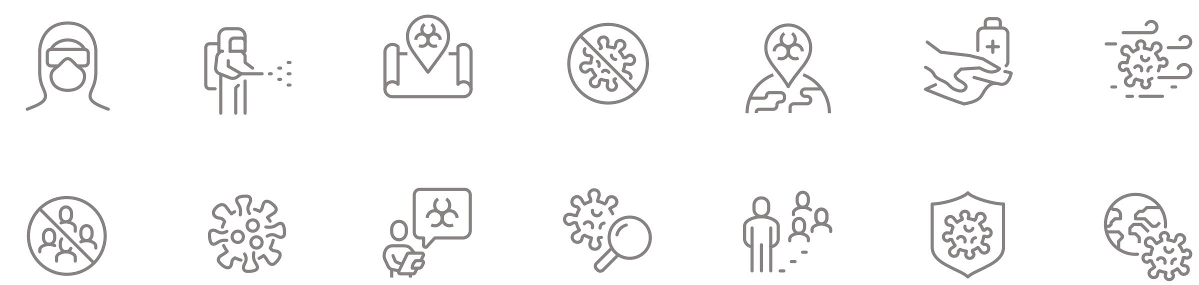


ASIAN RESEARCH POLICY

Enhancing the knowledge on science and technology policy issues in Asia

Published by KISTEP

contents

Foreword

Dear readers,

We are delighted to welcome you to our 11th issue of Asian Research Policy (ARP).

Since its launch in 2010, ARP serves as a unique facilitator of the cooperation and collaboration amongst more than 400 policymaking institutes in Asia. ARP focuses on policies and research outcomes on science, technology, innovation, and discusses timely crucial issues in depth.

This issue of ARP is even more special as we welcome our valued ASTN (Asian STI Think Tanks Network) members joining ARP 2020 as Editorial Board. ASTN, mainly consists of leading institutes of Asian innovation, has been actively participated in AIF (Asian Innovation Forum) for the last 5 years to share innovation experiences and development strategies. In continuation of the tangible network, I hope ARP will continue to act as an active platform to navigate STI polices across Asia starting from 2020.

Considering current pandemic, this issue features timely and thought-provoking articles and op-eds on COVID-19 and related STI polices, preferably in Asia. We hope our readers will find them informative and insightful as they reevaluate STI policies towards this global issue.

I truly believe that Asian Research Policy will become a practical network among key actors of Asian STI policy making by addressing emerging issues and taking the initiative in developing a global agenda in STI.
I would like to extend our sincere gratitude to authors who have contributed in publication of ARP 2020 by sharing their invaluable knowledge and insight to the world in time of need.

We all hope you enjoy ARP this year.

Respectfully yours,

Sang-Seon Kim,
President of KISTEP

Introduction of Asian STI Institutes

KISTEP

STPI NARLabs

Bridge to the Future

KISTEP

WHO WE ARE

Today, our lives are built upon Science and Technology.
ICT connects us all, biotechnology makes us healthier and prosperous,
energy technology provides us a comfortable life, and AI technology smartizes things surrounding us.
'Innovation' has been chosen as a breakthrough for the uncertain future caused by rapid social changes and financial crisis.
Science, Technology and Innovation (STI) is becoming an essential tool for discovering new growth engines and economic growth.
Being central in our lives, STI generates a sustainable and promising society through innovation.
Taking the central role in STI, KISTEP leads national innovation as a Think-Tank.

Vision

A Global Institute that Creates Innovative Values for the Future

Mission

- To raise the effectiveness of R&D investment through enhancing the specialty in S&T planning and evaluation
- To create innovative growth engines through strengthening researches for policy and preemptively responding to future issues

Strategy

- Support and implement policies that the public can participate and understand
- Act as a mediator and expand communication for the embedment of policies
- Strengthen strategy researches and planning to make a leap forward as a Think-Tank

1999
Feb. Establishment of KISTEP

2001
Jul. Reorganized and strengthened planning function of KISTEP

2005
Jan. Redirected KISTEP's main functions to national S&T planning, coordination and R&D evaluation

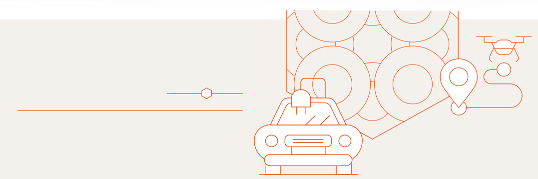
2011
Mar. KISTEP's affiliation was transferred to National Science & Technology Council (NSTC) from the Ministry of Education, Science and Technology
Nov. Assumed full responsibility for feasibility studies on R&D programs

2013
Mar. KISTEP's affiliation was transferred to the Ministry of Science, ICT and Future Planning (MSIP) from NSTC

2016
Jul. Ranked 'Excellent' in Mission-oriented GRI Evaluation

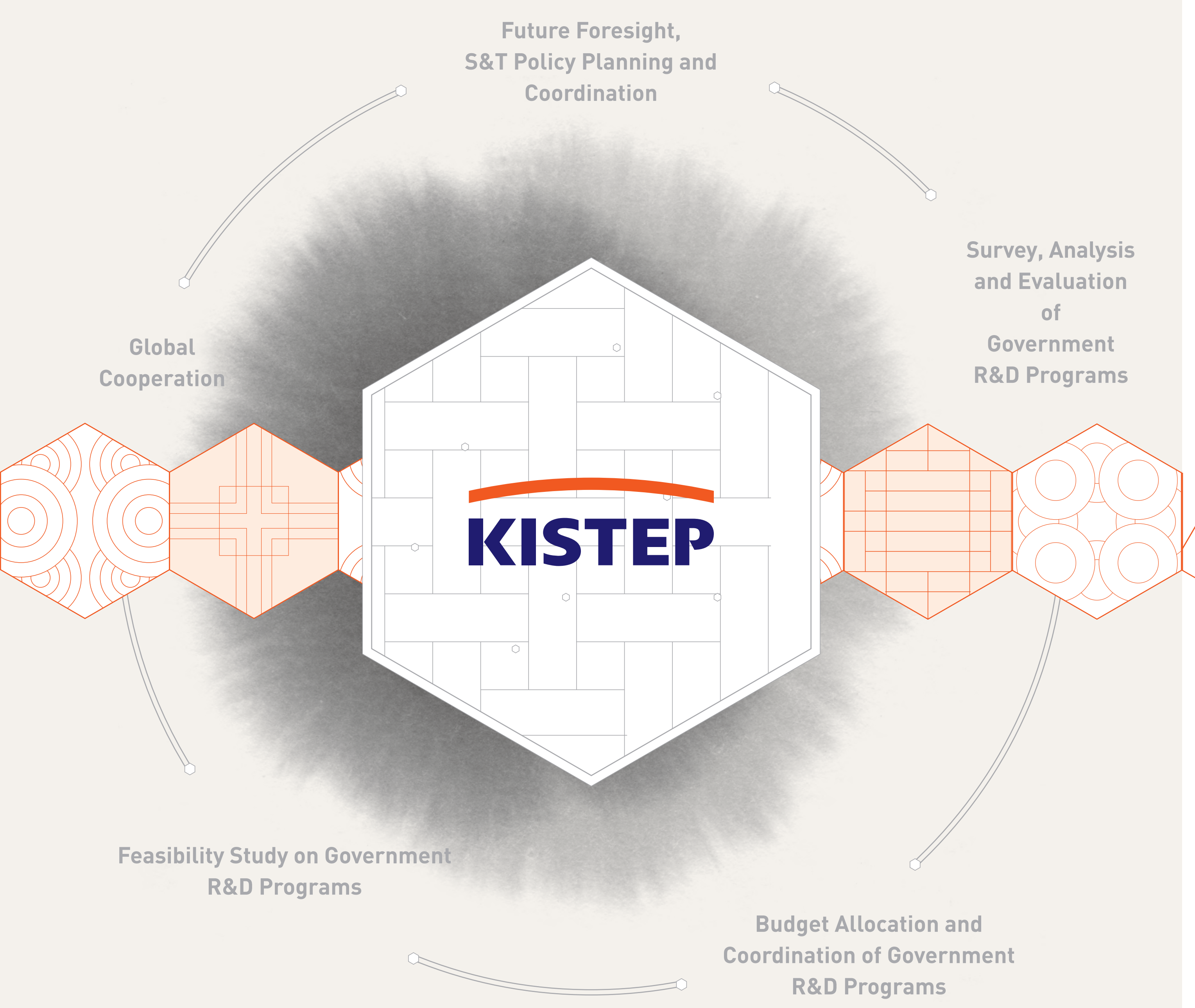
2019
Jul. KISTEP's affiliation was transferred to the Ministry of Science and ICT (MSIT) from MSIP

2020
Feb. Relocation to Chungbuk Innovation City



KISTEP is the only institute in Korea that encompasses all the aspects of national science and technology (S&T) planning, coordination and evaluation.

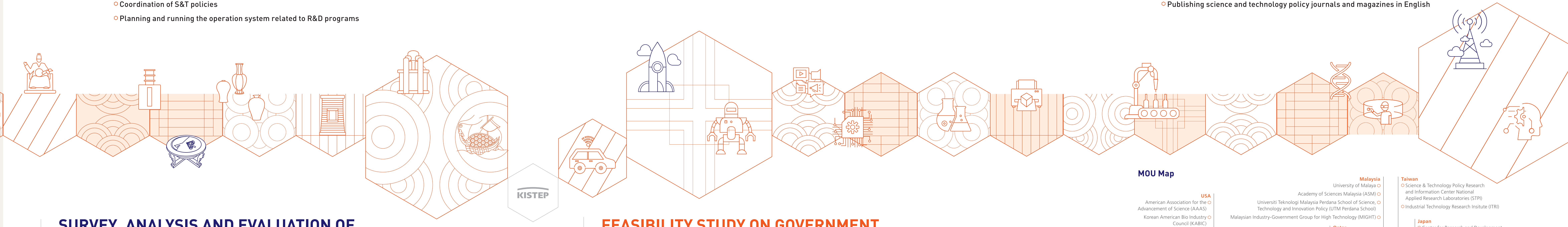
WHAT WE DO



FUTURE FORESIGHT, S&T POLICY PLANNING AND COORDINATION

Perform activities such as future trend analysis, technology foresight studies, technology level evaluation, technology impact assessment, and the development of the national standard S&T classification system in order to establish the national S&T strategies.

- Foreseeing scientific and technological future outlook
- Supporting the national S&T strategy establishment
- Performing technology level evaluation (every 2 years), technology assessment (every year), and establishing the national standard S&T classification system
- Policy planning for S&T
- Coordination of S&T policies
- Planning and running the operation system related to R&D programs



SURVEY, ANALYSIS AND EVALUATION OF GOVERNMENT R&D PROGRAMS

Conduct survey and analysis on all R&D investments and performances both in public and private sectors, evaluate government R&D programs based on these surveys and analysis, investigate notable performances, and establish effective measures to diffuse performance from government R&D programs.

- Surveying and analyzing government R&D programs and R&D activities in Korea
- Evaluating government R&D programs and government-funded research institutes
- Establishing the strategies for R&D performance diffusion and national intellectual property
- Publishing COmposite S&T Innovation Index (COSTII)

BUDGET ALLOCATION AND COORDINATION OF GOVERNMENT R&D PROGRAMS

Provide the outlays of government R&D budget allocation and coordination for a strategic investment in government R&D programs, establish directions and standards in overall government R&D investments and related budget deliberation, and investigate the investment strategies in association with S&T policies and technology development status.

- Providing support for establishing the directions for the effective government R&D investments and the standards of budget deliberation for the government R&D programs
- Supporting budget allocation and its coordination of government R&D programs

FEASIBILITY STUDY ON GOVERNMENT R&D PROGRAMS

Perform feasibility studies on new large-scale government R&D program, and conduct preliminary technological assessments to select suitable R&D programs that are qualified for feasibility study in order to verify the appropriateness of government investment prior to funding.

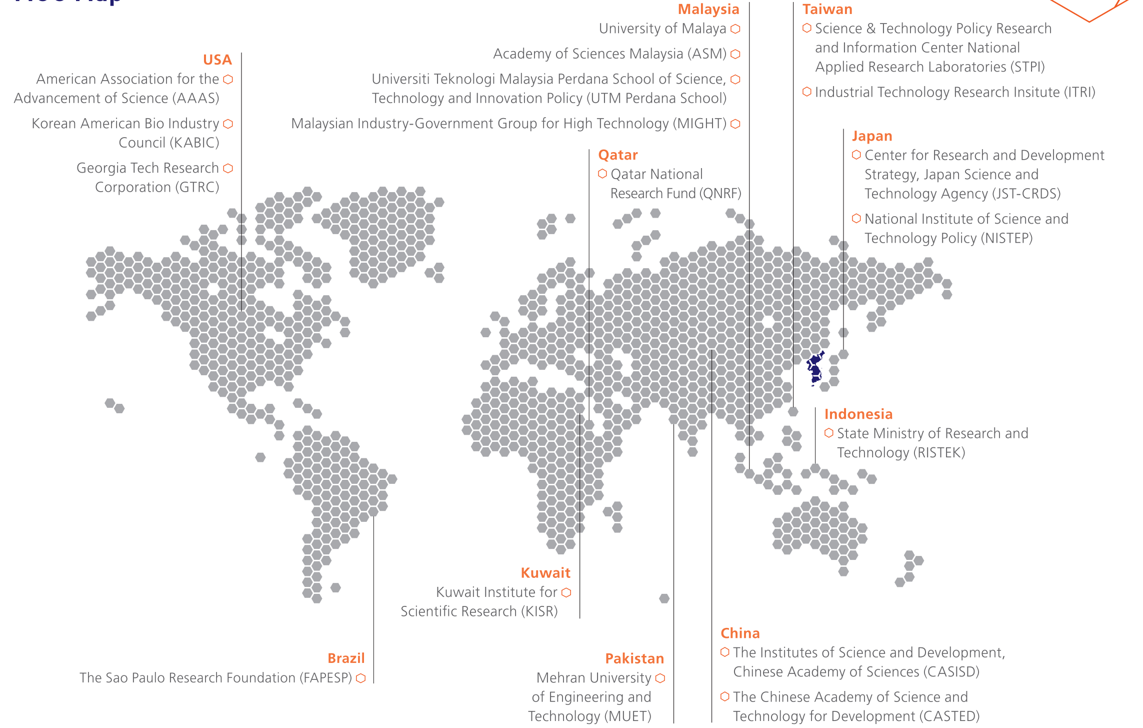
- Feasibility study on government R&D programs
- Preliminary technological assessment to select appropriate programs qualified for the feasibility study
- Research on improving the preliminary feasibility study system

GLOBAL COOPERATION

Share knowledge and experiences from national S&T-guided innovation with other countries, make various efforts to form the S&T network and S&T knowledge exchange hub with international communities, and collaborate with partner institutes.

- Establishing a global cooperation platform and strengthening national S&T diplomatic capacities with developed and developing countries, and international communities
- Sharing the experiences from national S&T-driven innovation in Korea with developing countries by providing S&T policy training programs and offering support to design their own S&T-guided master plans for building S&T innovation platforms
- Publishing science and technology policy journals and magazines in English

MOU Map



HOW WE WORK

every **5** years — ‘National S&T Foresight’ is conducted by KISTEP

every **5** years — ‘National S&T Basic Plan’ is established by KISTEP

every **1** year — the budget of government R&D programs are allocated and coordinated by KISTEP
(approx. 20 trillion KRW for 652 programs of 21 ministries in 2019)

about **35** — Preliminary Feasibility Studies (PFS) of new government R&D programs are performed by KISTEP every year

about **340** — national R&D programs are evaluated by KISTEP every year

about **51** institutes of **25** countries have cooperated with KISTEP

KISTEP R&D and Beyond

10 Emerging Technologies

Main Science & Technology Indicators of Korea

* All reports and policy materials published by KISTEP can be downloaded from the KISTEP homepage 〈Publication〉 section.

KISTEP Korea Institute of S&T Evaluation and Planning

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KISTEP
BRIDGE to the FUTURE

A Member of NARLabs
Science & Technology Policy Research and Information Center

STPI

2020

A Member of NARLabs
STPI
Science & Technology Policy
Research and Information Center

Policy Oriented, Technologically Innovative

Functioning as the main government think-tank for science and technology policy, STPI aims to support the government on S&T policy planning, evaluation and program management with advice regarding mid-and long-term technological development. STPI provides multifaceted assistance to the government to accelerate technological development and showcase research achievements, serving to enhance the global competitiveness of Taiwan.

1974

Science and Technology Information Center, NSC

Providing information services for domestic research institutions.

2005

Science & Technology Policy Research and Information Center, NARLabs

Performing research in S&T policy to support the government on promoting technological develop ment and innovation.

NARLabs

Science & Technology Policy Research and Information Center

- Policy Research Division
- Databases & Information Service Division
- Innovation & Entrepreneurship Promotion Division
- Information Management Division
- Administration Division
- Planning & Promotion Division
- Finance & Accoounting Division

Missions

1 To support the government on S&T policy planning

- Make recommendations in the S&T policy formulation process.
- Monitor international S&T policies and observe technological development in Taiwan.
- Link universities with research institutions and establish S&T policy research networks.
- Identify critical issues in S&T policies and provide analyses and suggestions.

Achievements

Assisted the Ministry of Science and Technology to organize the 10th National Science and Technology Conference, compiled the National Science and Technology Development Plan and formulated strategies for promoting AI technology in Taiwan.

2 To assist the government in evaluation and management of S&T programs

- Assist in reviewing and managing the government's S&T programs.
- Establish databases for national S&T research and development, including the National Profiles of Human Resources in Science and Technology (NPHRST) and Policy Research Indicators Database (PRIDE).

Achievements

Assisted the Board of Science and Technology of the Executive Yuan in launching the "Science & Technology Program Executive Review Board" and facilitating management and support services.

3 To promote major national S&T programs

(e.g. cultivating innovative and entrepreneurship talents)

- Plan and promote innovation and entrepreneurship talent training programs for the Ministry of Science and Technology and create an environment conducive to technological innovation.
- Cultivate young and talented innovators and connect them with the global innovation community.

Achievements

Assisted the Ministry of Science and Technology to execute the "From IP to IPO" (FITI) Program. A total of 1,632 business proposals were formulated over a course of 5 years (as of 2017), helping establish 139 startup companies with 553 employees and raise over NT$2.1 billion.

4 To establish S&T information systems and provide integrated services

- Maintain the Consortium on Core Electronic Resources in Taiwan (CONCERT). Assist 200 academic institutions in price negotiations and acquire more than 100 domestic and foreign databases.
- Maintain the Nationwide Document Delivery Service (NDDS) and provide Inter-Library Loan service for over 400 institutions.

Achievements

Negotiated the price of Science Direct and successfully reduced the cost and upgraded NDDS to meet the users' needs.

Major Reports

KISTEP
Strategies for the National Innovation System
in the Era of Post COVID-19

STPI
Analysis of Energy Research Fronts

Strategies for the National Innovation System in the Era of Post COVID-19

Jang-Jae Lee
KISTEP, Eumseong, Republic of Korea
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1. The world we are living today

The world is now battling World War III without gunfire. There are fierce battles between the infectious disease and economic activities in every part of the human world. It is the war against the COVID-19 pandemic. There are over 10 million confirmed cases with a death toll of 500,000 from 214 countries as of June 29, the mortality rate is approximately 4.92%. The COVID-19 that began to spread by the end of 2019 went on to the next year. It is the war on the virus in which the largest number of countries is involved for a single event since the world war II, causing the worst employment issue along with the massive economic damage. The Washington Post predicted that the COVID-19 will cost US economy USD 7.9 trillion (KRW 9,480 trillion) through 2030 based on the budget and economic outlook of the Congressional Budget Office (CBO).

COVID-19 continues to spread as of the end of June. There are approximately 200,000 new victims of the disease on average. Many experts cautiously predict that the COVID-19 infection will be continued until we have a vaccine and medicine for the disease and there will be the second big wave in the second half of this year. In the meantime, it is expected that the outbreaks of emerging infectious diseases may occur more frequently, causing more concerns, and there is a growing need to come up with permanent measures, instead of one-time approaches.

Korea is considered as an exemplary model in the fight against the disease. It means that the country has become one of the representative countries that succeed in catching two rabbits of controlling the disease and engaging in economic activities at the same time. Specifically, the fact that the country successfully respond to COVID-19 with the aggressive testing, isolation of people confirmed with the disease, and social distancing only without closing national or local borders was highly recognized by the world as evidenced by reports from "What we can learn from South Korea about containing COVID-19"(CNN) and "Special Report: How Korea trounced U.S. in race to test people for coronavirus" (Reuter).

COVID-19 is an infectious disease that has impacted on the life of humanity most significantly since the 20th century and it may lead a new paradigm shift along with the acceleration of the paradigm of the 4th industrial revolution. The discussions on a new normal after COVID-19 are already made. As noted by Thomas Freidman, an American opinion columnist and author of 'The World is Flat: A Brief History of the 21st Century', the world is now divided into the world B.C. -Before Corona- and the world A.C. -After Corona. It implies that we should not only respond to the global COVID-19 pandemic in the short term, but also we should prepare measures from the mid/long-term perspectives.

With regard to this, this article first provides a review on discussions on the essence of socio-economic impact of COVID-19 and the roles of government, diagnoses the national innovation system, and develops directions on the national innovation system to move forward in the future as well as strategies to achieve the goals.

2. The socio-economic impact of the COVID-19 pandemic

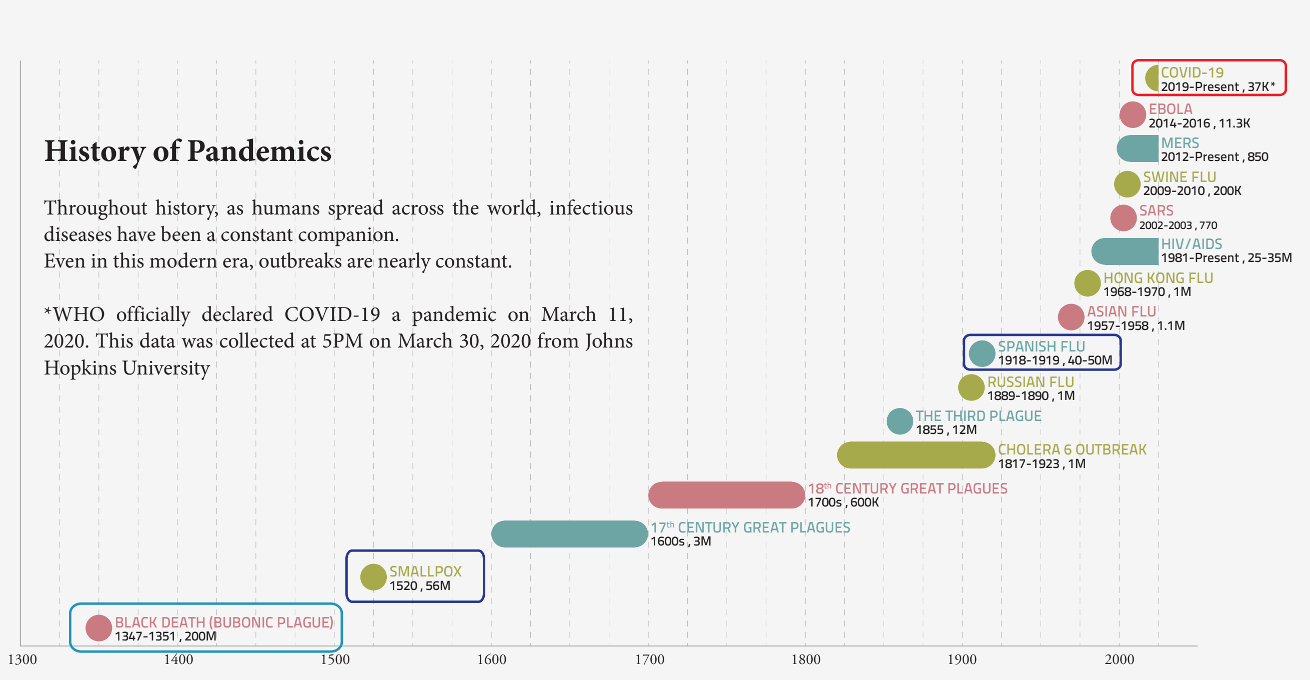
A. Differences between COVID-19 and other major infectious diseases

The Black Death is the deadliest pandemic recorded in human history which swept through Europe in the 14th century. The Black Death resulted in the deaths of approximately 200 million for the last 4 years. Another notorious infectious disease is Smallpox and the World Health Organization (WHO) certified the global eradication of the disease in August, 1980. The Smallpox has been with us for centuries and it was known to play a major role in the collapse of the Inca Empire in the 16th century. The Spanish flu was another infectious disease that had the biggest impact on the humanity in a short period of time. Since the outbreak in 1918, the disease took the lives of up to 500 million people for about 10 years. Comparing to such most contagious diseases spread to become pandemics (an epidemic of an infectious disease that has spread across the world), COVID-19 has very different characteristics. First, COVID-19 is highly contagious pathogenic viral infection and spread rapidly around the whole world due to onward transmission. It takes a long time to treat the disease, but its mortality rate is relatively low. Second, it is highly likely that young people may show no symptoms, but people with underlying medical conditions and seniors have shown critical symptoms, even leading to death. COVID-19 is a highly variable disease due to the characteristics of the virus. Hence, experts predict that it will take more than 1 year to develop a vaccine or treatment for COVID-19.

The governments of the world are now going through touch times to tackle the economic fallout caused by characteristics of COVID-19. They had to close their borders due to the rapid spread of the disease with infection rates, and which halted the economic activity leading to the rapid decline in jobs. However, the number of people who are willing to work has not shrunken owing to the asymptomatic characteristics of the disease with low mortality rates. Some experts argue that the economic damage from COVID-19 would be equivalent to that of the Great Depression in the 1930s. That is why countries of the world are investing heavily for the diagnosis, prevention, and development of vaccine and treatment of COVID-19, disaster relief fund, and restoration of the economy.

B. The socio-economic impact of the COVID-19 pandemic

It is expected that COVID-19 brings or will bring huge changes in our society and economy in diverse



Source: James Allen Insurance, https://jamesalleninsurance.com/coverage/commercial/pandemic-insurance-policy/

[Figure 1] History of pandemics (global epidemic)

aspects. "The COVID-19 outbreak will transform the way that we think about everything from family and healthcare to politics" (The Wall Street Journal, March 28, 2020). "'Covidiverces' and 'Coronababies': Life during a lockdown across the world. The pandemic is radically altering approaches to love, dating, sex and family relations, and the internet has emerged as a lifeline to millions of single people" (The New York Times, March 30, 2020) are examples of news report covering the impact of COVID-19. Key changes in our society and economy due to COVID-19 can be summarized as the spread of untact (non-contact) culture, increasing interest in health and environment, promotion of digital transformation, and acceleration of the 4th industrial revolution.

First, the spread of non-contact culture can be divided into two sub-categories. The former is the consumption paradigm shift. Specifically, the expansion of online consumer market, spread of the subscription economy, increase in indirect shopping experience are belonged to this category. The latter is the change in leisure and physical activities and examples are the spread of Home Ludens (a home for play)[1] culture and ontact (contact online), growth of online game market, etc. The second change is an increasing interest in health and environment, and which, too, can be classified as two areas. The former is the opening of remote medicine in full swing owing to the growing interest in health and hygiene, emergence of digital healthcare, increasing demand for wellness tourism, etc. The latter is the promotion

[Table 1] Paradigm shift due to COVID-19

Classification	Major changes	Examples
Spread of untact (non-contact) culture	Paradigm shift in consumption	▪ Expansion of online consumer market ▪ Spread of subscription economy* ▪ Increase in indirect shopping experience
	Changes in leisure and physical activities	▪ Spread of Home Ludens culture ▪ Spread of ontact (contact online) culture ▪ Growth of online game market ▪ Increase of non-contact transport means
Increasing interest in health and environment	Heightened interest in health and hygiene	▪ Opening of remote medicine in full swing ▪ Emergence of digital healthcare ▪ Increasing demand for wellness tourism ▪ Expansion of the health functional food (HFF) market
	A life taking care of the natural environment	▪ Promotion of echo life ▪ Expansion of the meat substitutes market ▪ Increasing demand for EVs/autonomous vehicles
Promotion of digital transformation	Changing work areas and methods	▪ Increasing demand for remote work ▪ Expansion of remote learning ▪ Promotion of digital finance ▪ Realization of smart administration
	Spread of unmanned solutions	▪ Spread of automation ▪ Advancement of unmanned technologies ▪ Increasing dependence on robots
Acceleration of the 4th industrial revolution	▪ Internet of Things (IoT) ▪ Big data ▪ Artificial Intelligence (AI) ▪ 3D printing ▪ 5G network ▪ Blockchain ▪ Cloud, etc.	

Subscription economy: It refers to an economic activity of consumers to receive desired products or services for a certain period by paying for the products or services on a regular basis
Source: Park Young-seo (2020), Paradigm shifts after COVID-19 and business strategies for the new normal

of echo life to care for the natural environment, expansion of the meat substitutes market, and increasing demand for EVs and autonomous vehicles. Third, changing work areas and methods thanks to the digital transformation and expansion of unmanned solution are noteworthy. The changing work areas and methods take the form of increasing demand for remote work, expansion of remote learning, promotion of digital finance, and realization of smart administration. As for the latter, the spread of automation, advance of unmanned technologies, increasing dependence on robots are the examples. Lastly, the symptoms of accelerating the 4th industrial revolution are found in technological advances such as IoT, big data, AI, 3D printing, 5G network, blockchain, and cloud (see [Table 1]).

C. Failure of a small government and changing social/economic values

Currently, discussions on the role of the government are underway due to COVID-19. Such discussion were brought after countries like the UK that have followed the small government notion failed to respond to COVID-19. The UK is a representative country privatizing or outsourcing government

1) The term was originated from Homo Ludens (playing man or a man of pleasure) argued by a Dutch historian Johan Huizinga and its meaning was transformed into a home for play. The word is currently used to describe activities and people who stay at home to work, rest, and play due to COVID-19.

functions to improve the efficiency. When a nation faces an emergency like COVID-19, the public sector of such countries has failed to fulfill its capacity, and countries have less options they can choose in order to response to the national disaster. It was due to that investment to build the capability of the public sector has reduced, while depending more on the private sector (Mazzucato & Ouaggiotto, May 19, 2020).

On the contrary, countries like Korea, Vietnam, and New Zealand are considered as ones that the government played its given roles successfully. That is why a necessity to build an efficient governance structure is emphasized along with the production and procurement capability of the government, public/private cooperation for the public interest, and the importance of building a digital infrastructure. At the same time, a need to develop the 'public/private partnership (PPP)' upon outsourcing critical capability of a nation to the private sector in order to serve for the public interest first is raised.

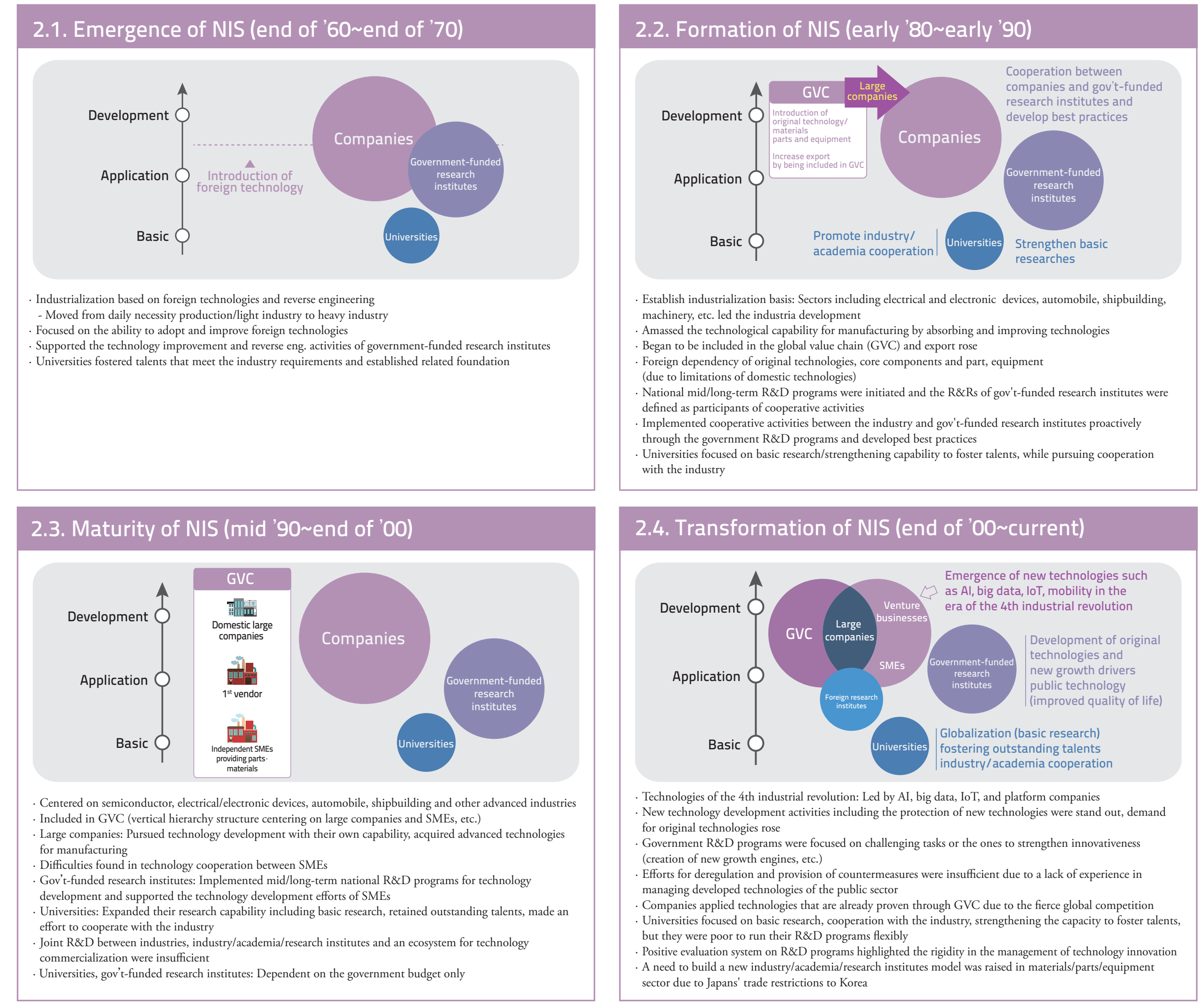
In the meantime, the effort to strengthen the roles and capability of the government such as building a social safety net and disaster alert system, and developing biotechnologies in response to emerging infectious diseases as national assets as well as new functions of the government to establish related governance structure are expected to be discussed in line with the failure of small government after the COVID-19 pandemic.

There is a growing demand for re-evaluating values that are highly praised in socioeconomic aspects as well, while discussing on the roles of the government. To be specific, more people are arguing that we need to review on the efficiency, performance-centric approach, integration, and others that are considered as the essence of capitalism until recently (Lee Jang-jae, 2020b). Instead, values like publicness, effectiveness, decentralization and redundancy began to stand out. In a nutshell, the time has come that we need to explore options to strike a new balance in the value system.

3. A diagnosis on the status of national innovation system (NIS)

The national innovation system (NIS) of a country is not fixed. Rather, it is flexible and changes while interacting with domestic/international politics, economy, society, culture, and technological environment (Lee Jang-jae, et al., 2019). Each country has its unique development paths and such elements affect the selection and implementation of NIS. For countries that have to chase others, therefore, matters on how to establish a NIS that would serve best for their development paths or how to improve the current system are significantly important topics for discussions to determine their approaches to build the NIS. In reality, many countries feel the need to improve their national innovation system due to its inefficiency or inconsistency with the environment of the time. With regard to the discussion on NIS, the roles of the government that can have an impact on all players leading the innovation, the system, and their functions are considered as important. Here, approaches for NIS have become useful tools to develop policy options to build the optimum NIS (Lee Jang-jae, et al., 2019).

The national innovation system of Korea has developed following the stages of emergence in the 1960s, formation in the early 1990s, and maturity in the mid-1990s and end of 2000s (see [Figure 2]). The national innovation system of today has a series of characteristics as follows (Lee Jang-jae, et al., 2019).



Source: Lee Jang-jae, et al.(2019), as cited in Lee Jang-jae (2020a)

[Figure 2] The evolution and characteristics of the national innovation system in KOREA

First, the country pursued a strategy to innovate its technologies to bridge the gap as a follower and which led to a phenomenon of path dependency. Therefore, the symptom of the 'loss of premium on the innovation of technologies as a follower' is getting worse as evidenced by the recent decline of the potential rate of growth. It appears that the law of diminishing marginal utility is applied rapidly when it comes to the performance of catch-up innovation technology path. Second, measures to respond to the paradigm shift in technology, economy and society properly in the era of the 4th industrial revolution that induces the transition to a new era of technology innovation are not insufficient. It is due to that the country fails to transform its development path from catch-up to post catch-up. Third, a series of symptoms are detected in the structure as a result that technology innovation was largely occurred by being reliant on external sources, rather than by being motivated and led by internal force. The decoupling of domestic innovation leaders who prefer to be linked with and operated by the external sources of innovation than interacting and cooperating with each other, and their decentralization and fragmentation are largely noticed. As the manufacturing process of multinationals operating in Korea maintains the optimal state of operation as it is belonged to the global supply chain or global value chain (GVC), the linkage of domestic innovation leaders with it is relatively weak. Therefore, the decoupling brings difficulties for the industry, academia, research institutes work together throughout the entire process from technology innovation to economic activities and it also intervenes the learning from the flow of knowledge, undermining the performance of technology innovation.

Fourth, the capability of the government and its governance structure related to technology innovation are inconsistent with the times, and which means that the two elements are designed to serve the best in the catch-up model. It can be summarized as that the NIS of Korea has evolved to be optimal to implement catch-up strategies. Hence, the system has revealed its weakness in the period of new paradigm shift, although it helps the nation maintain the position of manufacturing powerhouse on the global stage up until now.

In times of crisis like the COVID-19 pandemic, the capability of public sector is particularly important. Thus, we need to remind the lessons learned from the failure of small government, emphasizing efficiency. In addition, a new point of balance with regard to the value system that the government should pursue in the future should be reflected in the national innovation system. The NIS of Korea has encountered a moment of transition to the one that reflects new paradigms and values, while getting away from the conventional catch-up model.

4. Strategies for NIS in the post COVID-19 era

We have prepared strategies for the NIS that meet the demands of post COVID-19 era based on the diagnosis and solutions for the national innovation system of Korea which was built before COVID-19 in 2019 (see [Table 2]). To develop the strategies for NIS, the researchers have reflected new changes in our society and economy from COVID-19 and the roles and values of the government to previous strategies established based on the paradigms of the 4th industrial revolution.

First, we need to provide strategies to pursue the genuine path-creating innovative growth and implement them in practice in order to overcome the deteriorating conditions we are experiencing now for the loss of premiums as a follower, one of distinctive features of countries that follow the catch-up path to innovate their technologies. To this end, preemptive investment on untact (non-contact) technologies and industries and prioritizing them as key national agendas should be made as an important strategic direction considering changes after COVID-19. In the meantime, we need to foster K-biotechnology and industry as a pillar of innovative growth along with K-quarantine which was recognized by the world as the best approach in responding to the disease. Second, we should build an ecosystem for the industry/academia/research institutes cooperation proper to new paradigms and adust related systems, and develop new policies to promote the coupling among domestic innovation leaders as an effort to overcome the issue of their decoupling. At the same time, preparations to build an open NIS that reflects the international cooperation and linkage on personnel, materials, and data and information that are clearly noticed during the COVID-19 pandemic. In the meantime, providing strategic measures to complement and prepare for national emergency such as the US-China trade conflict, Japan's exclusion of Korea from its whitelist of nations, and the collapse of global supply chain due to COVID-19 (ex. reshoring the manufacturing of key items, etc.) has emerged as an important task. Third, it is urgent to build an ecosystem for the creation of new values such as the platform economy, data economy, smart mobility solution, etc. in response to paradigm shifts in technology, economy, and society along with the 4th industrial revolution. Furthermore, we should build the digital infrastructure and platforms proactively and prepare the systems and ecosystem to support them accordingly through the digital new deal initiative that is currently underway and others. In addition, we should embark on the digital transformation and set an order of priority in terms of personnel/physical investment on untact (non-contact) and unmanned solutions. The last strategy is related to the efforts to overcome a lack of government capability and inconsistency of governance with the times. Namely, we should make an effort to enhance the capability of the government related to technological innovation required to meet the new paradigms and reorganize national S&T innovation governance. With regard to expanding the role of government as a social safety net in the midst of COVID-19 crisis, the government needs to improve its capability. To make this happen, we

[Table 2] Diagnosis and proposed solutions on the NIS

Diagnosis	Strategic directions (I): Respond to the paradigms of the 4th industrial revolution	Strategic directions (II): Respond to the paradigms of the 4th industrial revolution + Post COVID-19
Worsening loss of premiums on technological catch-up and innovation	Setting goals of NIS and implementation: Pursue a new path-creating innovative growth	· Same · Preemptive investment on the non-contact technologies and innovation and prioritization · Build K-bio, K-quarantine platforms and lead the technology innovation
Poor operating performance of NIS due to decoupling among technology innovation leaders	Create a cooperative ecosystem among the industry/academia/research institutes and change related system, increase learning curve and openness within NIS	· Same · Strengthen the openness of NIS (pursue international cooperation, etc.) · Strategies to complement GVC (reshoring the manufacturing of key items, etc.)
Poor to respond to paradigm shifts in technology, economy, and society along with the 4th industrial revolution	Build an ecosystem to create new values such as the platform economy, data economy, smart mobility solution, etc.	· Same · Proactively build the digital infrastructure · Promote the digital transformation
A lack of government capability and inconsistency of governance with times	Improve the capability of the government and consistency of NIS	· Same · Strengthen the role of government as a social safety net and reinforce related capability · Establish a governance on public/private cooperation · Reflect new values such as publicness, effectiveness, decentralization, redundancy, etc.

Source: Compiled based on Lee Jang-jae, et al. (2019)

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should implement and reorganize the governance on private/public cooperation that puts the public interest first. In the meantime, the development, operation, and performance evaluation of NIS rebuilt based on new values such as publicness, effectiveness, decentralization, etc. should be made. Of course, such values should be properly reflected on the system, while striking a balance with the conventional ones. Specifically, the importance of redundancy, which was previously excluded in the catch-up model, should be reconsidered.

5. Conclusion

People of the world will remember 2020 as the year that marked a milestone in human civilization. As the globalization has reached a plateau from the physical and cyber perspectives, the outbreak of novel virus has devastated one side of a coin abruptly. In 2020, we are now living a bizarre world where the physical world has collapsed while the cyber world has flourished further. Fortunately, humans have imagined and prepared for such world as they have predicted for a long time. Globalization in the cyber space allows us to see and experience the world, although countries have closed their borders and the globalization in the physical aspect has contained. A problem occurs in that the globalization in the cyber space has not prepared to encompass the socio-economic systems. We are facing various issues caused by the disease including job and unemployment, economic slowdown and negative growth, conflicts between haves and have-nots and between generations, conflicts caused by digital divide, etc. It is highly likely that changes and new aspects that have emerged recently will not go away, even though COVID-19 has ended with the development of vaccines and treatments. That is why we should accept the paradigm shifts due to COVID-19 with a heavy heart in the midst of the 4th industrial revolution.

The 4th industrial revolution and post COVID-19 era may serve as another entry barrier for Korea as the country begins to embark on the uncharted journey called post catch-up technology innovation strategy. On the other hand, we may have expected for catching two birds with one stone, considering that we need to get away from the path dependency any way. In other words, the role of national think tank has become all the more important. The government should have the capability to conduct the functions with the authority to design all relevant systems and institutions, adjust and implement them. In the modern world, the government cannot build and exert its capability all by itself. It can fulfill the responsibility and live up the expectation of the public based on close linkage and cooperation with the leaders of knowledge and innovation in the private sector such as think tanks both at home and abroad. To this end, we need close cooperation between the private/public sector and among the industry, academia, research institutes, and the government, as well as governance to support such cooperative efforts.

In order to respond best to the paradigm shifts, we need to explore them precisely and make decisions accurately for the future based on concrete analysis and diagnosis on the present. We hope that the digital new deal and green new deal initiatives and others that are deemed to be implemented through the 3rd supplementary budget of the government can reflect the elements mentioned above with a sense of urgency.

References

Park Young-seo (2020), Paradigm shifts after COVID-19 and business strategies for the new normal, KISTEP Knowledge Seminar presentation material

Lee Jang-jae·Ahn Seung-gu (2019), A Study on Diagnosis and Reconstructing of Korean National Innovation System (NIS) (I), Korea Institute of Science & Technology Evaluation and Planning (KISTEP)

Lee Jang-jae (2020a), Strategies for National Innovation System (NIS) in 2020s: Diagnosis and tasks, 'The Science and Technology' April issue, 2020

Lee Jang-jae (2020b), Lights and shadows of COVID-19, and implications, 'TePri column' KIST. June issue, 2020

Mazzucato & Ouaggiotto (May 19, 2020), The Big Failure of Small Government, Project Syndicate

Analysis of Energy Research Fronts

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Abstract

This article is a revised version of the executive summary of a STPI's 2019 report named Analysis of Energy Research Fronts, written in Chinese. The report offers a broad perspective on the development of energy research as well as a reference for enhancing the allocative efficiency of government resources. Research fronts in the Clarivate Analytics database are widely recognized as valuable information about the development of scientific research. This study was conducted to identify the Top 30 (most frequently cited) energy research fronts (ERFs) extracted from 8,914 research fronts across all disciplines published by Clarivate Analytics in March 2019. The 676 core papers related to the Top 30 ERFs were elaborately discussed with analyzing their global distribution, trends in the citation, publishing institutes, and funding agencies. Furthermore, the prominent works associated with the Top 30 ERFs were clearly delineated. The statistical results indicated that the 42.5% and 39.8% of the 676 core papers were respectively published by the USA and China research groups. However, there were only 14 core papers published by research groups of Taiwan, 5 of them accomplished by international collaborations. Finally, the Top 30 ERFs were grouped into 16 subjects for further analysis.

Research Background and Purpose of This Study

Nowadays, the global demand for energy is growing explosively owing to the rapid demographic and economic growth. Meanwhile, the Taiwan government is promoting green energy to achieve the 2025 goal which is 20% of the country's electricity generated by renewable sources. Therefore, we must invest in some prospective energy research topics to ensure the opportunity of mastering new energy technologies in the future. This study provides an overview of energy research fronts (ERFs), which all are hot topics in global energy research in the past five years. It can help researchers or the government to evaluate the emerging technologies for energy.

Methodology

The "Research Fronts (RF)," defined and developed by Clarivate Analytics firstly in 2013, has become an important tool for researchers to observe the trends in major disciplines. An RF represents a cluster of highly cited papers over a five-year period, named "core papers," and papers citing them, which are about the same, specialized topic. The core papers are the topmost 1% cited ones, ranked by "Essential Science Indicators" database, among papers within the same discipline published in the same year. The essence of analyzing RFs is to find commonality in popular research articles in an area. Differing from human's subjective categorization, RF analysis applies human-assisted "cluster analysis," namely a semi-automatic process, semantic analyzing titles of the highly-cited papers and of the ones citing them.

When defining the cluster of the core papers of an RF, two thresholds are applied. The first threshold is that each pair from the core papers should be cited by two or more of the same papers (co-cited). The second threshold is that the normalized co-citation (NCC) should greater than 0.1, where

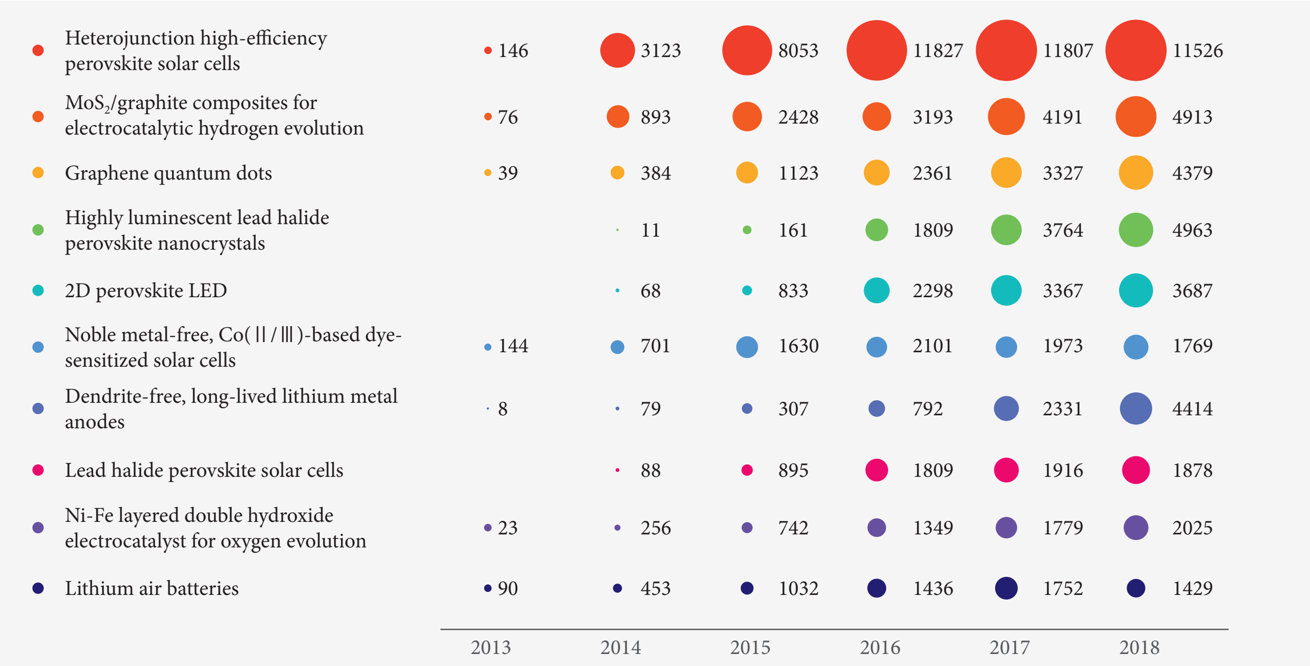
$$NCC=\frac{\text{co-citation frequency of A and B}}{(\text{citation frequency}_{\text{paper A}}\times\text{citation frequency}_{\text{paper B}})^{0.5}}$$

wherein the pair of A and B represents any pair of papers extracted from the core papers. As a result, an RF has at least two core papers; the upper limit of the number of core papers within an RF, assigned by Clarivate Analytics, is so far 50. In short, any pair within an RF has NCC > 0.1, and an RF has 2 to 50 papers with the highest NCCs.

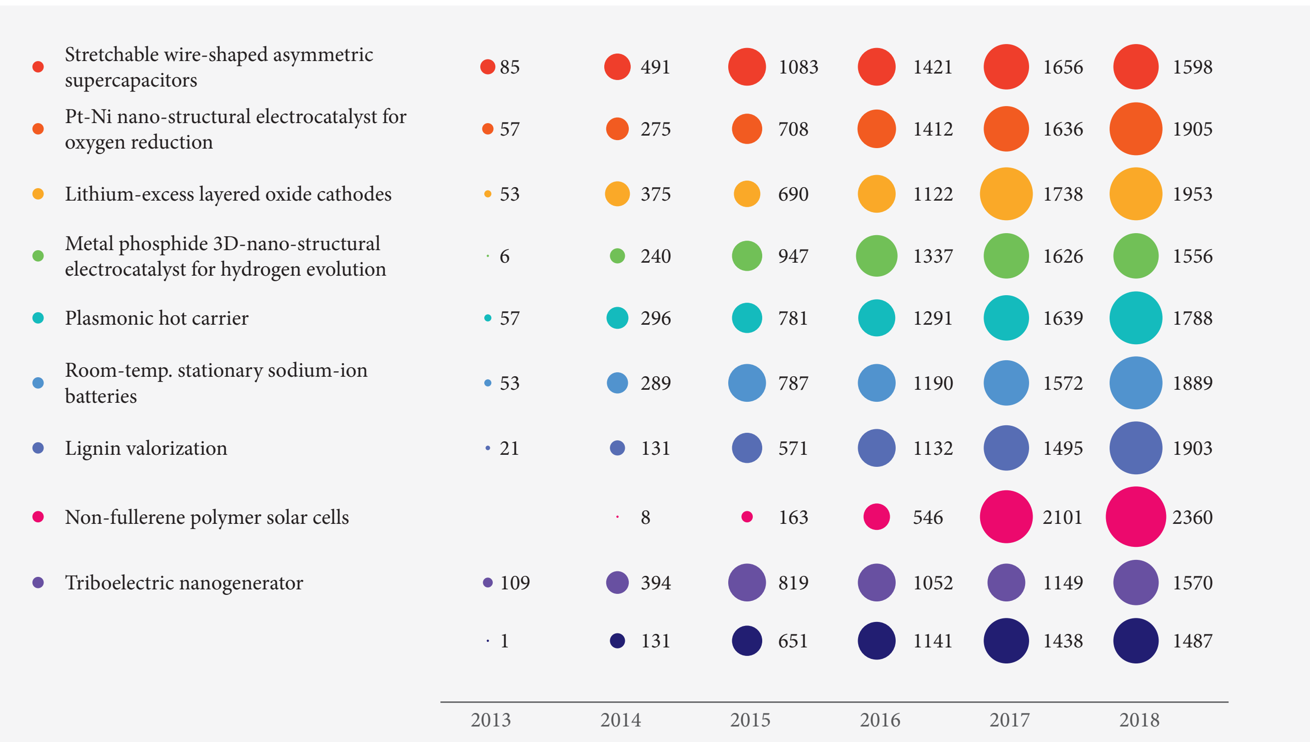
The top 30 RFs about energy studies, extracted from 8,914 RFs posted in March 2019, included 676 core papers. These core papers were analyzed by (1) global core papers analyses, namely core papers distribution on the world map and core papers annually publication trends; (2) core papers feature statistics, namely numbers of core papers, total citation counts, and impacts per core paper; (3) institutes analysis; and (4) funding agencies analysis.

Overview

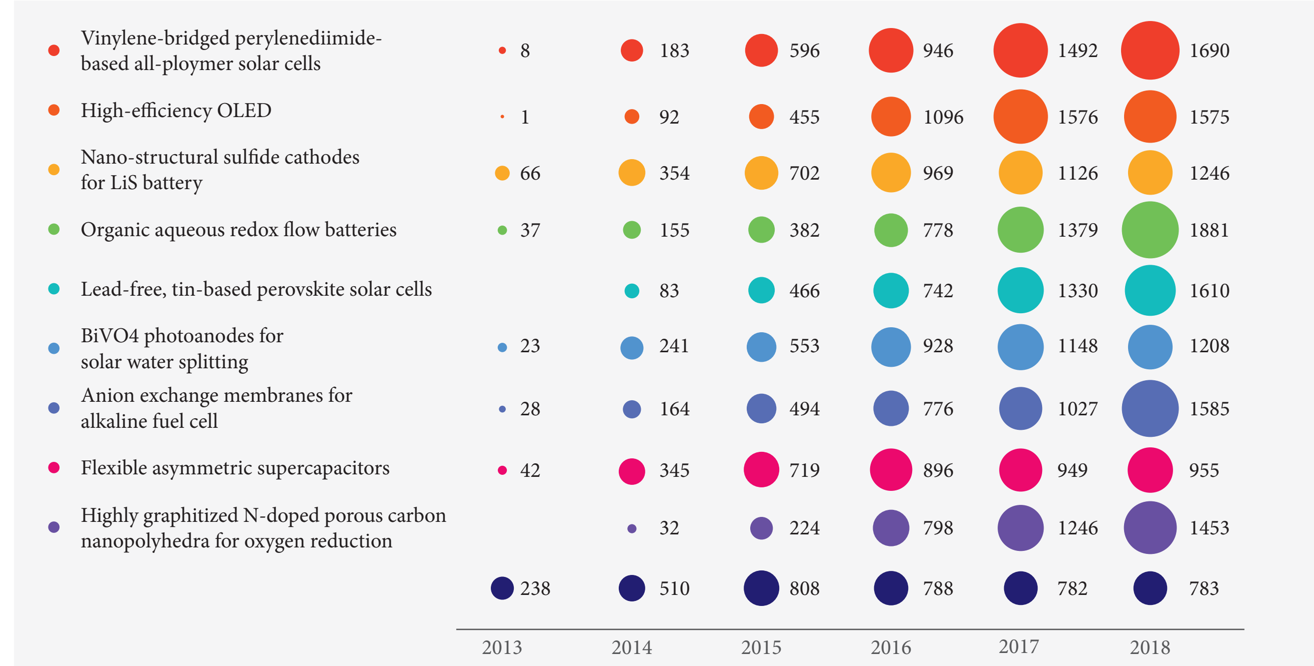
Bubble sizes within Figs. 1 to 3 represent annual citations of each ERF, ranked by total citations. Figure 1 shows the trends of ERFs top 1 to 10, wherein RF "heterojunction high-efficiency perovskite solar cells" had the highest total citation, a much higher citation growth rate, especially during 2013 to 2016, than those of the other ERFs, and annual citations staying at a high level during 2016 and 2018. "MoS_2/graphite composites for electrocatalytic hydrogen evolution," "graphene quantum dots," "highly luminescent lead halide perovskite nanocrystals," "2D perovskite LED," and "dendrite-free, long-lived lithium metal anodes" had lower citation growth rates, while "lead halide perovskite solar cells" and "Ni-Fe layered double hydroxide electrocatalyst for oxygen evolution" had much lower ones. Annual citations of "Noble metal-free, Co(II/III)-based dye-sensitized solar cells (DSSCs)" and "lithium-air batteries" were declining during the period. Figure 2 shows the trends of ERFs top 11 to 20; it is worth notice that the annual citations of RF "non-fullerene polymer solar cells" had grown dramatically since 2015. Figure 3 shows the trends of ERFs top 21 to 30, wherein most annual citations of the ERFs had grown evenly and steadily



[**Figure 1**] Citation trends of ERFs top 1 to 10



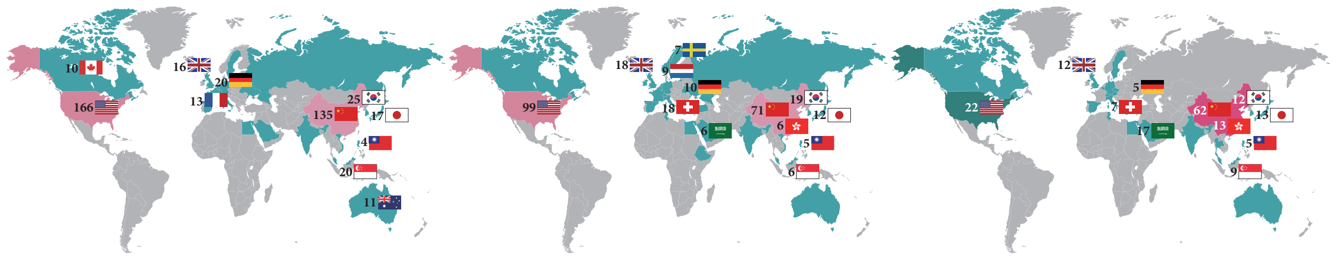
[**Figure 2**] Citation trends of ERFs top 11 to 20



[**Figure 3**] Citation trends of ERFs top 21 to 30

during the period, besides the slightly declining one of RF "kesterite solar cells."

Figure 4 categorizes the ERFs into three groups- "energy storage," "energy generation," and "energy conservation" and highlights the top 10 countries with their numbers of core papers in the three domains respectively on the world map. The first row of the table below the maps lists the numbers of core papers and total citations of the ERFs in their corresponding groups. The second row lists the ERFs, wherein the green-colored ones are the ERFs including the studies of Taiwan researchers, whose counts are shown inside the parentheses. Figure 4 shows that the USA led in the groups of "energy storage" and "energy generation," while China was ranked second in both groups. On the other hand, China led in "energy conservation," publishing much more core papers than other countries. In addition, England, Germany, Japan, and South Korea performed well in all three groups. Taiwan contributed 4, 5, and 5 core papers in these three categories and was ranked 10th in "energy conservation" as Germany was. The group "energy storage" had the most core papers of 341, and "energy generation" and "energy conservation" had 198 and 137 core papers, respectively. The total citations were 90,901 of "energy storage" (267 per core paper), 90,030 of "energy generation" (454 per core paper), and 35,953 of "energy conservation" (262 per core paper). There were 14 Taiwanese-authored papers listed within the top 30 ERFs, accounting for 2.1% of the core papers. The corresponding ERFs were "MoS_2/graphite composites for electrocatalytic hydrogen evolution," "lithium-excess layered oxide cathodes" of the group "energy storage;" "noble metal-free, Co(II/III)-based DSSCs," "non-fullerene polymer solar cells," and "lead-free, tin-based perovskite solar



Energy storage
- 341 papers
- Cited 90,901 times

- MoS2/graphite composites for eletrocatalystic hydrogen evolution (2)
- Dendrite-free, long-lived lithium metal anodes
- Ni-Fe layered double hydroxide electrocatalyst for oxygen evolution
- Lithium air batteries
- Stretchable wire-shaped asymmetric supercapacitors
- Pt-Ni nano-structural electrocatalyst for oxygen reduction
- Lithium-excess layered oxide cathodes (2)
- Metal phosphide 3D-nano-structural electrocatalyst for hydrogen evolution
- Room-temp. stationary sodium-ion batteries
- Ni-Co sulfides/graphene oxide composite electrodes for asymmetric supercapacitor
- Nano-structural sulfide cathodes for LiS battery
- Organic aqueous redox flow batteries
- BiVO4 photoanodes for solar water splitting
- Anion exchange membranes for alkaline fuel cell
- Flexible asymmetric supercapacitors
- Highly graphitized N-doped porous carbon nanopolyhedra for oxygen reduction

Energy generation
- 198 papers
- Cited 90,030 times

- Heterojunction high-efficiency perovskite solar cells
- Noble metal-free, Co(Ⅱ / Ⅲ)-based dye-sensitized solar cells (3)
- Lead halide perovskite solar cells
- Plasmonic hot carrier
- Lignin valorization
- Non-fullerene polymer solar cells (1)
- Triboelectric nanogenerator
- Vinylene-bridged perylenediimide-based all-ploymer solar cells
- Lead-free, tin-based perovskite solar cells (1)
- Kesterite solar cells

Energy conservation
- 137 papers
- Cited 35,953 times

- Graphene quantum dots (1)
- Highly luminescent lead halide perovskite nanocrystals (2)
- 2D perovskite LED
- High-efficiency blue OLED (2)

* Green-colored ones are the RFs containing works participated by Taiwanese, whose counts are showed inside the parentheses

[**Figure 4**] Top 30 ERFs categorized by the 3 groups

cells" of "energy generation;" and "graphene quantum dots," "highly luminescent lead halide perovskite nanocrystals," and "high-efficiency blue organic light-emitting diodes (OLEDs)" of "energy conservation."

In order to recognize Taiwan's capacity and strengths in energy research, we listed the 14 Taiwanese-authored core papers in Table 1. There were 9 core papers completed solely by Taiwanese. The other 5 were achieved by international cooperation, involving the USA, China, and India. The Taiwanese-authored core papers substantially evenly distributed in the three groups of "energy storage," "energy generation," and "energy conservation," wherein the most ones, 3 core papers, devoted to the 6th highly cited RF of "noble metal-free, Co(II/III)-based DSSCs." In terms of institutes, National Taiwan University contributed the most core papers of 4, and Academia Sinica and National Taiwan University of Science

[**Table 1**] ERFs including works participated by Taiwanese

Category	Rank	Research Front	Title	Corresponding or key TW author	Institute	paticipation
Energy storage	2	MoS_2/graphite composites for eletrocatalystic hydrogen evolution	Highly Efficient Electrocatalytic Hydrogen Production by MoSx Grown on Graphene-Protected 3D Ni Foams	Lain-Jong Li	Institute of Atomic & Molecular Sci., Academia Sinica	TW
Energy storage	2	MoS_2/graphite composites for eletrocatalystic hydrogen evolution	MoSe2 nanosheets and their graphene hybrids : synthesis, characterization and hydrogen evolution reaction studies	Chao-Cheng Kaun	Research Center For App. Sci., Academia Sinica	TW
Energy storage	13	Lithium-excess layered oxide cathodes	Direct In situ Observation of Li_2O Evolution on Li-Rich High-Capacity Cathode Material, $Li[Ni_xLi_{(1-2x)}/3Mn_{(2-x)/3}]O_2$ $(0 \leq x \leq 0.5)$	Bing Joe Hwang	Dep. Of Chem. Eng., NTUST	TW
Energy storage	13	Lithium-excess layered oxide cathodes	Performance and design considerations for lithium excess layered oxide positive electrode materials for lithium ion batteries	Bing Joe Hwang	Dep. Of Chem. Eng., NTUST	USA & TW
Energy generation	6	Noble metal-free, Co(Ⅱ / Ⅲ)-based dye-sensitized solar cells	Porphyrin-sensitized solar cells	Eric Wei-Guang Diau	Dep. Of App. Chem., NCTU	TW
Energy generation	6	Noble metal-free, Co(Ⅱ / Ⅲ)-based dye-sensitized solar cells	Molecular Engineering of Push-Pull Porphyrin Dyes for Highly Efficient Dye-Sensitized Solar Cells : The Role of Benzene Spacers	Chen-Yu Yeh	Dep. Of Chem., NCHU	TW
Energy generation	6	Noble metal-free, Co(Ⅱ / Ⅲ)-based dye-sensitized solar cells	Metal-Free Tetrathienoacene Sensitizers for High-Performance Dye-Sensitized Solar Cells	Chun-Guey Wu	Dep. Of Chem., NCU	USA, TW, & IN
Energy generation	18	Non-fullerene polymer solar cells	A Facile Planar Fused-Ring Electron Acceptor for As-Cast Polymer Solar Cells with 8.71% Efficiency	Chun-Jen Su	Nat. Synchrotron Radiation Research Center	CN & TW
Energy generation	25	Lead-free, tin-based perovskite solar cells	Binary-Metal Perovskites Toward High-Performance Planar-Heterojunction Hybrid Solar Cells	Chien-Yi Liao	Inst. Of Polymer Sci. & Eng., NTU	USA & TW
Energy conservation	3	Graphene quantum dots	Unravelling the Multiple Emissive States in Citric-Acid-Derived Carbon Dots	King-Chuen Lin	Dep. Of Chem., NTU	TW
Energy conservation	4	Highly luminescent lead halide perovskite nanocrystals	Mesoporous Silica Particles Integrated with All-Inorganic CsPbBr3 Perovskite Quantum-Dot Nanocomposites (MP-PQDs) with High Stability and Wide Color Gamut Used for Backlight Display	Ru-Shi Liu	Dep. Of Chem., NTU	TW
Energy conservation	4	Highly luminescent lead halide perovskite nanocrystals	Organolead Halide Perovskite Nanocrystals : Branched Capping Ligands Control Crystal Size and Stability	Ying-Chih Pu	Dep. Of Master., NUT	USA, CN, & TW
Energy conservation	22	High-efficiency blue OLED	Sky-Blue Organic Light Emitting Diode with 37% External Quantum Efficiency Using Thermally Activated Delayed Fluorescence from Spiroacridine-Triazine Hybrid	Ken-Tsung Wong	Dep. Of Chem., NTU	TW
Energy conservation	22	High-efficiency blue OLED	A New Molecular Design Based on Thermally Activated Delayed Fluorescence for Highly Efficient Organic Light Emitting Diodes	Chien-Hong Cheng	Dep. Of Chem., NTHU	TW

[Table 2] Publication observation of 16 subjects

Subject	Works participated by Taiwanese	Global	TW/global
Dye-sensitized solar cells	640	7554	8.5%
Organic Light-emitting Diodes	453	6572	6.9%
Polymer solar cells	234	4496	5.2%
Perovskite light-emitting Diodes	12	235	5.1%
Perovskite solar cells	232	5293	4.4%
Thin film compound semiconductor solar cells	39	1004	3.9%
Solar hydrogen production	75	1991	3.8%
Surface plasmon	604	18093	3.3%
Nanogenerators	28	1112	2.5%
Fuel cells	633	25977	2.4%
Redox flow batteries	31	1339	2.3%
Supercapacitors	124	5357	2.3%
Quantum dots	807	38754	2.1%
Li-ion batteries	371	24360	1.5%
Na-ion batteries	45	3701	1.2%
Lignin valorization	31	5243	0.6%

and Technology (NTUST) equally contributed 2 core papers, wherein the NTUST ones were "energy storage" studies solely accomplished by Prof. Bing Joe Hwang's research team.

For the analysis of Taiwan's research output related to the top 30 ERFs, we summarized the top 30 ERFs into 16 research subjects and used the database Web of Science to search Taiwanese-authored papers corresponding to the 16 subjects (see Table 2). The targets were SCI papers typed article or review. Among the 16 subjects, the 3 most studied ones by Taiwanese were DSSCs, OLED, and polymer solar cells, accounting for 8.5%, 6.9%, and 5.2% of the global publications. Taiwanese-focused research subjects with more than 100 publications were DSSCs, polymer solar cells, perovskite solar cells, and surface plasmon of the group "energy generation;" fuel cells, supercapacitors, and lithium-ion batteries of "energy storage;" and OLEDs and quantum dots of "energy conservation."

Conclusion

The top 30 ERFs, announced by Clarivate Analytics in March 2019, including 676 core papers. The USA's and China's numbers of core papers were 287 and 269 respectively, ranked the first and second, the most of which were published by the Chinese Academy of Sciences, United States Department of Energy, and Stanford University. Taiwan contributed 14 core papers, ranked 13th as Netherlands and France were. The top 5 most cited ERFs were "heterojunction high-efficiency perovskite solar cells," "MoS_2/graphite composites for electrocatalytic hydrogen evolution," "graphene quantum dots," "highly luminescent lead halide perovskite nanocrystals," and "2D perovskite LED," wherein RFs related to perovskite accounted for 3/5 of the ERFs, revealing that perovskite material had been a hot topic in recent years. The RFs in the group of "energy storage" had the most core papers of 341 among the top 30 ERFs and was followed by

[Table 3] Highlights of RFs about energy storage

Research front	Highlights
MoS_2/graphite composites for electrocatalytic hydrogen evolution	■ Low dimension MoS_2 has low cost and high activity. ■ Research direction : improving catalyticity by nano-structuralization or doping
Dendrite-free, long-lived lithium metal anodes	■ Many approaches preventing dendrite formation has been found ■ Research direction : integrating the approaches for practical usages.
Ni-Fe layered double hydroxide electrocatalyst for oxygen evolution	■ Metal-air batteries can have stable catalytic reaction applying Ni-Fe layered double hydroxide ■ Research direction : developing bifunctional catalysts for secondary battery
Lithium-air batteries	■ Reasons why Li-air batteries with carbon-based cathodes are short-lived are being discovered ■ Research direction : practical long-lived cathodes for Li-air battery
Stretchable wire-shaped asymmetric supercapacitors	■ Stretchable wire-shaped supercapacitors have power density or volumetric energy density no less than those of commercial supercapacitors ■ Research direction : mass-produced stretchable supercapacitors for wearable devices
Pt-Ni nano-structural electrocatalyst for oxygen reduction	■ Platinum is the key catalytic material for fuel cells ■ Research direction : lowering expensive platinum usage per unit fuel cell
Lithium-excess layered oxide cathodes	■ Li-ion batteries' lifetime can be increased by applying cathodes containing 4d or 5d transition metal compounds ■ Research direction : reducing material costs
Metal phosphide 3D-nano-structural electrocatalyst for hydrogen evolution	■ Metal phosphide has high catalyticity even under harsh acidic or basic conditions ■ Research direction : improving catalyticity and stability by nano-structuralization or doping
Room-temp. stationary sodium-ion batteries	■ Na-ion batteries cost much lower than Li-ion ones ■ Research direction : developing better electrode materials and improving charge-discharge stability
Ni-Co sulfides/graphene oxide composite electrodes for asymmetric supercapacitor	■ Supercapacitors have high energy density and can be quickly charged or discharged ■ Research direction : composite electrodes and device structures
Nano-structural sulfide cathodes for LiS battery	■ LiS battery has high energy density ■ Research direction : composite materials or nano-structural designs for cathode
Organic aqueous redox flow batteries	■ They are cheap and save, and the redox potential or solubility can be tailored by modifying chemical structures of the electrolytes ■ Research direction : improving lifetime
$BiVO_4$ photoanodes for solar water splitting	■ $BiVO_4$ photoanode has high solar water splitting efficiency ■ Research direction : improving the efficiency by nano-structuralization or doping
Anion exchange membranes for alkaline fuel cell	■ Anion exchange membrane plays a crucial role when separating fuel and oxygen in a fuel cell ■ Research direction : improving the efficiency or stability by nano-structuralization or applying composites
Flexible asymmetric supercapacitors	■ Applying solid-state electrolytes makes encapsulation easier ■ Research direction : developing proper electrolytes and asymmetric electrodes
Highly graphitized N-doped porous carbon nanopolyhedra for oxygen reduction	■ Nano-structuralized carbons provide high catalyticity and stability ■ Research direction : synthesizing N-doped porous carbon nano-structures via metal-organic framework

[**Table 4**] Highlights of RFs about energy generation

Research front	Highlights
Heterojunction high-efficiency perovskite solar cells	■ The efficiency has been improved beyond 20% ■ Research direction : enhancing stability and lifetime
Noble metal-free, Co(Ⅱ/Ⅲ)-based DSSCs	■ No efficiency breakthrough over 14% has been made for a while ■ Research direction : finding new dyes
Lead halide perovskite solar cells	■ Ion migration within the active layer was observed ■ Research direction : retarding the ion migration to improve device lifetime
Plasmonic hot carrier	■ Making good use of hot carriers within a solar cell can ease heat energy loss ■ Research direction : precise controlling surface plasmonic effects to improve solar cells' efficiency
Lignin valorization	■ Some plants have been found to have high lignin valorization efficiency ■ Research direction : mass-productive lignin valorization for agricultural wastes
Non-fullerene polymer solar cells	■ The efficiency has exceeded 14% ■ Research direction : simplifying synthetic methods and finding new materials
Triboelectric nanogenerator	■ Utilizing wave power via triboelectric nanogenerator is expected to be practical ■ Research direction : developing wave power-utilizing nanogenerators not harm to marine life
Vinylene-bridged perylenediimide-based all-polymer solar cells	■ In terms of all-polymer solar cells, the efficiency of vinylene-bridged perylenediimide-based ones has been surpassed ■ Research direction : simplifying synthetic methods and finding new materials
Lead-free, tin-based perovskite solar cells	■ Research direction : understanding how doping affects device performance and stability
Kesterite solar cells	■ The efficiency has exceeded 10% ■ Research direction : improving the active layers' quality processed either in vacuum or ambient atmosphere

[**Table 5**] Highlights of RFs about energy conservation

Research front	Highlights
Graphene quantum dots	■ Graphene quantum dots' electroluminescence is observed ■ Research direction : mass-producing graphene quantum dots with uniform particle sizes
Highly luminescent lead halide perovskite nanocrystals	■ Perovskite nanocrystals have high quantum efficiency ■ Research direction : applications in display or optical communication
2D perovskite LED	■ Low-temp. aqueous produced perovskite films have ultimately high optical gain ■ Research direction : applications in large-area LEDs
High-efficiency blue OLED	■ Thermally activated delayed fluorescence materials have properties breaking physical limits of those of fluorescent materials ■ Research direction : applications in blue phosphorescent materials

the ones in the groups of "energy generation" and "energy conservation," including 198 and 137 core papers, respectively. Taiwan contributed 4, 5, and 5 core papers in the three groups and was ranked 10th in "energy conservation" as Germany was. Within the top 30 ERFs, Taiwanese contributed to 8, which were "MoS_2/graphite composites for electrocatalytic hydrogen evolution," "lithium-excess layered oxide cathodes," "noble metal-free, Co(II/III)-based DSSCs," "non-fullerene polymer solar cells," "lead-free, tin-based perovskite solar cells," "graphene quantum dots," "highly luminescent lead halide perovskite nanocrystals," and "high-efficiency blue OLEDs." Countries having the highest indices of impacts per core paper were Switzerland (2.32), Italy (1.76), and England (1.74; using 1 as global average).

Highlights of the top 30 ERFs, categorized into groups "energy storage," "energy generation," and "energy conservation," are summarized in Tables 3-5 in the following:

Analysis of Taiwanese-authored papers related to the top 30 ERFs revealed that Taiwan's works about nanogenerators had the highest impacts per paper. Taiwan's three leading research topics were DSSCs, OLED, and polymer solar cells, accounting for 8.5%, 6.9%, and 5.2% of the global publications.

It is worth mentioning that Taiwan's lithium-ion batteries studies had the worst impacts per paper despite two Taiwanese-authored works selected in the RF of "lithium-excess layered oxide cathodes." This suggests that academic performances cannot be accurately assessed by using a single indictor. Some excellent research teams cannot get noticed while people overview the whole country's capacity and strengths in a research area." The methodology of Clarivate Analytics' Research Fronts offers a perspective to discover global hot topics and related outstanding research teams. Therefore, the Research Fronts database is useful for decision-makers to allocate resources to help outstanding research teams pursue excellence.

While quantitative analyzing citation growth rates uncovers the developing speed of RFs, research directions can only be discovered via advanced qualitative analysis. Since RF analysis so far applies a semi-automatic-not fully automatic-process which semantically analyzes titles of highly-cited papers and of the ones citing them, achieving advanced qualitative analysis still costs researchers a lot of effort. We think, based on context analyzing the evolutions of keywords within RFs updated every two months by Clarivate Analytics, the methodology may one day, with the help of experts from each research area, become a more automatic process, make easy advanced qualitative analysis, and successfully predict upcoming RFs. The RF database in the future is expected to provide a scientific research evolution model which is helpful to the observation (even forecast) of global emerging scientific topics and to government resource allocations.

Article

On-Site Personnel's Use of Mobile Cloud Computing Applications -
A Case Study of An LCD Panel Manufacturing Company

On-Site Personnel's Use of Mobile Cloud Computing Applications - A Case Study of An LCD Panel Manufacturing Company

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Abstract

More enterprises are now integrating mobile cloud computing into their operations. This study combines and modifies the Task-Technology Fit theory and the Unified Theory of Acceptance and Use of Technology to form a new model. A questionnaire was administered to the employees of a company that has applied mobile cloud computing. The purpose is to investigate what happens when this new technology is introduced in the workplace and what the influencing factors may be. After confirming the validity and reliability of the instrument through a pilot, 239 formal responses were collected and analyzed using descriptive statistics, one-way ANOVA, and structural equation modeling. It was found that employees' perception of how well the technology fits the nature of their work positively affects their effort expectancy of the technology and their view of the task-technology fit, which in turn affects their performance impact (user satisfaction) and actual technology use. Also, employees' behavioral intention to use this new information technology is affected by their perceived effort expectancy, performance expectancy, and facilitating conditions. The behavioral intention then affects their use behavior and performance impact (user satisfaction).

1. Introduction

Since the start of the COVID-19 pandemic, all enterprises are now faced with a new normal, and the use of mobile devices with cloud computing applications has become a trend in the marketplace (Market Intelligence & Consulting Institute [MIC], April 2020). Gartner Survey Research reported in August 2020 a continuous growing revenue for enterprises that have adopted cloud computing, especially public cloud services. The providers of infrastructure as a service (IaaS) are expected to increase their revenue as higher adoption is occurring worldwide; for example, Amazon Web Services earned the largest increased revenue (19.99 billion USD) last year. Even though International Data Corporation [IDC] (June 2020) expects that smartphone shipments are to decline in Q3 2020 due to the pandemic, the first quarter of next year will see the growth return. Forrester Consulting (October 2020) reported that having more cloud computing service providers will further propel cloud application development and delivery to satisfy business needs in Q4 2020. In addition, Infosys (July 2020) indicated that mobile management will continue as one of the trends in manufacturing, driven by innovations in mobile applications. As suggested by Gartner Survey Research (July 2020), during the COVID-19 pandemic, collaboration software, mobile device management, and applications that support remote work functionality are critically needed by more enterprises. Taiwan's manufacturing sector includes many different industries. Among them, liquid crystal display (LCD) materials' output value has always been challenged by global competitions such as factories in China, Korea, and Japan (Taiwan Institute of Economic Research [TIER], August 2019). Specifically, during the pandemic, the output value fell 12% to approximately 1.329 billion USD profit gain (Industrial Economics & Knowledge Center [IEK], May 2020). However, Business Net (April 2020) considered that due to the quarantines in most countries, Taiwan's LCD industry can still expect a promising future. The LCD-panel and related industries employ over a hundred thousand people, who are important for the economic development of Taiwanese society.

Prior studies have stated that work efficiency improvement is positively influenced by cloud technology (Kulkarni et al., 2014; Stieglitz & Brockmann, 2012). The use of mobile cloud computing applications can also improve overall operational efficiency, competitiveness, corporate image, and energy cost reduction (Banerjee et al., 2013; Bauer, 2018; Guerrero-Contreras et al., 2016; He et al., 2019). However, many factors can make or break the adoption process, such as enterprise software, the hardware environment (e.g., network environment), and individual factors (e.g., acceptance of new information systems) (Arinze, 2010; Chiu et al., 2017; Lian et al., 2014).

Most of the studies on operational efficiency utilize the Task-Technology Fit (TTF) theory proposed by Goodhue & Thompson in 1995 (e.g. Cady & Finkelstein, 2014; D'Ambra et al., 2013; Kim & Ammeter, 2014; Lin, 2014). Task-technology fit refers to the degree of match between a technology and a work task. When the two are well-matched (has good fit), the technology supports the tasks to a higher extent, making the user more willing to use the technology and resulting in higher efficiency in completing the task. Therefore, this study uses the TTF to investigate the relationship between mobile cloud computing application and work tasks and how the two affect operational efficiency.

Moreover, recent studies on technology adoption mostly use the Unified Theory of Acceptance and Use of Technology (UTAUT) proposed by Venkatesh et al. (2003) as their research framework (e.g., Gupta et al., 2019; Lai & Lai, 2014; Wang, 2016; Williams et al., 2015; Oliveira et al., 2014). The UTAUT includes four dimensions: performance expectancy, effort expectancy, social influence, and facilitating conditions. The current study explores users' acceptance of new information technology and the factors of that acceptance. Among these factors,

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performance expectancy, effort expectancy, and social influence have a direct impact on the intention to use, while use behavior is affected by the intention and facilitating conditions. The enterprise in this study has applied mobile cloud computing to its operations. It is worth using the UTAUT to study the factors that influence its employees' use of new technology.

Overall, the current study combines and modifies the TTF and the UTAUT and formulates a new model to investigate the impact of enterprise adoption of mobile cloud computing on employees' operational efficiency and to find the key factors that influence their task efficiency after adopting the technology.

The scope of this study is limited to companies that manufacture LCD panels and components. These companies are already using cloud computing and are actively encouraging staff members to apply this technology to their work. The employees of these companies are the object of this study. Through a comprehensive analysis, a cohesive set of results are concluded, and specific proposals can be provided to other companies as guidance for future development.

2. Literature review

2.1 Application and development of cloud computing and mobile devices

The National Institute of Standards and Technology (NIST) defines cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (NIST, January 2018 updated). Based on this definition, cloud computing provides three service models, four deployment models, and five essential characteristics. The service models are infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). The deployment models are private cloud, public cloud, community cloud, and hybrid cloud. The essential characteristics are on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service (NIST, June 2020 updated).

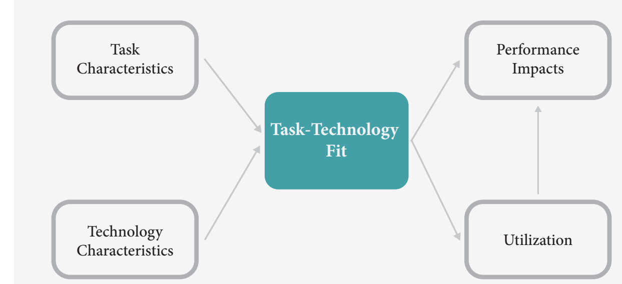
Since cloud computing can operate at any time without restriction, and it accepts requests from anywhere to connect to the company's information service system for data exchange, it can improve the information worker's efficiency and competitive edge (Banerjee et al., 2013; Bauer, 2019). Cloud computing applications are diverse and flexible and are commonly used in the corporate world (Guerrero-Contreras et al., 2016; He et al., 2019; Lee et al. al., 2013; Stieglitz & Brockmann, 2012; Yuan et al., 2010). The development of the cloud has also directly driven the widespread use of mobile devices. As the degree of mobility varies widely among the devices, the applications of cloud computing also vary widely (Chiu et al., 2017; Forrester Consulting, October 2020). In the literature, mobile devices combined with cloud computing applications fall into four categories: mobile enterprise, mobile office, mobile commerce (m-commerce), and bring-your-own-device (BYOD).

BYOD adopts the idea of mobile computing, which refers to using mobile phones at home, in the office, even on the street. Mobile computing is characterized by portability, connectivity, low power, platform independent, and integrated environments (Kulkarni et al., 2014, p.565). BYOD means that employees bring their personal devices to work. The devices may be notebook computers, tablets, smartphones,

etc., which are easy to use, can be connected anytime from anywhere, and has low energy consumption and low cost. Kulkarni et al. (2014) researched BYOD from six angles: employee privacy, financial liability, compliance and legal concerns, appropriate device usage, mobile device management (MDM), and mobile device storage (local storage). Overall, the use of BYOD can effectively reduce equipment costs and energy consumption and has a positive impact on the organization's operational efficiency and cost reduction (Banerjee et al., 2013; Guerrero-Contreras et al., 2016; He et al., 2019). One of the four major information technology application development future trends in the manufacturing industry is the emerging cloud and mobile technologies. Therefore, the improvement of mobile computing technology can effectively manage the mobility of factories, after-sales customer service, and tasks such as massive data collection, mobile communication, and collaboration between partners.

2.2 Task-technology fit

The TTF theory was proposed by Goodhue & Thompson (1995) (Figure 1). The main thesis is the relationship between the information system and the individuals' performance. The TTF theory came from Vessey's (1991) cognitive-fit theory, which explains the mutual influence between the presentation of information and the task. The TTF theory touches upon the cognitive-fit theory, defining it as understanding the degree of fit between a technology's characteristics and the task that it is supposed to support. In other words, when the cognitive-fit model yields a good fit, auxiliary systems or tools can be used to process specific tasks, thereby improving task efficiency (Zhou et al., 2010). The so-called auxiliary systems or tools can be regarded as the use of information technology. The ability of information technology users also affects the extent that technology can support work tasks. If using information technology can significantly support the work tasks, the users will have a positive perception of the technology and use it more habitually (Dishaw & Strong, 1999; Lian et al., 2014; Wang, 2016; Zhou et al., 2010)



Source: Goodhue and Thompson, 1995, p. 220

[Figure 1] The Task-Technology Fit Model

The work tasks of manufacturing LCD panels and components can be divided into three categories: directly related to the production line, indirectly related to the production line, and general operations. The tasks include raw material management, manufacturing and production process control, finished product management, customer management, etc. These tasks have some common characteristics: immediacy, repetitiveness, and unfixed location. Immediacy means that real-time information is needed to perform the task smoothly. For example, equipment engineers need to be able to know the equipment conditions at any given time, so information devices are used to monitor the real-time conditions of the production line equipment. Repetitiveness refers to a work task that has a fixed or standardized operating mode and needs to be performed repeatedly at certain time intervals. For example, the production unit needs to routinely confirm the stock of raw materials. If the safety stock is insufficient, raw materials should be purchased. This type of operation has the characteristics of being cyclical and has a regular and standardized procedure. Unfixed location means that there is no fixed location for the task; rather, it needs to be constantly moved to be completed. For example, the daily inventory operations of warehouse managers require them to go to different locations to take inventory of the various items. For the tasks that are repetitive and with unfixed locations, the combination of cloud computing systems and mobile devices can be applied to execute the tasks to effectively improve the efficiency of the work.

In general, the technology characteristics of mobile devices combined with cloud computing can be matched to the task characteristics, and application programs can be developed accordingly for employees to use in their work. Combining mobile device and cloud computing applications would better reflect the five technology characteristics: portability, connectivity, low power, platform independent, and integrated environments (Kulkarni et al., 2014). Based on this understanding, the following two hypotheses are proposed:

H1 : Task characteristics have a positive impact on the task-technology fit in the LCD panel and component manufacturing industry.

H2 : Technology characteristics of mobile cloud computing application programs have a positive impact on the task-technology fit.

In addition, TTF is mainly used to study the situation where the task characteristics and technology characteristics are appropriately matched, which affect performance and intention to use. Performance impact and use tend to improve with a higher degree of fit (Goodhue & Thompson, 1995). In the past, the literature on TTF included a wide range of research topics such as websites, medical information systems, mobile communications, and e-books (Cady & Finkelstein, 2014; D'Ambra et al., 2013; Kim & Ammeter, 2014; Lin, 2014). More recently, the research topic has shifted toward mobile information technology, and all research results agree that if the task characteristics are effectively supported by the information technology, then the performance impact and use behavior will be impacted significantly (Alyoubi & Yamin, 2019; Tam & Oliveira, 2016; Wang & Lin, 2019). Continuous use also has a significant effect on performance impact. Therefore, this research uses TTF as the theoretical basis to explore the LCD panel and component manufacturing industry, which has begun to introduce the characteristics of mobile cloud computing technology and to examine the performance impact and use behavior of its staff, and the relationship between these two. Performance impact can be regarded as the employees' multi-faceted operational efficiency (D'Ambra et al., 2013; Lin, 2014; Tam & Oliveira, 2016). However, prior studies have pointed out that, in the discussion of organizational behavior and the implementation of information systems, performance evaluation based on user satisfaction is generally accepted (Au et al., 2002; Brown et al., 2008). Therefore, to improve the explanation of variances in operational efficiency, this research uses user satisfaction to measure performance impact. Based on the above discussion, the following three hypotheses are made:

H3 : The task-technology fit of the mobile cloud computing application in the LCD panel and component manufacturing industry has a positive impact on the employees' performance impact (user satisfaction).

H4 : The task-technology fit of the mobile cloud computing application in the LCD panel and component manufacturing industry has a positive impact on the employees' use behavior.

H5 : The LCD panel and component manufacturing industry employees' use behavior of mobile cloud computing application program has a positive impact on their performance impact (user satisfaction).

However, the TTF theory does not take into account the influence of users' personal factors or community factors. Therefore, to make up for the shortcomings of a single structure and strengthen the explanatory power of TTF, Dishaw and Strong (1999) proposed a model that integrated the TTF theory and the technology acceptance model (TAM). To conduct more comprehensive analyses and research, many scholars have chosen to use the TTF-UTAUT integrated model to explore the key factors that affect user behavioral intention and actual use behavior (Lee et al., 2007; Oliveira et al., 2014; Tai & Ku, 2014; Zhou et al., 2010). This new integrated model is the best choice to predict and explain user behaviors. Many studies have used the UTAUT to predict the user's use of the system and have obtained a higher explanatory power than the TAM (e.g., Gupta et al., 2019).

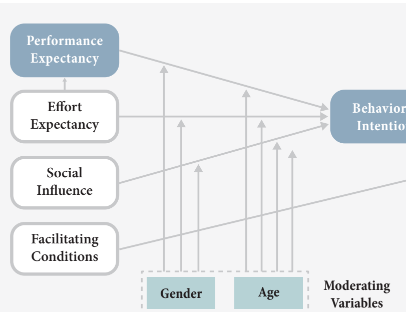
2.3 UTAUT

The UTAUT was developed by Venkatesh et al. (2003) based on two theoretical models: Theory of Reasoned Action (TRA) and Technology Acceptance Model (TAM). Additionally, the UTAUT integrated six other theoretical models: MM (Motivational Model), TPB (Theory of Planned Behavior), C-TAM-TPB (Combined TAM and TPB), MPCU (Model of PC Utilization), IDT (Innovation Diffusion Theory), and SCT (Social Cognitive Theory).

The TRA was published by Fishbein and Ajzen in 1975 to illustrate the causal relationship between an individual's specific behavior intention and the actual behavior; this relationship is affected by two factors—the attitude toward the behavior and subjective norms. Attitude refers to the assessment resulting from beliefs about the consequences of one's behaviors, and it has a positive impact on behavioral intention. Subjective norms refer to external social pressures when performing specific behaviors, and it also directly affects an individual's behavioral intention, which in turn determines the actual behavior of the individual. Davis (1986) proposed the TAM based on the TRA. The TAM introduces two dimensions: perceived usefulness and perceived ease of use. It aims at evaluating user behavior related to the internal information system of an organization. Perceived usefulness is the subjective perception of users when using a specific information system, which can improve performance impact and is affected by external variables and perceived ease of use. Perceived ease of use is the subjective perception of users in learning to use a specific information system. The degree of effort required is affected by external variables; the attitude toward technology use is affected by perceived usefulness and perceived ease of use. The user's positive and negative emotions are affected by their attitude when using a specific information system as an aid, and the attitude affects the use behavior of that technology. Later, in 1989, Davis studied IBM laboratory employees and found that behavioral intention has an impact on use behavior, and perceived usefulness is directly related to behavioral intention. Therefore, the TAM theoretical model was modified again, and behavioral intention was added to the newly proposed TAM2.

It is worth noting that Venkatesh et al. revisited the UTAUT in 2012 and re-integrated the aforementioned eight theories into the theory and proposed the Extended Unified Theory of Acceptance and Use of Technology (UTAUT2), into which they added hedonistic motivation, price value, and habit as influencing factors. Although the newly added factors have a significant impact at the individual level, they have a low degree of impact in corporate organizations. As the research participants of this study worked in the LCD panel and component manufacturing industry, factors such as entertainment, price value, and habits are already being controlled as task characteristics and are not affected by the technological characteristics of mobile cloud computing that is introduced in the workplace. Therefore, UTAUT is more suitable for this study than UTAUT2.

As the theory evolved from TRA to UTAUT, behavioral intention has been used to predict the final use behavior of users. However, behavioral intention is affected by various factors, and these influencing factors are mostly derived from the user's cognitive psychology (Vessey, 1991). In other words, individual behaviors are specific outward expressions based on personal expectations. The UTAUT has been used in various fields such as medical care, agriculture and forestry, web services, mobile business, psychology, sociology, and information systems (Gupta et al., 2019; Lai & Lai, 2014; Lee et al., 2013; Oliveira et al., 2014; Wang, 2016; Williams et al., 2015; Zhou et al., 2010). According to the key influencing factors found by previous studies, to analyze user behavioral intention for the research purpose of this study, the modified UTAUT has four independent variables: performance expectancy, effort expectancy, social influence, and facilitating conditions, and two moderating variables: gender and age (Figure 2). Detailed descriptions of these four independent variables are as follows.



Source: Revised from Venkatesh, Morris, Davis and Davis, 2003, p. 447.

[Figure 2] The Modified UTAUT

Performance expectancy refers to the degree to which an individual can use a specific system to improve operational efficiency (Venkatesh et al., 2003). It is similar to TAM's perceived usefulness. Users' subjective perceptions about the use of a specific information system can improve their performance impact and affect their intention to use (Zhou et al., 2010). This research proposes the following hypothesis:

H6 : LCD panel and component manufacturing employees' performance expectancy of mobile cloud computing application program has a positive impact on their behavioral intention to use the technology.

Effort expectancy refers to how easy it is for an individual to use a specific system (Venkatesh et al. 2003). It is similar to TAM's perceived ease of use, which means that the user's subjective perception about learning a system. For information systems, the degree of effort required has an impact on the user's behavioral intention (Zhou et al., 2010). According to the correlation between TAM's perceived usefulness and perceived ease of use, it can be deduced that effort and expectation will have a positive effect on the behavioral intention of using the technology (Lee et al., 2007). The technology characteristics in the TTF model correspond to the five technology characteristics of mobile cloud computing applications (i.e., portability, connectivity, low power, platform independent, and integrated environments). Users (workers in the LCD panel and component manufacturing industry) will have expectations about the effort required for a specific system due to these characteristics. Their expectations will have positive effects on their behavioral intention (Lee et al., 2007). Therefore, this research proposes the following hypothesis:

H7 : LCD panel and component manufacturing employees' effort expectancy about mobile cloud computing applications has a positive impact on their behavioral intention.

Social influence refers to the degree to which an individual believes that he or she should use a new system because someone important also uses it (Venkatesh et al., 2003). The concept is similar to the subjective norm concerning behavior mentioned by the TRA, which means that when a specific behavior is performed, external social pressure affects the user's behavioral intention to use the system (Zhou et al., 2010). This research proposes the following hypothesis:

H8 : LCD panel and component manufacturing employees' social influence about mobile cloud computing application has a positive influence on their behavioral intention.

Facilitating conditions refer to "the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system," which directly affects whether an individual adopts the system (Venkatesh et al., 2003). Facilitating conditions are similar to the idea of perceived behavioral control in the Theory of Planned Behavior (TPB) proposed by Ajzen (1985, 1991). Perceived behavioral control refers to the ability to control one's behavior and is affected by one's capabilities and external resources (Zhou et al., 2010). In the context of mobile cloud computing applications, users need to have some basic skills to operate the application systems, as well as external factors that support the data networks. Otherwise, users would not adopt this system. In addition, according to several studies on mobile commerce, facilitating conditions positively affect behavioral intention (Lai & Lai, 2014; Lee et al., 2007; Oliveira et al., 2014; Zhou et al., 2010). The current study thus proposed the following hypothesis:

H9 : The facilitating conditions of mobile cloud computing's application in LCD panel and component manufacturing positively affect employee's behavioral intention.

Performance expectancy, effort expectancy, and social influence positively affect the behavioral intention, which in turn affects the user's use behavior of the new technology (Venkatesh et al., 2003). Ajzen and Fishbein (1980) and Davis (1989) have pointed out that the intention of use indeed impacts actual system use. Behavioral intention is defined as an individual's inclination to take a certain action. This study proposed the following hypothesis:

H10 : LCD panel and component manufacturing employees' behavioral intention to use cloud computing application programs positively affects their use behavior.

Due to the advantage of mobile cloud computing being easy to operate and having simple system interfaces, users would find it convenient to use. Consequently, mobile cloud computing's technology characteristics are positively related to effort expectancy (Zhou et al., 2010). When the users' work demands ubiquitous, fast, and convenient services, they may perceive that the system could increase their efficiency. The users would then determine that the effort associated with adopting mobile cloud computing may have a positive impact on their performance (Bauer, 2018). Thus, two hypotheses were proposed:

H11 : LCD panel and component manufacturing employees' effort expectancy positively affects their performance expectancy.

H12 : The technology characteristics of cloud computing application programs positively affect the effort expectancy of LCD panel and component manufacturing employees.

The UTAUT includes four moderators; their impact on the intention of use had been confirmed through cross-analysis. The moderators are gender, age, experience, and voluntariness of use (Venkatesh et al., 2003; Venkatesh & Davis, 2000). However, the current study's research scope is within the sector of LCD panel and component manufacturing, which had just in recent years started to require employees to use cloud computing application programs in their operations. Therefore, experience and voluntariness of use are not applicable to this study. The other two variables are detailed as follows: (1) Gender is dichotomized as male or female. The literature indicates that gender plays an important role in the process of technology adoption (Venkatesh et al., 2003; Venkatesh & Davis, 2000). Females tend to be impacted by social influence more so than males when using innovative technology. They are affected more by social factors than individual factors when making decisions. They also have higher levels of computer anxiety than their male counterparts. (2) Age has been confirmed by previous studies as a factor that, alongside gender, affects user perception of specific information technologies by having a moderating effect (Tai & Ku, 2014). Some scholars have pointed out that age and gender have a positive impact on behavioral intention; moreover, the facilitating conditions' impact on the use behavior is affected by the moderating effects of age (Venkatesh et al., 2012; Yu, 2012). Therefore, this study proposed the following seven hypotheses:

H13a : In the context of mobile cloud computing applications in LCD panel and component manufacturing, the employees' gender (particularly female corporate employees) indirectly affects their performance expectancy, which in turn affects their behavioral intention.

H13b : In the context of mobile cloud computing applications in LCD panel and component manufacturing, the employees' gender (particularly female corporate employees) indirectly affects their effort expectancy, which in turn affects their behavioral intention.

H13c : In the context of mobile cloud computing applications in LCD panel and component manufacturing, the employees' gender (particularly female corporate employees) indirectly affects the social influence, which in turn affects their behavioral intention.

H14a : In the context of mobile cloud computing applications in LCD panel and component manufacturing, the employees' age indirectly affects their performance expectancy, which in turn affects their behavioral intention.

H14b : In the context of mobile cloud computing applications in LCD panel and component manufacturing, the employees' age indirectly affects their effort expectancy, which in turn affects their behavioral intention.

H14c : In the context of mobile cloud computing applications in LCD panel and component manufacturing, the employees' age indirectly affects the social influence, which in turn affects their behavioral intention.

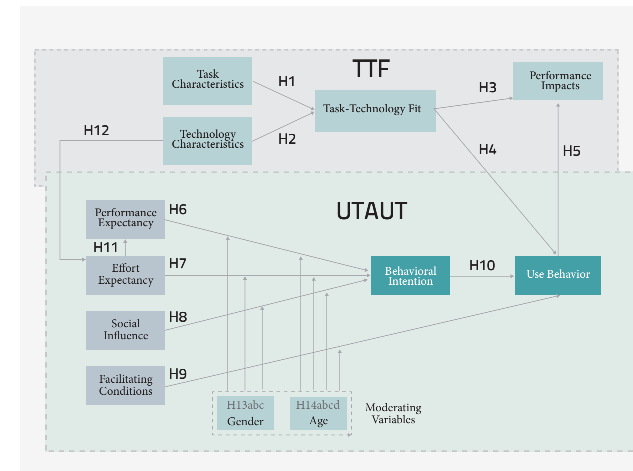
H14d : In the context of mobile cloud computing applications in LCD panel and component manufacturing, the employees' age indirectly affects the facilitating conditions, which in turn ffect their use behavior.

3. Methodology

3.1 Instrument

For our research purpose, this study integrated TTF and UTAUT to build a research model that includes ten constructs and two moderator variables (Figure 3). Table 1 lists the operational definition and measurement items of all the variables. All items were measured with a five-point Likert scale. In the questionnaire, we asked for the respondents' demographic information, such as gender, age, education, department in the case company, job title, years of work experience, and years of using mobile cloud computing systems. We used both online and paper questionnaires to gather data and then utilized SPSS 17.0 and AMOS 20.0 to conduct structural equation modeling to verify this new research model.

A pilot for the questionnaire was conducted, and a total of 33 valid pilot questionnaires were collected. Four experts were invited to establish the content validity of the instrument. They modified items A1, A2, B2-B5, B7-B9, B10-B11, B13-B15, D3, and I1 to make the item read more smoothly and easier to understand. Then, reliability analysis was carried out using Cronbach's α reliability coefficient, item-to-total correlation, and "alpha if item deleted" (Nunnally & Bernstein, 1994). To confirm the construct validity of the scale, after the item analysis was completed, exploratory factor analysis was performed as a verification step, using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (Kaiser, 1974), and Bartlett's test of sphericity and other methods to evaluate the results. The principal axis factoring method was used for factor analysis; factor loading was determined based on the recommendations of DeVellis (2012), and community was judged based on the recommendations of Hair, et al. (2010). As a result, the α coefficient after deleting item B1 was 0.727, greater than the original scale α coefficient (0.633). Besides, the community and factor loading of this item were both lower than the standard (<0.5 and <0.7, respectively), so it was deleted from the scale. For B7, B13, D1, E2, F1, G3, H2, and J3, the α coefficient after removing the items was greater than the original scale α coefficient, but the reliability coefficients of these items were all greater than 0.7, and the sample size of the pilot analysis was not quite representative of the population, thus, these items were temporarily retained. Although the KMO values of G1-G3 (<0.6) were lower than the standard, the community and factor loading were both higher than the standard, and the pilot sample size cannot represent the population, so these were also temporarily retained. There were 44 items in the entire questionnaire, and it was expected that at least 220 valid questionnaires would be collected (Hair et al., 2010).



[Figure 3] Research Model

3.2 Mobile cloud computing applications in the case company

The current study's respondents were the employees at all levels in a corporate enterprise. The company uses four types of platforms: the Citrix Xen app, the Microsoft Remote app, Microsoft Exchange, and

[Table 1] The operational definition and measurement items of all constructs

Constructs	The operational definition and measurement items
Task characteristics	The characteristics of the tasks that employees are responsible for, namely, immediacy, repetitiveness, and unfixed work locations (Goodhue & Thompson, 1995).
	A1. I often need to monitor in real-time the tasks that I am responsible for. A2. I often need to manage in real-time the tasks that I am responsible for. A3. Processing the tasks that I am responsible for requires repetitive procedures. A4. The tasks that I am responsible for remain mostly static. A5. The tasks that I am responsible for do not occur in a fixed location but require that I move around.
Technology characteristics	In the context of LCD panel and component manufacturing, when employees use mobile cloud computing to carry out their tasks, the five main technology characteristics of mobile computing are portability (B2-B3), network connection, low power (B4-B6), platform independent (B7-B9), and integrated environments (B10-B12) (Kulkarni et al., 2014, p.565).
	B1. I think that mobile cloud computing devices, such as tablets and phones, can be carried around easily (Note: This item was removed after the pilot analysis.). B2. I think that the mobile cloud computing devices provided by the company, such as tablets or cell phones, can be used easily when I'm on the move. B3. I think that the portability of the mobile cloud computing devices provided by the company, such as tablets or cell phones, do not interfere with my completing the tasks at work. B4. I think that the mobile cloud computing provided by the company has high network-connection speed. B5. I think that the mobile cloud computing provided by the company offers a convenient way of connecting to the network (such as WiFi or 3G). B6. In the area that I am in charge of, the signal strength of the network connection is enough to let me use my company's mobile cloud computing application system. B7. I think that the battery life of the mobile cloud computing devices provided by the company, such as tablets or cell phones, should match what the tasks require. B8. I think that the battery life of the mobile cloud computing devices provided by the company, such as tablets or cell phones, are more energy-saving than other information technology equipment (e.g., laptops, desktop computers, etc.). B9. I think that the battery life of the mobile cloud computing devices provided by the company, such as tablets or cell phones, can help the company lower its energy consumption. B10. I think the mobile cloud computing provided by the company can be easily installed with popular cell phone operating systems, such as Android and IOS. B11. I think the mobile cloud computing provided by the company is convenient because it can be used with popular cell phone operating systems. B12. I think the mobile cloud computing provided by the company can be easily executed with popular cell phone operating systems. B13. I think the mobile cloud computing provided by the company is convenient because it can be used in combination with peripheral information technology equipment (e.g., scanners, printers, etc.). B14. I think the mobile cloud computing provided by the company can be easily used in combination with peripheral information technology equipment (e.g., scanners, printers, etc.). B15. I think the mobile cloud computing provided by the company can be efficiently combined with peripheral information technology equipment (e.g., scanners, printers, etc.).
Task-technology fit	The degree of fit when applying mobile cloud computing to the tasks (Goodhue & Thompson, 1995; Zhou et al., 2010)
	C1. Mobile cloud computing provides me with the information I need for work. C2. Mobile cloud computing provides me with real-time information I need for work. C3. Mobile cloud computing is beneficial to the execution of my tasks.

Constructs	The operational definition and measurement items
Performance impact (user satisfaction)	The relationship between the LCD panel and component manufacturing employees' performance impact (user satisfaction) and their use behavior and the task-technology fit (Au et al., 2002; Brown et al., 2008).
	D1. I am satisfied with using mobile cloud computing for my tasks. D2. I am satisfied with the results that mobile cloud computing has given me. D3. I am satisfied with how using mobile cloud computing has affected my job performance.
Performance expectancy	The LCD panel and component manufacturing employees' perception of the degree to which applying mobile cloud computing may increase their operational efficiency (Venkatesh et al., 2003; Zhou et al., 2010)
	E1. I think mobile cloud computing can increase work efficiency. E2. I think mobile cloud computing can reduce workload. E3. I think mobile cloud computing can increase the task processing speed.
Effort expectancy	The LCD panel and component manufacturing employees' perception of the amount of effort required to use the mobile cloud computing systems (Venkatesh et al., 2003; Zhou et al., 2010)
	F1. I am proficient at using mobile cloud computing. F2. I can quickly learn how to use mobile cloud computing. F3. I can easily learn how to use mobile cloud computing.
Social influence	The degree to which the LCD panel and component manufacturing employees' perceptions of applying the mobile cloud computing systems are influenced by their co-workers and supervisors (Venkatesh et al., 2003; Zhou et al., 2010)
	G1. My colleagues think that I should apply mobile cloud computing to my work. G2. My supervisor thinks that I should apply mobile cloud computing to my work. G3. My company encourages employees to apply mobile cloud computing to their work.
Facilitating conditions	The degree to which the LCD panel and component manufacturing employees' perceptions of applying the mobile cloud computing systems are influenced by their co-workers and supervisors (Venkatesh et al., 2003; Zhou et al., 2010)
	H1. I think I know what resources are needed to apply mobile cloud computing to my work. H2. I think I have the necessary knowledge for applying mobile cloud computing to my work. H3. There is dedicated staff in the company that can help me when I have trouble applying mobile cloud computing to my work. H4. There is a dedicated department in the company that can help me when I have trouble applying mobile cloud computing to my work.
Behavioral intention	The LCD panel and component manufacturing employees' intention to apply mobile cloud computing to their work (Ajzen & Fishbein, 1980; Venkatesh et al., 2003)
	I1. I will continue to use mobile cloud computing. I2. I may continue to use mobile cloud computing in the future. I3. I plan to continue to use mobile cloud computing.
Use behavior	The frequency and experience of the LCD panel and component manufacturing employees' use o mobile cloud computing for work (Oliveira et al., 2014; Tai & Ku, 2014)
	J1. I have positive experiences with applying mobile cloud computing to my work. J2. I often apply mobile cloud computing to my work. J3. I think that it is beneficial to apply mobile cloud computing to one's work.

others (38 different services). The Citrix Xen app and Microsoft Remote app share similar functionalities. They can provide mobile cloud computing services by establishing a connection through the mobile cloud computing application platform without making any changes to any of the systems or web services provided by the company. Users can connect to the system services required by the cloud computing application platform's web pages or application software. In addition, the Citrix Xen app provides application software that supports various mobile devices, which is easier to use than the Microsoft Remote app. The setup cost is relatively high, so it is mainly used by the executives and business departments higher than the manufacturing level. The Microsoft Remote app is mainly used by the officials above the division level and personnel with relevant business needs. Microsoft Exchange is the mail server, which provides functions such as sending and receiving mail messages, online contact lists, and calendars. Users can connect and use Microsoft Exchange through the browser of the mobile device or the mail application software. Mobile cloud services provided are Outlook Web App and Exchange ActiveSync. The Outlook Web App service can be connected and used with a browser on any mobile device. The service is provided for all corporate members. Exchange ActiveSync is an application program and mail server accessed through the mobile device. It is more complete and more convenient than Outlook Web App and mainly provides officials above the department level and personnel with relevant business needs.

Finally, the other mobile cloud computing application systems were developed by the company based on its internal operating requirements. For example, the "WHMS" warehouse management system is a mobile cloud computing application system combined with a wireless scanner device. It was developed mainly for inventory operations and can be integrated with other peripheral devices (such as printers) through a wireless network to produce paper-based outputs. This service is mainly provided for the warehouse team. Other mobile cloud computing applications and the teams they provide service for are not listed here.

3.3 Research scope

The scope of this research is limited to the LCD panel and component manufacturing industry. The case company specializes in the production of color filters. It is one of the 500 largest manufacturing companies in Taiwan and has nearly 1,000 employees. It has already adopted mobile cloud computing, and the employees are already using this technology in their work. Therefore, the sample of this study is limited to the data of the company's employees who use mobile cloud computing applications. This will help to understand the impact of the company's adoption of mobile cloud computing, the key factors for such adoption, and their impact on the operational efficiency of the staff.

4. Results

In this study, 239 valid responses were returned (a response rate of 74.22%). The demographic of all valid responses is listed in Table 2. One-way ANOVA was first used to analyze the within-group and between-group variances. The homogeneity of gender, age, work experience, and other variables was confirmed. Next, the Games-Howell test was used to verify that there were no significant differences between the following variables: education (behavioral intention), department (effort expectancy), job title (task characteristics, technology characteristics, task-technology fit, user satisfaction, performance expectancy), experience in using mobile cloud computing (performance expectancy, effort expectancy, social influence, facilitating conditions, behavioral intention, use behavior), frequency of using mobile cloud computing system (effort expectancy, social influence, facilitating conditions, use behavior). In the end, the homogeneity of these variables was confirmed.

Subsequently, this study used Harman's one-factor test of common method variance. Also, following the suggestion of Podsakoff and Organ (1986), principal factor analysis was conducted for all 44 items across the constructs. Eleven factors were extracted that had a characteristic value of >1. The cumulative variance explained was 72.242%, with the first factor accounting for 31.494% of the variance (<50%). It was concluded that common method variance was not a significant problem in the current study.

The results of the descriptive statistical analysis are shown in Table 3. As for the results of the reliability analysis, first, we determined the critical ratio between the high-scoring group (top 27% of the total score) and the low-scoring group (bottom 27% of the total

[Table 2] Demographics of all valid responses (N=239)

Demographic	Group	Number	Percentage
Gender	Male	164	68.62%
	Female	75	31.38%
Age	21 and below	50	20.92%
	31~40	161	67.30%
	41 or above	28	11.72%
Education	High school	17	7.11%
	Associate degree	31	12.97%
	College	136	56.90%
	Graduate school	55	23.01%
Department	Biotechnology manufacturing	133	55.65%
	Management-related	78	32.64%
	Information-related	28	11.72%
Job title	On-site personnel	79	33.05%
	Engineer	94	39.33%
	Manager	38	15.90%
	Supervisor	28	11.72%
Work experience	Less than 1 year	19	7.95%
	1 to 3 years	45	18.83%
	4 to 6 years	67	28.03%
	7 to 9 years	47	19.67%
	10 years or more	61	25.52%
Year of using mobile cloud computing systems	1 year or less	86	36.00%
	2 to 3 years	99	41.49%
	4 to 5 years	37	15.50%
	6 years or more	17	7.10%
Frequency of using mobile cloud computing systems	Every day, each time taking > 1 hour	98	41.00%
	Every day, each time taking < 1 hour	65	27.20%
	Not every day, but more than 5 times a week	30	12.55%
	Seldom, no more than 5 times a week	46	19.25%

score) for each of the 44 items in the measurement scale. Performing the t-test on the critical ratio showed that all t-values were greater than 3, ranging from 8.85 to 23.45, indicating that all items have good discrimination. Secondly, the item-total correlation values were at least 0.3, ranging from 0.3 to 0.78. This means that the internal homogeneity of the items in the questionnaire was adequate. The Cronbach's α reliability value of each construct was also greater than 0.7, ranging from 0.71 to 0.83, indicating that the various constructs being studied have a certain degree of stability and consistency. Judging from the three reliability analyses and measurement standards, we conclude that the questionnaire in this research has good credibility (Table 3).

Before conducting a path analysis for the overall model, it was necessary to effectively measure the latent variables to correctly estimate the path coefficients in the overall model. A confirmatory factor analysis was performed to confirm whether the questionnaire data can measure the latent variables and verify the appropriateness of the various constructs and items of this research. As for the model's basic appropriateness, item removal based on the modification index (MI) can help achieve the highest explanatory power and improve the model's goodness of fit. The maximum MI value and the absolute value of the maximum "par change" value should be used when modifying the model. In addition, according to Hair et al. (2010), before evaluating the model's goodness of fit, it is necessary to check whether there is any offending estimate and check that the error variance is not a negative value, and the standardized coefficient is not greater than 0.95. In this study, A3-A5, B4, B7, B10, B13, C1, D1, E1, F1, G1, H1, H4, I1, J1 were deleted from the questionnaire. The final 28 measurement items in the research model all had a positive error variance, and the factor loadings were between 0.679 and 0.931. Hence, there was no violation of statistical assumptions.

The main indicators for the overall model fit are absolute fit measures, incremental fit measures, and parsimonious fit measures (Hair et al., 2010). The results of the overall fit of the model in this study yielded the following absolute fitness indexes: RMSEA = 0.079, RMR = 0.036, GFI = 0.8, and AGFI = 0.757, all of which met the standards. Then, the incremental fit measures yielded NFI = 0.800 and CFI = 0.869. Finally, the parsimonious fit measures yielded PNFI = 0.583 and PCFI = 0.576. Although not all indexes exceeded the ideal values, the overall model was still deemed as acceptable.

Construct validity is divided into convergent validity and discriminant validity. The results of the analysis of convergence validity showed that the average variance extracted (AVE) for the constructs ranged from 0.529 to 0.788. All AVE values were >0.5. Next, factor loading of the questionnaire items showed that, except for item E2, which had a value of 0.679, all other items' factor loadings were greater than 0.7. As a factor loading of 0.6 or above is considered acceptable by Hair et al. (2010), the factor loading of the items was regarded as meeting the criterion. Finally, the composite reliability values of all the constructs ranged from 0.6913 to 0.9627, which were all greater than 0.6, indicating that this model has convergent validity. The other validity, discriminant validity, measures whether there is a degree of differentiation between the items under different variables. According to Hair et al. (2012), the square root of the AVE of each construct should be greater than its correlation coefficient with all other constructs to be considered as having sufficient discriminant validity. Such was the case

[Table 3] Descriptive statistical analysis results of all valid responses (N=239)

Item	Mean	Standard deviation	Factor loading
A1	4.12	0.75	0.756
A2	3.98	0.67	0.882
A3	3.96	0.78	-
A4	3.78	0.91	-
A5	3.60	1.07	-
Overall A	**3.89**	**0.58**	
B2	3.64	0.96	0.851
B3	3.86	0.80	0.764
B4	3.58	0.91	-
B5	3.44	0.96	0.792
B6	3.38	1.08	0.87
B7	3.49	0.88	-
B8	3.57	0.85	0.823
B9	3.49	0.85	0.786
B10	3.72	0.83	-
B11	3.73	0.91	0.824
B12	3.67	0.87	0.923
B13	3.71	0.88	-
B14	3.44	0.92	0.931
B15	3.47	0.88	0.912
Overall B	**3.59**	**0.14**	
C1	3.54	0.915	-
C2	3.86	0.790	0.857
C3	3.99	0.756	0.818
Overall C	**3.80**	**0.67**	
D1	3.94	0.70	-
D2	3.66	0.71	0.891
D3	3.67	0.76	0.848
Overall D	**3.76**	**0.63**	
E1	3.72	0.65	-
E2	4.02	0.60	0.679
E3	3.91	0.72	0.773
Overall E	**3.88**	**0.53**	
F1	3.92	0.77	-
F2	3.63	0.84	0.923
F3	3.74	0.77	0.851
Overall F	**3.76**	**0.65**	
G1	3.58	0.784	-
G2	3.55	0.665	0.793
G3	3.58	0.734	0.72
Overall G	**3.57**	**0.60**	
H1	3.58	0.789	-
H2	3.58	0.773	0.821
H3	3.35	0.861	0.849
H4	3.77	0.795	-
Overall H	**3.57**	**0.62**	
I1	3.87	0.668	-
I2	3.97	0.604	0.86
I3	3.97	0.597	0.819
Overall I	**3.94**	**0.51**	
J1	3.93	0.65	-
J2	4.01	0.58	0.757
J3	3.85	0.65	0.743
Overall J	**3.93**	**0.54**	

for all the constructs in this study. It was therefore concluded that this model has adequate discriminant validity (Table 4). Once the research model was confirmed as having a good fit, path coefficient testing, moderating variable analysis, and path effect analysis were conducted using the statistical software AMOS to observe the causal relationships between the variables and the latent variables. Table 5 and Figure 4 present the path coefficients and the results of hypothesis testing.

Additionally, moderating variable analysis was performed to verify whether gender and age have an impact on each construct. Gender was divided into two groups, male and female. Each group's parameters were set in AMOS, and the hypotheses were specified in Manage Models for the analysis (A1 = A2; B1 = B2; C1 = C2). Age was also divided into two groups: 30 years old and under, and over 30 years old. Similarly, each group's parameters were set in AMOS, and the hypotheses were specified in Manage Models for the analysis (A1 = A2; B1 = B2; C1 = C2; D1 = D2). The overall analysis results are shown in Table 6. As shown in Figure 5, the female group's explanatory power (R^2 =0.704) is greater than that of the male group (R^2 =0.374). Figure 6 shows that the younger age group had an explanatory power of behavioral intention (R^2 = 0.853) that was greater than that of the older group (R^2 =0.414). Besides, the explanatory power of the older group for use behavior was as high as R^2 =0.801.

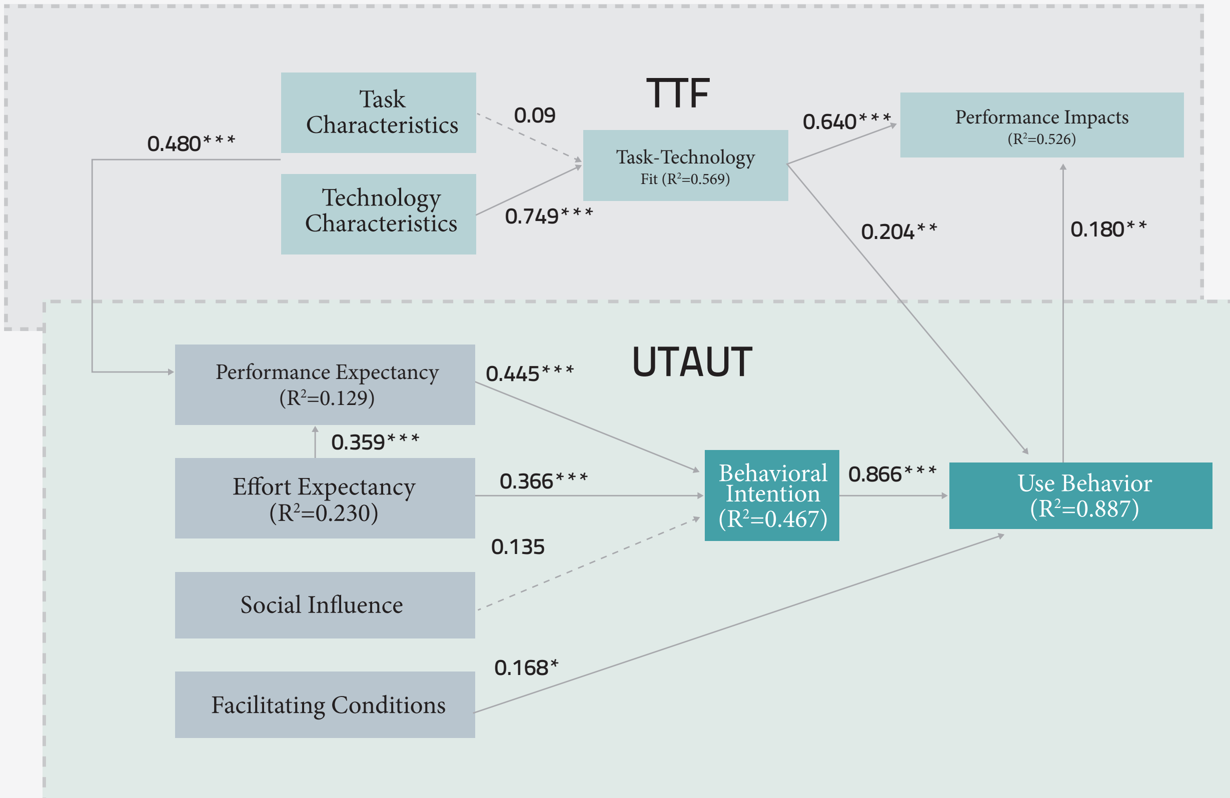
[Table 4] Results of correlation coefficient analysis results and discriminant validity

Constructs	AVE	C.R.	Technology characteristics	Facilitating conditions	Social influence	Task characteristics	Effort expectancy	Performance expectancy	Behavioral intention	Task-technology fit	Use behavior	User satisfaction
Technology characteristics	0.722	0.963	**0.850**									
Facilitating conditions	0.697	0.822	0.172	**0.835**								
Social influences	0.574	0.729	0.217	0.587	**0.758**							
Task characteristics	0.675	0.805	0.042	0.596	0.582	**0.822**						
Effort expectancy	0.788	0.881	0.247	0.326	0.465	0.378	**0.888**					
Performance expectancy	0.529	0.691	0.212	0.393	0.324	0.388	0.264	**0.727**				
Behavioral intention	0.705	0.827	0.189	0.198	0.233	0.281	0.308	0.403	**0.840**			
Task-technology fit	0.702	0.825	0.196	0.397	0.298	0.323	0.300	0.568	0.291	**0.838**		
Use behavior	0.563	0.720	0.204	0.296	0.320	0.295	0.465	0.463	0.328	0.293	**0.750**	
User satisfaction	0.757	0.861	0.250	0.457	0.400	0.451	0.439	0.506	0.371	0.413	0.731	**0.870**

[Table 5] Path coefficients of the structural equation model and the corresponding research hypotheses

Hypotheses	Latent variable	Estimated unstandardized weighted regression coefficient	Standardized weighted regression coefficient (path coefficient)	S.E.	C.R. (t-value)	Sig.	Supported
H1	Task characteristics → Task-technology fit	0.107	0.090	0.076	1.402	0.161	No
H2	Technology characteristics → Task-technology fit	0.860	0.749	0.109	7.906	***	Yes
H3	Task-technology fit → Performance impact (user satisfaction)	0.593	0.640	0.078	7.638	***	Yes
H4	Task-technology fit → Use behavior	0.126	0.204	0.040	3.171	0.002	Yes
H5	Use behavior → Performance impact (user satisfaction)	0.270	0.180	0.101	2.684	0.007	Yes
H6	Performance expectancy → Behavioral intention	0.405	0.445	0.086	4.697	***	Yes
H7	Effort expectancy → Behavioral intention	0.239	0.366	0.049	4.858	***	Yes
H8	Social influences → Behavioral intention	0.130	0.135	0.083	1.568	0.117	No
H9	Facilitating conditions → Use behavior	0.110	0.168	0.044	2.488	0.013	Yes
H10	Behavioral intention → Use behavior	0.707	0.866	0.068	10.348	***	Yes
H11	Effort expectancy → Performance expectancy	0.258	0.359	0.061	4.242	***	Yes
H12	Technology characteristics → Effort expectancy	0.636	0.480	0.106	5.998	***	Yes

Note : N = 239 *p < 0.05 **p < 0.01 ***p < 0.001



Note: *p < 0.05, **p < 0.01, ***p < 0.001; the dotted lines are not significant

[Figure 4] Path coefficient diagram of the structural equation model

5. Discussions and conclusions

The current study developed a conceptual framework by integrating the TTF theory and the revised version of the UTAUT. Using this framework as the theoretical foundation, the study explored mobile cloud computing application systems' effect on user performance impact, as well as the key factors that affect such systems' adoption.

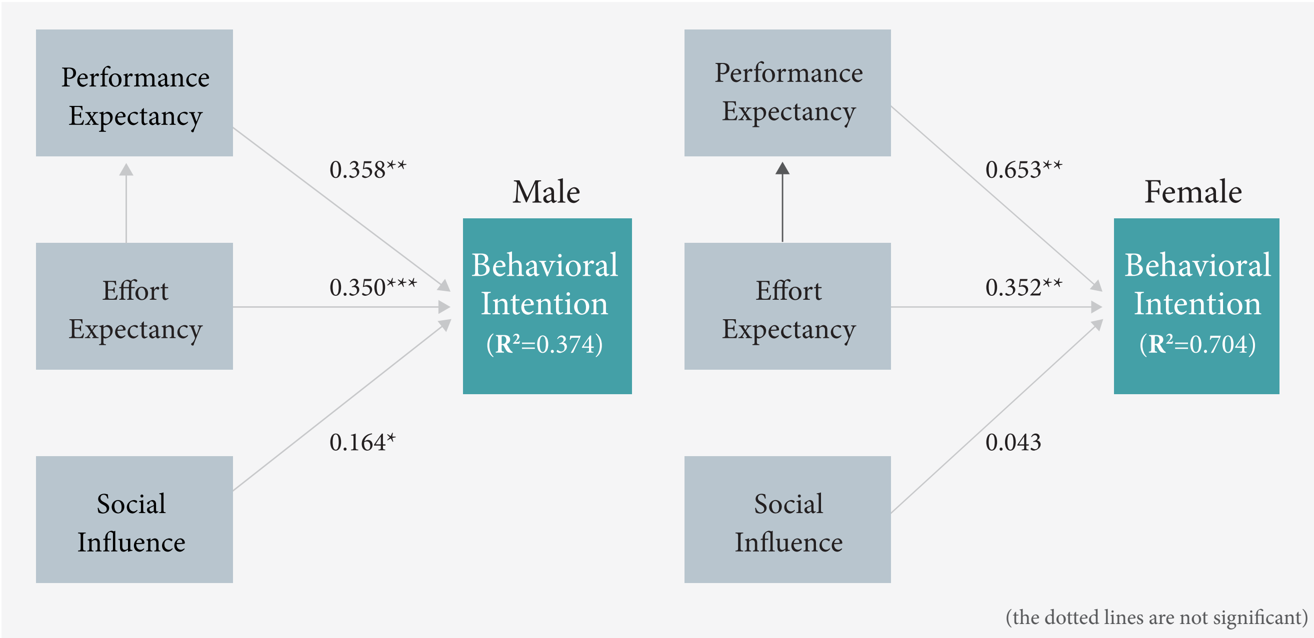
5.1 Academic implications

First, we used the TTF model proposed by Goodhue & Thompson (1995) to explore the impact of the fit between the user's tasks and mobile cloud computing application system on their work performance. The analysis results showed that task-technology fit has a significant positive effect on performance impact ($\beta = 0.640$, $p < 0.001$), which verifies the argument of Zhou et al. (2010) that when the cognitive fit reaches a certain threshold, specific auxiliary systems or tools can be used to help process tasks more efficiently. Dishaw & Strong (1999) have also pointed out that the abilities of information technology users also affect how well the tasks are supported by the technology. If information technology can positively support the task, users will have a positive perception of the technology,

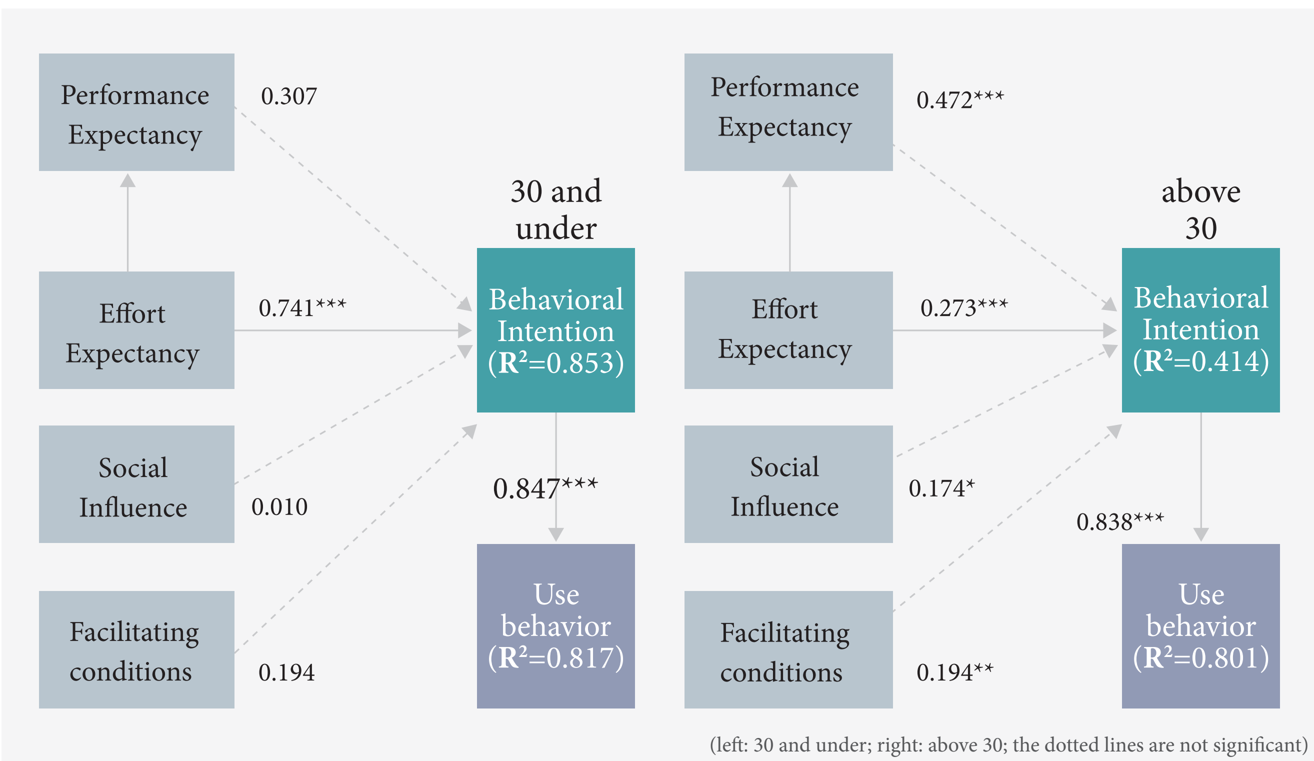
[Table 6] The effect analysis of the adjustment variables of the structural equation model and the corresponding research hypotheses

Hypotheses	Latent variable	Gender / Age	Estimated unstandardized weighted regression coefficient	Standardized weighted regression coefficient (path coefficient)	S.E.	C.R. (t-value)	Sig.	Supported
H13a	Performance expectancy → Behavioral intention	Male	0.325	0.358	0.099	3.273	0.683	No
		Female	0.598	0.749	0.153	3.911		
H13b	Effort expectancy → Behavioral intention	Male	0.244	0.35	0.062	3.906	0.226	No
		Female	0.204	0.352	0.067	3.049		
H13c	Social influences → Behavioral intention	Male	0.201	0.164	0.097	2.061	0.122	No
		Female	0.008	0.043	0.116	0.065		
H14a	Performance expectancy → Behavioral intention	<= 30	0.246	0.307	0.132	1.861	0.019	Yes
		> 30	0.429	0.472	0.097	7.349		
H14b	Effort expectancy → Behavioral intention	<= 30	0.451	0.741	0.116	3.900	0.192	No
		> 30	0.178	0.273	0.051	0.2475		
H14c	Social influences → Behavioral intention	<= 30	0.002	0.010	0.122	0.014	0.352	No
		> 30	0.178	0.174	0.089	2.035		
H14d	Facilitating conditions → Use behavior	<= 30	0.111	0.194	0.059	1.885	0.024	No
		> 30	0.124	0.194	0.048	2.606		

Note 1: GMale: N = 164; Female: N = 75
Note 2: 30 and under : N = 50; Above 30 : N = 189
Note 3: *p < 0.05 **p < 0.01 *** p < 0.001



[**Figure 5**] The analysis results of the effects of gender as a moderating variable



[**Figure 6**] The analysis results of the effects of age as a moderating variable

and they will become accustomed to using it. Therefore, it was not surprising that this study also found that task-technological fit had a significant and positive impact on use behavior (β = 0.204, p < 0.01), which is consistent with what scholars have concluded (Dishaw & Strong, 1999). Some scholars have pointed out that because mobile cloud computing is not limited by time or space constraints and can connect to the company's information service system to exchange data, it effectively increases operational efficiency and a company's competitive edge (Banerjee et al., 2013; Bauer, 2018). Due to mobile cloud computing's diverse and flexible operation modes, it has been widely adopted by enterprises (Guerrero-Contreras et al., 2016; Kulkarni et al., 2014; Stieglitz & Brockmann, 2012; Yuan et al., 2010). The current study found from the path analysis that technology characteristics significantly affected task-technology fit directly and significantly affected performance impact indirectly. These findings indicate that the diversity and flexibility of mobile cloud technology can indeed increase the task-technology fit when applied to workplace operations. The increased fit then improves operational efficiency. This finding also agrees with the literature. Thus, it can be concluded that the task-technology fit model is appropriate for analyzing enterprise mobile cloud computing applications.

This study also used the UTAUT to explore the user's behavioral intention and use behavior of mobile cloud computing application systems and explored their effect on performance impact. Venkatesh et al. (2003) have stated that behavioral intention is affected by performance expectancy, effort expectancy, and social influence, and it affects the use behavior of new technologies. From the results, we can conclude that the behavioral intention to use the technology has a significant impact on use behavior (β = 0.866, p < 0.001). Unlike social influence, performance expectancy (β = 0.445, p < 0.001) and effort expectancy (β = 0.366, p < 0.001) did have a significant impact on behavioral intention. The reason for the insignificant impact of the social influence dimension is due to the research object being a corporate company, where all employees were required to implement the company's new policies, regardless of individual users' willingness. While this conjecture should be further observed and verified, on the whole, it agrees with the arguments that Venkatesh et al. (2003) have made. Zhou et al. (2010) have defined perceived behavioral control as the ability to control one's behavior and is affected by one's capabilities and external resources. Similarly, the results showed that the facilitating conditions (β = 0.168, p < 0.05) have a significant impact on use behavior, which is consistent with the arguments of some scholars (Lai & Lai, 2014; Lee et al., 2007). The model that combines task-technology fit UTAUT also verifies that behavioral intention, facilitating conditions, and task-technology fit all have a significant impact on use behavior, which is also in line with the findings of Oliveira et al. (2014).

Regarding the moderating variables, the study found that age affected only performance expectancy and did not significantly affect effort expectancy, social influence, or facilitating conditions. The research participants were mainly in two age groups, with 88.1% of the participants falling in either the 21-30 years old group (20.8%) or the 31-40 years old group (67.3%). Since the respondents' ages had a small range, this variable's effect on the various dimensions was not discernable. The other moderating variable, gender, had a similar issue. Women accounted for 31.38% (75 people) of the participants. Of these, only 9.3% (7 people) were on-site personnel. The vast majority of the female employees were not on-site personnel, and they mainly used mobile cloud computing application systems such as Microsoft Remote App to connect to the system service. The only notable difference was the connection login method; once the system connection was complete, the mode of operation was no different from working on a PC. Thus, due to the limitations of the respondents' characteristics, the moderating variables' effects on the dimensions of performance expectancy, effort expectancy, and social influence were consequently not significant.

The above analyses lead to the conclusion that our model, which integrates the TTF and the UTAUT, can be used to research mobile cloud computing applications as an effective analytical framework for the impact of enterprises' adoption of mobile cloud computing application systems.

5.2 Practical implications

The study indicated that performance impact was affected more by task-technology fit than by use behavior in a practical situation. This was probably because the respondents were all employees in the same company. Therefore, when the enterprise requires the use of the new information technology system to complete the work tasks, all employees had to follow the policy. Thus, the impact of use behavior was limited. Additionally, when the new technology is adopted and meets the needs of the tasks that it is supposed to support, it increases the operational efficiency (Bauer, 2018; Guerrero-Contreras et al., 2019). Therefore, the task-technology fit has more influence in the workplace than the other factors do. The technology characteristics' effects on task-technology fit were found to be significant, but the task characteristics were not. This is probably because when the enterprise was visited for the study, it was still in the early phase of adopting cloud computing application systems and not in a mature phase. The tasks were therefore still not fully in line with the needs of the users (employees). Technology characteristics had a significant impact on effort expectancy, while effort expectancy had a significant impact on performance expectancy and behavioral intention. In practice, when users are aware that mobile cloud computing is simple and easy to use and when they are willing to learn, they will also be looking forward to this new information technology as a means to increase productivity. On the questionnaire, the overall average score of performance expectancy was higher than that of the performance impact. Respondents indicated that they had high expectations that mobile cloud computing would increase operational efficiency, which in turn increased their willingness to learn and use it at work to make their company more competitive.

The study also found that facilitating conditions allowed users to be willing to continue using mobile cloud computing. With sufficient resources, knowledge, and assistance, users can be encouraged to continue to use it. It was found that performance expectancy was positively related to the 31-and-above group and that people in this age group were more willing to use mobile cloud computing. The 30-and-below group accounted for about 79% of respondents. This indicates that the employee age is significant when the age is above 30, meaning that this factor can strengthen awareness of performance expectancy and effectively enhance the behavioral intention for the majority of the company employees in this age group.

The above analyses demonstrate that the integration of TTF and UTAUT is effective in studying cloud computing applications and in implementing such applications in enterprises.

Drawing from the results, it can be concluded that mobile cloud computing applications indeed have a positive effect on operational efficiency. Consequently, the following suggestions are made based on the key influencing factors for companies that plan to adopt the technology in the future:

① Focus on communication and interaction with the users before adopting the systems (improving the impact of task characteristics on task-technology fit)

Before introducing a mobile cloud computing application system, it is necessary to communicate with the users and evaluate their current operations to find a method that is acceptable to the user to ensure that the system is feasible. Afterward, a small-scale test is recommended. Once the test results meet the basic requirements of the operation and can effectively improve the efficiency, the system can then be formally introduced and deployed. After the adoption, the user's work situations should be tracked, and improvements can be made accordingly until the system can meet the operational needs of most users and can effectively increase the operational efficiency, that is, until it reaches the system maturity period.

② Improve the hardware environment (strengthening the technology characteristics of mobile cloud computing)

As stated in the results section, technology characteristics have the greatest impact on operational efficiency. Therefore, it is recommended that the technology characteristics of mobile cloud computing application systems be first enhanced before the system enters the maturity period. Doing so can maximize the increase in operational efficiency. One example is connectivity. The coverage of the company's internal wireless network should be enhanced so that users will not find themselves unable to use mobile cloud computing systems due to signal problems at certain work locations. Other examples are portability and integrated environments. For the case company in this study, it used to be necessary to go to the existing factory to take the inventory manually and record the numbers on paper, and then use a personal computer to enter the data into the inventory system, then print out the reports. The process was complex and the data might be incorrect due to paperwork errors. The company has since adopted mobile cloud computing. In the early stage of development, a tablet computer combined with a wireless scanner was used for inventory operations. The inventory was uploaded to the cloud. However, printing still had to be done from a personal computer. In a single inventory operation, two mobile devices had to be carried and used at the same time. Therefore, although the operation efficiency was improved, it was still inconvenient. At present, the technology characteristics of mobile cloud computing have been improved in both portability and integrated environments. It now takes just one wireless scanner to complete the inventory and printing operations, which greatly improves operational efficiency. The single-person inventory operation has proven to be problem-free. For the company, this means that it can effectively reduce the number of people needed.

③ Improve users' awareness

As seen from the results related to performance expectancy and facilitating conditions, strengthening these two factors can effectively improve performance impact. Therefore, seminars, training, and consulting services can be held to provide users with information, resource, and assistance to use the mobile cloud computing application systems. At the same time, strengthen the users' understanding of how mobile cloud computing applications can improve operational efficiency. This will enhance users' willingness to use the new system and their attitude toward use behavior, which will increase the company's tangible benefits and its competitive edge.

5.3 Limitations and future research

The results can be used as a reference for enterprises before adopting mobile computing applications in the future. However, two limitations should be considered when referring to this study's results. The first is the data collection source. This study only sampled the employees in the case company to collect the data on mobile cloud computing application systems. However, as the number of companies using mobile cloud computing application systems is gradually increasing, the results may lack broader meaning due to this limited research sample. It is suggested that follow-up research can enlarge the sample in the same industry to enhance the objectivity of the current findings. Future studies can also research different types of industries to explore whether their users have different perceptions of mobile cloud computing application systems. The second limitation is the data collection methods. The sample of data in this research was investigated through questionnaires, which is a quantitative research method. It is recommended that future studies employ qualitative research methods instead and use in-depth interviews to discuss the users' feelings about mobile cloud computing application systems so that the data is more complete and can reach into the core of the issue.

References

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. *Action Control*, 11-39.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179-211.

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social*. Behaviour. Englewood Cliffs, NJ: Prentice-Hall.

Alyoubi, B. A. & Yamin, M. A. Y. (2019). The impact of task technology fit on employee job performance. *Marketing and Management of Innovations*, 4, 140-159.

Arinze, B. (2010). Factors that determine the adoption of cloud computing: A global perspective. *International Journal of Enterprise Information Systems, 6*(4), 55-68.

Au, N., Ngai, E. W., & Cheng, T. C. (2002). A critical review of end-user information system satisfaction research and a new research framework. *Omega, 30*(6), 451-478.

Banerjee, A., Agrawal, P., & Iyengar, N. Ch. S. N. (2013). Energy efficiency model for cloud computing. International Journal of Energy. *Information and Communications, 4*(6), 29-42.

Bauer, E. (2018). Improving operational efficiency of applications via cloud computing. *IEEE Cloud Computing, 5*(1), 12-19.

Brown, S. A., Venkatesh, V., Kuruzovich, J., & Massey, A. P. (2008). Expectation confirmation: An examination of three competing models. *Organizational Behavior and Human Decision Processes*, 105(1), 52-66.

Business Net (April 2020). Can Taiwan LCD find a new market? [translated from Chinese] Retrieved from https://www.bnext.com.tw/article/57171/taiwan-lcd.

Cady, R. G., & Finkelstein, S. M. (2014). Task–Technology Fit of Video Telehealth for Nurses in an Outpatient Clinic Setting. *Telemedicine and e-Health, 20*(7): 633–639.

Chiu, C. Y., Chen, S., & Chen, C. L. (2017). An integrated perspective of TOE framework and innovation diffusion in broadband mobile applications adoption by enterprises. *International Journal of Management, Economics and Social Sciences, 6*(1), 14-39.

D' Ambra, J., Wilson, C. S., & Akter, S. (2013). Application of the task-technology fit model to structure and evaluate the adoption of e-books by academics. *Journal of the American Society for Information Science and Technology*, 64(1), 48-64.

Davis, F. D. (1986). *A technology acceptance model for empirically testing new end-user information systems: Theory and results, doctoral dissertation*. Cambridge, MA: MIT Sloan School of Management.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319-340.

DeVellis, R. F. (2012). *Scale development: Theory and applications*. Los Angeles: Sage Publications.

Dishaw, M. T., & Strong, D. M. (1999). Extending the technology acceptance model with task–technology fit constructs. *Information & Management, 36*(1), 9-21.

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention, and behavior: An introduction to theory and research*. Reading, MA: Addison-Wesley.

Forrester Consulting (October 2010). The Forrester Wave™: Services providers for oracle SaaS business apps, Q4 2020. Retrieved from https://www.forrester.com/oracle.

Gartner Survey Research (August 2020). Gartner says worldwide IaaS public cloud services market grew 37.3% in 2019. Retrieved from https://www.gartner.com/en/newsroom/press-releases/2020-08-10-gartner-says-worldwide-iaas-public-cloud-services-market-grew-37-point-3-percent-in-2019.

Gartner Survey Research (July 2020). Gartner forecasts worldwide public cloud revenue to grow 6.3% in 2020. Retrieved from https://www.gartner.com/en/newsroom/press-releases/2020-07-23-gartner-forecasts-worldwide-public-cloud-revenue-to-grow-6point3-percent-in-2020.

Goodhue, D. L., & Thompson, R. L. (1995). Task-technology fit and individual performance. *MIS Quarterly, 19*(2), 213-236.

Guerrero-Contreras, G., Garrido, J. L., Balderas-Diaz, S., & Rodriguez-Dominguez, C. (2016). A context-aware architecture supporting service availability in mobile cloud computing. *IEEE Transactions on Services Computing, 10*(6), 956-968.

Gupta, K. P., Manrai, R., & Goel, U. (2019). Factors influencing adoption of payments banks by Indian customers: Extending UTAUT with perceived credibility. *Journal of Asia Business Studies, 13*(2), 173-195.

Hair Jr., J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2010). *Multivariate data analysis: A global perspective* (7th ed.). Upper Saddle River: Pearson Education.

Hair, J. F., Sarstedt, M., Ringle, C. M., & Mena, J. A. (2012). An assessment of the use of partial least squares structural equation modeling in marketing research. *Journal of the Academy of Marketing Science, 40*(3), 414–433.

He, Y., Ma, L., Zhou, R., Huang, C., & Li, Z. (2019). *Online task allocation in mobile cloud computing with budget constraints. Computer Networks*, 151, 42-51.

Industrial Economics & Knowledge Center [IEK] (May 2020). Impact of COVID-19 on Taiwan LCD materials industry. Retrieved from https://ieknet.iek.org.tw/iekrpt/rpt_more.aspx?rpt_idno=680836644.

Infosys (July 2020). Global trends in the asset and wealth management industry 2020. Retrieved from https://www.infosys.com/about/knowledge-institute/documents/asset-wealth-management-2020.pdf.

International Data Corporation (June 2020). IDC expects worldwide smartphone shipments to plummet 11.9% in 2020 fueled by ongoing COVID-19 challenges. Retrieved from https://www.idc.com/getdoc.jsp?containerId=prUS46466720.

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, 39, 31–36.

Kim, D. & Ammeter, T. (2014). Predicting personal information system adoption using an integrated diffusion model. *Information & Management, 51*(4), 451-464.

Kulkarni, G., Shelke, R., Palwe, R., Solanke, V., Belsare, S., & Mohite, S. (2014). Mobile cloud computing-Bring Your Own Device. In the Proceedings of *the 2014 Fourth International Conference on Communication Systems and Network Technologies* (pp. 565-568). IEEE Computer Society, Washington DC, USA.

Lai, I. K., & Lai, D. C. (2014). User acceptance of mobile commerce: An empirical study in Macau. *International Journal of Systems Science, 45*(6), 1321-1331.

Lee, C. C., Su, K. W., Lu, C. T., & Yu, X. X. (2007). Task-technology fit and adoption behaviors of mobile business systems. Paper presented at *the International DSI / Asia and Pacific DSI 2007*. Retrieved from http://gebrc.nccu.edu.tw/proceedings/APDSI/2007/papers/Final_100.pdf.

Lee, J., Park, M. C., & Moon, J. (2013). Factors affecting the performance of mobile office outsourcing: An approach using the FORT model and the MoBiS-Q. *Management Decision, 51*(7), 1422-1441.

Lian, J. W., David Yen, C., & Wang, Y. T. (2014). An exploratory study to understand the critical factors affecting the decision to adopt cloud computing in Taiwan hospital. *International Journal of Information Management, 34*(1), 28-36.

Lin, T. C. (2014). Mobile nursing information system utilization: The task-technology fit perspective. *Computers Informatics Nursing, 32*(3), 129-137.

Market Intelligence & Consulting Institute [MIC] (April 2020). Enterprise report. Retrieved from https://mic.iii.org.tw/AISP/Reports.aspx?id=CDOC20200416008.

National Institute of Standards and Technology [NIST] (January 2018 updated). Final version of NIST cloud computing definition published. Retrieved from https://www.nist.gov/news-events/news/2011/10/final-version-nist-cloud-computing-definition-published#:~:text=According%20to%20the%20official%20NIST,and%20released%20with%20minimal%20management.

NIST (June 2020 updated). Cloud computing: Project overview. Retrieved from https://csrc.nist.gov/projects/cloud-computing.

Nunnally, J. C., & Bernstein, I. H. (1994). The assessment of reliability. *Psychometric Theory*, 3, 248-292.

Oliveira, T., Faria, M., Thomas, M. A., & Popovič, A. (2014). Extending the understanding of mobile banking adoption: When UTAUT meets TTF and ITM. *International Journal of Information Management, 34*(5), 689-703.

Stieglitz, S. & Brockmann, T. (2012). Increasing organizational performance by transforming into a mobile enterprise. *MIS Quarterly Executive 11*(4), 189-204.

Tai, Y. M., & Ku, Y. C. (2014). Will insurance brokers use mobile insurance service platform: An integration of UTAUT and TTF. Paper presented at the *20th Americas Conference on Information Systems*. Retrieved from https://aisel.aisnet.org/cgi/viewcontent.cgi?article=1525&context=amcis2014.

Taiwan Institute of Economic Research [TIER] (August 2019). Current and future trends of LCD panels and components [translated from Chinese]. Retrieved from https://www.tier.org.tw/achievements/pec3010.aspx?GUID=7d799b06-023e-4172-abaf-5e84de046f1c.

Tam, C. & Oliveira, T. (2016). Performance impact of mobile banking: Using the task-technology fit (TTF) approach. *International Journal of Bank Marketing 34*(4), 434-457.

Venkatesh, V. Y. L. Thong, J., & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology. *MIS Quarterly, 36*(1), 157-178.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the Technology Acceptance Model: Four longitudinal field studies. *Management Science, 46*(2), 186–204.

Venkatesh, V., Morris, M.G., Davis, G.B., and Davis, F.D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27(3), 425-478.

Vessey, I. (1991). Cognitive fit: A theory-based analysis of the graphs versus tables literature. *Decision Sciences*, 22(2), 219-240

Wang, M. H. (2016). Factors influencing usage of e-learning systems in Taiwan's public sector: Applying the UTAUT model. *Advances in Management & Applied Economics*, 6(6), 63-82.

Wang, S. L. & Lin, H. I. (2019). Integrating TTF and IDT to evaluate user intention of big data analytics in mobile cloud healthcare system. *Behaviour & Information Technology, 38(9)*, 947-985.

Williams, M. D., Rana, N. P., & Dwivedi, Y. K. (2015). The unified theory of acceptance and use of technology (UTAUT): A literature review. *Journal of Enterprise Information Management*, 28(3), 443-488.

Yu, C. S. (2012). Factors affecting individuals to adopt mobile banking: Empirical evidence from the UTAUT model. *Journal of Electronic Commerce Research, 13*(2), 104-121.

Yuan, Y., Archer, N., Connelly, C. E., & Zheng, W. (2010). Identifying the ideal fit between mobile work and mobile work support. *Information & Management, 47*(3), 125-137.

Zhou, T., Lu, Y., & Wang, B. (2010). Integrating TTF and UTAUT to explain mobile banking user adoption. *Computers in Human Behavior, 26*(4), 760-767.

S&T Trends

Emerging Technologies in the Post COVID-19 Era

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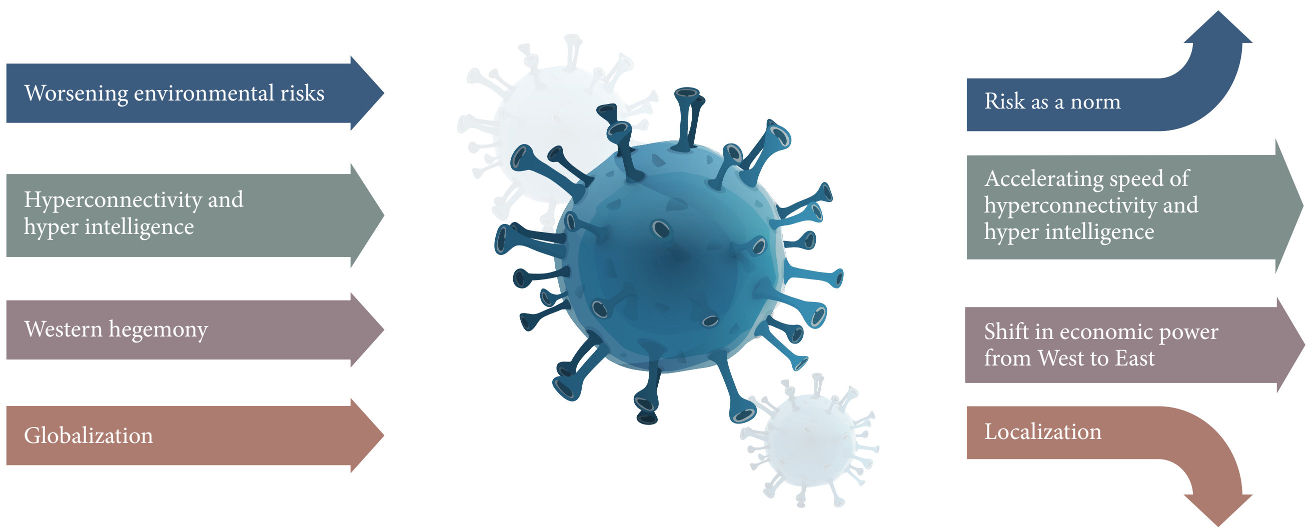
1. Background

When we closely look at the changes in the landscape surrounding us, it is easily found that mega trends such worsening environmental risks including natural disaster and destruction of ecosystem, hyperconnectivity and hyperintelligence that are key features of the 4th industrial revolution, Western hegemony, and globalization have encountered a black swan event called COVID-19, and have begun to change to take the new forms. It is expected that risks will be everywhere, the speed of hyperconnectivity and hyperintelligence will be accelerated, the shift in economic power from West to East will continue, and localization will replace globalization. As we move forward in the midst of such rapid and uncertain changes in our landscape, it is important to develop countermeasures based on predictions of the future. The digitalization and other scientific and technological advances are important elements leading such changes in the post COVID-19 era, Therefore, it is necessary to identify emerging technologies that will soon to be considered as important in our society and come up with measures

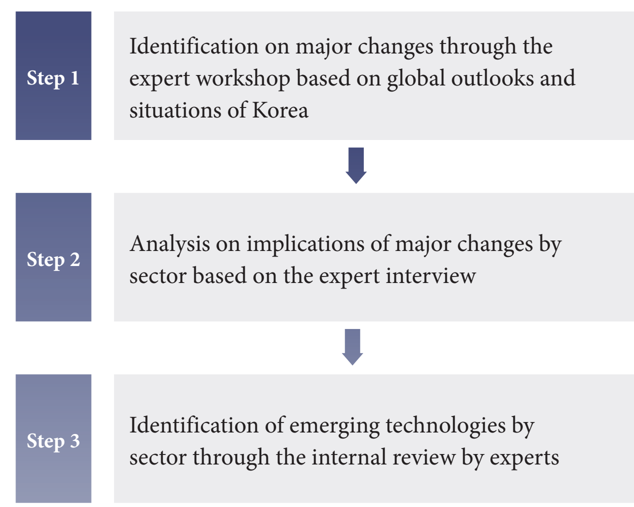


[**Figure 1**] Landscape changes after COVID-19

responding them in advance. In the meantime, it is expected that the government, research institutes, and companies can apply the emerging technologies identified through this research to develop their investment strategies in the post COVID-19 era.

2. Methods and procedures

To predict the future after COVID-19, the 3-phase approach using a series of methods including a workshop with the participation of experts in various areas and others was used. First, the four major changes that can be considered as important in our society within the next 5 years were identified during the expert workshop based on the global outlook for the future predicted by the world's leading research institutions and news media as well as situations in Korea. Second, researchers explored 8 sectors that the four major changes may have a significant impact in terms of science and technology, and analyzed such impact by sector through scenarios, which contain drivers (future



[**Figure 2**] Methods and procedures for the prediction of the future in the post COVID-19 era

issues) that should be considered as important, product/service, future outlook, expected outcome, etc. Lastly, we have identified 25 emerging technologies encompassing the 8 sectors after expert interview and internal review.

3. Major changes in the landscape of Korea

Based on the global outlook by the world's leading research institutions and media outlets and in consideration of changing domestic environment, 4 major changes that may have a significant impact on the Korean society were identified including ① Emergence of non-contact services as the norm of daily life, ② Challenges and opportunities of the biohealth market, ③ risk response as the norm, ④ Strengthening of nation-centrism.

A. Transformation into the non-contact society

As the non-contact society has become the norm through the internet, it is expected that regulations on remote medicine and other online tools will be eased. The Politico, an American daily newspaper specializing in politics, said that COVID-19 has served positively to the revitalization of remote medicine and remote learning, and the non-contact society via online will be continued after COVID-19. In addition, there will be a new type of innovation as the disease has accelerated the speed of the industry in applying to digital technologies. Copenhagen Institute for Futures Studies (CIFS) predicted that COVID-19 will promote the innovation and distribution of technologies as the disease continues to spread, and examples of such trends include blockchain-based e-voting system and using autonomous vehicles for delivery to isolation wards, etc.

[Table 1] Major changes in the landscape of Korea that may affect the country significantly after COVID-19

Forecast on the changing global landscape	Changing circumstances in Korea	Major changes in the landscape
Transformation into the non-contact society and relaxation of related regulations	· Changes in people's lifestyle due to the transformation into the non-contact society	① Transformation into the non-contact society - Transformation into the non-contact society where products/services without contact have become the norm
Changes in the healthcare system	· A growing importance on domestic resources and experience for the prevention and control of infectious diseases	② Challenges and opportunities of the biohealth market - Activation of the biohealth market such as the development of diagnostic kits, treatment, and vaccines
New normal society that takes risk as the norm	· An emphasis on self-reliance of domestic value chain to remove foreign dependency	③ Risk response as the norm of daily life - Periodic occurrence of so-called black swan event (X-Event) such as prevalence of infectious disease, etc.
Changes in the world economic order: · Localization of supply chain · Rising protectionism · Lack of global leadership · Shift in economic power to East	· Increasing roles of the government and public confidence in responding to COVID-19	④ Strengthening of nation-centrism - Countries across the world took nation-centric approaches to curb the spread of COVID-19

B. Challenges and opportunities of the biohealth market

Ed Yong, a science journalist at The Atlantic, an American current affairs magazine reported that COVID-19 could last long and the US would shift its focus on the public healthcare after the global COVID-19 pandemic as it did so on counterterrorism after 9/11. CIFS, too, predicted that the healthcare system would put much emphasis on the healthcare management from the patient care after the disease and said that the collection and sharing of health data will be more important.

Domestic resources and experience with regard to the prevention and control of infectious diseases have become more important. The COVID-19 crisis has reminded us of the importance of the management of supply and demand of medical staff (doctors, nurses, etc.), medical facilities (public/private hospitals, research institutes, etc.), and medical supplies (testing tools and equipment, diagnostic kits, negative pressure facilities, face masks, etc). As for Korea, the past experience of responding and managing infectious diseases such as SARS, swine flu, and MERS has served as a biggest advantage in response to COVID-19[1]. The government has supported companies to embark on the development of diagnostic kits in the early January even before the country had its first confirmed cases of COVID-19

1) Korea Institute of S&T Evaluation and Planning (KISTEP), Future Horizon Plus, Vol.44, January, 2020.

infection and provided an approval to them promptly via the 'emergency use authorization system'.

C. Risk response as the norm of daily life

It is predicted that we may have entered into the society of taking risk response as the norm of daily life as black swan events such as the global COVID-19 pandemic continue to occur frequently. Also, concerns over monitoring are raised along with the development of tracing and monitoring technologies to prevent the spread of infectious diseases. Ben Zimmer, an American columnist at the Wall Street Journal, pointed out that black swan was not as rare as once believed. The economist, a weekly newspaper of the UK, predicted that the big government that was needed to fight the pandemic will last for a while. Foreign Policy, an American news publication focusing on domestic and international policy, argued that drastic measures that were on the horizon during the process of overcoming the outbreak of COVID-19 had become the new normals, and which would serve to concrete the totalitarianism.

D. Strengthening of nation-centrism

It is expected that the world economy would be plunged into recession as the world has entered into a shrinking society, while facing a black swan event called COVID-19, and globalization would be in retreat due to localization of supply chain, and spread of protectionism. In its global economic outlook assessing the fallout from the COVID-19 pandemic, JP Morgan predicted that the China's GDP will shrink by 40% in the first quarter and the US economy is projected to contract by 14% in the second half of this year.

According to Foreign Policy, it appears that self-reliant economy and protectionism will spread further as COVID-19 has revealed the weakness of global manufacturing network. It also provided the concept of G-Zero era by referring to the fact that US President Donald Trump and other global leaders were focusing on domestic politics. It went further by raising the possibility that the globalization could be led by China based on the lack of US leadership and the failure of Europe in the fight against the global COVID-19 pandemic, and predicted that the disease would accelerate the shift of power and influence from West to East. As for Korea, the country's technological competitiveness of the materials and parts sector related to the advanced industries is evaluated to be only 66% of that of advanced countries such as Germany and Japan. As of 2017, the number of materials companies on the global 2000 list was 40 for the US and 29 for Japan, but we had only 7 materials companies on the list[2]. In the meantime, vulnerabilities are found in domestic materials, parts, and equipment sector of the nation's key industries such as 'semiconductor, display, and automobiles' compared to global value chain (GVC). Therefore, a need to foster an ecosystem of the industries and companies for the self-reliance of domestic value chain by getting away from the dependence on GVC.

2) Korea Development Institute (KDI) Economic Information Center, 「Finding ways for technology independence」, Economic Bulletin, September, 2019.

4. Future outlook by area

After reviewing detailed changes and predicting scenarios of 8 sectors through the interview with experts, majors issues were found including changes in medical system focusing on healthcare management and remote medicine, improvement of convenience, effectiveness, and security of various non-contact/remote services, and automation and intellectualization of industrial sectors such as transport, logistics, and manufacturing.

[Table 2] Major issues by sector

Sector	Major issues
Healthcare	· Weaknesses of healthcare system of each country and cooperative system in the global healthcare were stand out · Paradigm shift of the public healthcare system from medical treatment to prevention and management of diseases · Acceleration of digital transformation in the healthcare system (adoption of AI, automation, data sharing, etc.)
Education	· Confusions of schools and families over the unprecedented 'beginning of new school year with online classes' (concerns over online learning contents and infrastructure, exposure of blind spots in education/welfare including emergency care service for the marginalized groups, etc.) · A growing importance for schools to prepare for the possibility of periodic/short-term outbreak of emerging infectious diseases in advance · Changes in the work methods lead the changes in the skills needed, and which drives changes in education
Transport	· Spread of the non-contact culture in the modes of transport to respond to COVID-19 · More people tend to avoid to use densely-populated public transport, ride-hailing and other sharing services in urban areas · Raising awareness on climate change, the destruction of ecosystem, etc. · Increasing demand for personal mobility and micro mobility
Logistics	· Decline in transnational cargo demand due to closing national borders, movement restrictions, discontinuation of manufacturing across the globe · Explosive growth of e-commerce and non-contract purchase in Korea due to physical distancing practice to prevent the spread of infectious disease · Blurring boundaries among manufacturing, distribution, and logistics industries and intensifying competition due to the increasing demand for precise delivery service
Manufacturing	· Response to COVID-19 pandemic and expectation on economic recovery · Exposure of weakness of GVC (emergence of local value chain, etc.) · Adoption of smart technologies in manufacturing factories and smart tools (adoption of AI, digitalization, flexibilization, learning, etc.) · Constant increase of manufacturing costs (material cost, labor cost, manufacturing cost) and decline of production workers
Environment	· Climate change being pushed back on the priority list and changing roles of environmental regulations due to global economic slowdown · Increasing volume of waste generated by persons infected with COVID-19, those isolated, and medical staff · Increasing use of disposable products as more consumers seek convenience along with the spread of non-contact economy · Smartization of environmental technologies converging with the latest S&T (AI, IoT, etc.)
Culture	· Financial damage in the cultural industry that largely takes place in physical spaces, and increase of non-contact cultural content · Acceleration of the stay-at-home economy and single economy · Changes in the production, distribution, and consumption of products and services in the culture industry · Increasing awareness on 'K-brands' based on proper response to COVID-19
Data security	· Expansion of non-contact services such as video conferencing, online learning, working from home, etc. · Strengthening protection of personal data and contradictions in utilizing the data upon disaster · Smartization (including AI, big data, robotics) of public security systems of a nation (defense, security, fire-fighting, etc.)

5. Emerging technologies

After predicting the future of major sectors in the post COVID-19 era, 25 emerging technologies were identified based on the performance of technological innovation and the impact on the society and economy. They were mapped onto major changes and 8 sectors and the result found that the emerging technologies were related the most to the 'transformation into the non-contact society' among major changes in the landscape.

With regard to 'healthcare', 5 emerging technologies were identified including AI-based diagnosis of disease in real-time, real-time measurement and analysis of biometric information, prediction on the spread of infectious disease and early warning, and RNA-based vaccines resistant to viruses, etc. For 'education', three technologies were explored including VR/MR technologies for immersive learning, and high-capacity communication technology for online classes. There were 3 emerging technologies for 'transport' including personalized last mile mobility and autonomous vehicle to transport persons with suspected virus disease. The three emerging technologies were identified in the 'logistics' sector such as smartization of logistics/distribution center and autonomous driving robots. For 'manufacturing' sector, 3 promising technologies for smartization and automation were found including digital twin and human augmentation technology. When it comes to the 'environment' sector, there were 2 novel technologies including the one related to integrated management of zoonotic diseases. Sectors of 'culture' and 'data security' had 3 emerging technologies for each, including immersive broadcasting service and one to assure video conferencing security, respectively.

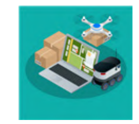
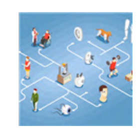
[**Table 3**] Mapping of emerging technologies onto major changes and 8 sectors

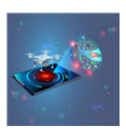
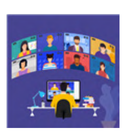
Sector	Transformation into non-contact society	Challenges and opportunities of the biohealth market	Risk response as the norm of daily life	Strengthening of nation-centrism
Healthcare		· Digital therapeutics · AI-based diagnosis of disease in real-time · Real-time measurement and analysis of biometric information · RNA-based vaccines resistant to viruses	· Prediction on the spread of infectious disease and early warning	
Education	· VR/MR technologies for immersive learning · Tailored learning technologies based on AI and big data · High-capacity communication technology for online classes			
Transport	· Personalized last mile mobility · Integration of multiple modes of transport (Mobility as a Service, MaaS)		· Autonomous vehicles to transport persons with suspected virus disease	
Logistics	· ICT-based integrated platform of logistics data · Autonomous driving robots · Smartization of logistics/ distribution center			
Manufacturing				· Digital twin · Human augmentation technology · Cooperative robot
Environment		· Robots to collect and transport medical waste	· Technologies for integrated management of zoonotic diseases	
Culture	· Immersive broadcasting service · GIS mapping with drones and 3D imaging technologies		· Deepfake detection techniques	
Data security	· Technologies to assure video conferencing security		· Quantum-encrypted video conferencing for security · Movement tracing system using homomorphic encryption (HE)	

[**Table 4**] Emerging technologies by sector and description

Sector	Technology	Description
Healthcare	 **Digital therapeutics**	(Definition) Contents technologies as therapeutic interventions approved by the US Food and Drug Administration (FDA) to treat a mental illness or psychiatric disorder with SW (app, game, VR, etc.) instead of medicine (Composition) - Contents technology - Immersive interactive technology - Information analysis technology - UI/UX (Areas of application) Treatment of mental disorders (depression, addiction, PTSD, etc.) via non-contact interventions
	 **AI-based diagnosis of disease in real-time**	(Definition) SW technology to screen the disease and provide an optimum treatment method based on the analysis of medical big data (Composition) - Information analysis technology - Algorithms for automatic diagnosis - Cloud, communication technology - Data security technology (Areas of application) Real-time disease diagnosis (support)
	 **Real-time measurement and analysis of biometric information**	(Definition) Technologies that collect and analyse biometric information of individuals regardless of time and space and constantly monitor their health condition (Composition) - Sensing technology - Information analysis technology - Alert for abnormal symptoms - UI/UX - Data security technology (Areas of application) Users can constantly monitor their health condition anywhere and link the information with health management and medical treatment in hospital
	 **Prediction on the spread of infectious disease and early warning**	(Definition) Technologies that predict the probability of an infectious disease outbreak and provide warnings in advance based on big data including transmission path, infected patients, demographic data, etc. (Composition) - Information analysis technology - Location data tracking - Risk alert (Areas of application) Response to infectious disease (in advance), epidemiological investigation
	 **RNA-based vaccines resistant to viruses**	(Definition) A technology that activates the immune system resistant to RNA virus to prevent or minimize the damage to human body by the infection (Composition) - Mutation prediction - Antigen identification - Mass production technology - High-efficiency delivery technology (Areas of application) Prevention and treatment of diseases originated from RNA viruses

Sector	Technology	Description
Education	 **VR/MR technologies for immersive learning**	**(Definition)** Specialized technologies that converged various domains including humanities, society, arts, etc. to provide immersive learning and experience based on VR/MR **(Composition)** - Mixed reality MR - Big data processing - Interface - Rendering techniques **(Areas of application)** Special education to help student overcome physical disabilities and improve cognitive ability
	 **Tailored learning technologies based on AI and big data**	**(Definition)** Technologies that provide learning contents tailored to students through real-time analysis on their big data and level adjustment with AI engine **(Composition)** - Learning management system (LMS) - Tailored learning SW **(Areas of application)** System development for the collection and analysis of learning and interactive data (between student-contents, students-students, and students-lecturer)
	 **High-capacity communication technology for online classes**	**(Definition)** Network technology that distributes traffic and delivers online learning contents and other large capacity contents to users promptly and stably **(Composition)** - Big data transmission - Cloud-based CDN* * Contents Delivery Network **(Areas of application)** Secure the infrastructure for online classes
Transport	 **Autonomous vehicles to transport persons with suspected virus disease**	**(Definition)** Unmanned autonomous driving service for the transfer of persons suspected of infection to airport, home, hospital or connecting major hubs tailored to cities **(Composition)** - Autonomous driving AI - Measurement sensor - Vehicular communication system **(Areas of application)** Provide unmanned services upon the occurrence of risk situations such as natural disaster, radiation pollution, etc.
	 **Personalized last mile mobility**	**(Definition)** Service technologies linking with personal/micromobility allowing users to move to the final destination after arriving at a post by public transport such as bus and subway and shared mobility **(Composition)** - Micromobility - Assistance driving technology - Authentication technology **(Areas of application)** An eco-friendly way to solve traffic congestion by providing means of transport to move a short distance quickly and conveniently
	 **Integration of multiple modes of transport (MaaS)**	**(Definition)** Service technologies that integrate various modes of transport such as car, subway, bus, taxi, etc. and provide the best tailored solution to the users based on big data (Mobility as a service) **(Composition)** - Platform technology - Blockchain - Traffic information service **(Areas of application)** Strengthening the complex linkage with conventional modes of transport and provision of tailored service considering the patterns of movement

Sector	Technology	Description
Logistics	 **ICT-based integrated platform of logistics data**	**(Definition)** Technologies that convert logistics information into digital data, standardize platforms to realize the real-time prediction of delivery and inventory management based on big data, IoT, and blockchain **(Composition)** - Data solution - Big data - Block chain **(Areas of application)** Applicable to the entire areas of logistics services including freight cargo, marine logistics inventory management, logistics contract
	 **Autonomous driving robots for delivery**	**(Definition)** Technologies linking autonomous driving robots for end-point delivery enabling cooperation with the drivers of living logistics trucks and smart storage **(Composition)** - Autonomous driving - Finding optimal routes - Smart storage **(Areas of application)** On-demand parcel delivery service, unmanned delivery service by linking with self-driving trucks
	 **Smartization of logistics/ distribution center**	**(Definition)** Technologies for automation and intellectualization of logistics process from warehousing to release of multiple items in small quantity that occur frequently in the logistics/distribution center (fulfillment) **(Composition)** - Automation robotics - Autonomous driving - Data processing **(Areas of application)** Transfer of goods within the center, dealing with the movement of heavy items and risky activities in the center, optimal use of space
Manufacturing	 **Digital twin (Advanced CPS)**	**(Definition)** Technologies that creates a digital twin of a physical entity in the real world, develops simulations on circumstances that may occur in practice to predict the result (high-level design of cyber-physical system (CPS)) **(Composition)** - Sensor technology - Digital replica or design of things - Virtual simulation **(Areas of application)** Production design, monitoring of plant operation, prediction on workload and production loss, failure diagnosis and prediction, performance analysis
	 **Human augmentation technology**	**(Definition)** A combination of technologies including bioengineering, electronic engineering, and mechanical engineering to enhance (augment) existing or insufficient capabilities of humans by using natural or artificial methods and techniques **(Composition)** - Brain-computer interface (BCI) - Cognitive processing capacity - Robotics for human augmentation **(Areas of application)** Cochlear implant, artificial vision, brain implants, prosthetic arms and legs, sleep inducement, concentration improvement, neurofeedback device, BMI technologies to implement advanced driver assistance systems (ADAS) functions
	 **Cooperative robot**	**(Definition)** Technologies that are designed to interact with humans mostly in manufacturing site, conduct simple repetitive tasks, precision or dangerous works instead so that people can work in a safe environment **(Composition)** - Multi-degree-of-freedom (MDOF) robot - Robot interface - Detection of cooperative space **(Areas of application)** Vehicle assembly, cooperative robots for quality inspection, streetlight assembly, cooperative robots for plant, packaging of cosmetics products, picking & placing, cooperative robots for the manufacturing of multiple items in small quantity

Sector	Technology	Description
Enviroment	 **Robots to collect and transport medical waste**	(Definition) Robots that collects medical wastes such as clothes, gloves of medical staff and persons confirmed with a disease and transport them to the disposal site (Composition) - AI algorithms - Robot control through mobile communication - Secondary battery (Areas of application) Safe collection and transport of medical wastes occurred in medical institutions, testing/inspection institutions, etc.
	 **Technologies for integrated management of zoonotic diseases**	(Definition) Technologies for integrated management on detection, inspection, and response to zoonotics diseases transmitted between humans and animals (Composition) - Vaccines for animals and humans - Big data on zoonotic diseases - Prevent/control of natural reservoirs (Areas of application) Disease control and management, and preventive measures for public health upon the outbreak of epidemic or pandemic
Culture	 **Immersive broadcasting service**	(Definition) Technologies that provide Immersive video/audio services in real-time that improve the sense of reality and immersion to present users a new experience as in the case of VR broadcasting and 3D TV (Composition) - VR/AR technologies - 5G technology - Display technology to provide immersive service (Areas of application) Immersive sports broadcasting, immersive worship, immersive live concert broadcasting
	 **Deepfake detection techniques**	(Definition) A technology that detects deepfakes* to determine whether or not the a video is deepfake-forged content * It refers a fake video created by using AI and facial mapping techniques, and which can be abused for fake news and scams (Composition) - AI for deepfake detection - Blockchain (Areas of application) To determine the authenticity of videos and voices used for scams and fake videos
	 **GIS mapping with drones and 3D imaging technologies**	(Definition) A technology to build GIS* by using video data from drones and converting them into 3D videos through post processing * GIS (Geographic Information System): It refers to the Information system that converts the necessary geographic information to digital data to utilize it efficiently (Composition) - Drone technology - AI - VR/AR (Areas of application) Provision of VR and other services by converting the scenes of tourist attractions into 3D videos
Data security	 **Technologies to assure video conferencing security**	(Definition) Video conferencing system that detects vulnerabilities to ensure the security and provides various functions (participant authentication, safe video/data transmission, recording limitations, sending/receiving files, etc.) (Composition) - Authentication and access technologies - Technology to recognize fake calls - Data encryption on video calls (Areas of application) Video conference, online class, work from home, non-contact tasks

Sector	Technology	Description
Data security	 **Quantum-encrypted video conferencing for security**	(Definition) A future technology for secure communication that transmits video with the quantum mechanics without a need to relay on intermediaries, solving problems of storage in the middle server and potential risk of hacking (Composition) - Quantum key distributor (QKD) technology - Video conferencing system - Transmission of quantum-encrypted video (Areas of application) Hacking free video conference, data communication for quantum computing
	 **Movement tracing system using homomorphic encryption**	(Definition) A system of security monitoring that provides a series of functions including movement tracing upon disaster, while protecting personal data (Composition) - Homomorphic encryption (HE) technology - Pseudonymisation - Security monitoring for data protection (Areas of application) Tracing of travel routes while protecting personal data, remote medicine

References

Allen, J., et al. (2020). How the World Will Look After the Coronavirus Pandemic. *Foreign Policy.*

Chosun biz. (2020). LG Uplus plans to support network/solution for online classes for free.

Copenhagen Institute for Futures Studies. (2020). Beyond the COVID-19.

IPCC. (2007). Fourth Assessment Report.

Joint report by related ministries. (2020). Measures to revitalize export.

Korea JoongAng Daily. (2020). Using COVID-19 crisis as an opportunity to adopt Edu-Tech of the 21st century.

Korean Federation of Science and Technology Societies. (2020). Changes that will be brought by COVID-19.

Maker News. (2019). A research team led by KAIST professor Kim Min-ki demonstrated the learning effect of AI-enabled coaching programs for the first time in the world.

National Assembly Research Service. (2020). Comprehensive report on the response to COVID-19.

National Information Society Agency. (2019). Status and future of smart mobility service.

National Institute of Environmental Research. (2019). 2018 Establishment of histopathological examination and sample collection system for precise diagnosis of wild animal diseases.

Politico Magazine. (2020). Coronavirus Will Change the World Permanently. Here's How.

Samjong KPMG Economic Research Institute. (2020). Macroeconomic impact of COVID-19 and countermeasures.

TechDaily. (2019). KT demonstrates VR/AR-based education services at the last class of Cheongnahm Learning.

Yong, E. (2020). How the Pandemic Will End. *The Atlantic.*

COVID 19 in the ECO Region: Impact, Status of Health Care and ICT Infrastructure, and Response by the Member States

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1. COVID-19 in the ECO region

With current outbreak of the COVID-19, the pandemic has now spread in nearly all regions of the world. As this crisis unfolds, it highlights the importance of healthcare facilities and preparedness to respond to this crisis. Although, no country has been fully prepared for the pandemics of this scale; this virus does not know any borders, all countries must prioritize and exercise the capabilities required to prevent, detect, and rapidly respond to public health emergencies.

The COVID-19 has exposed the fragile limits of healthcare facilities and infrastructures around the world. Even in the countries with best healthcare system, their overall preparedness seems to be weak in handling this situation. However, situation is even worse when it comes to the developing world. Many developing countries lack the health capacities and capabilities that are needed to detect, and respond to significant infectious disease outbreaks.

It is even more challenging when we think of resource-limited regions with poor sanitation and weak health systems, which is actually the case in some of the ECO Member Countries. The COVID-19 outbreak is creating significant additional pressure on an already overburdened health system in the Member Countries. This brief is an attempt to assess the status of healthcare and ICT infrastructure in the ECO Member Countries and how these countries have responded during the outbreak of this this pandemic. Almost all ECO Countries are under the state of emergency; where schools, universities, workspace, cinemas, and sports venues are currently closed and air travel remains suspended[1].

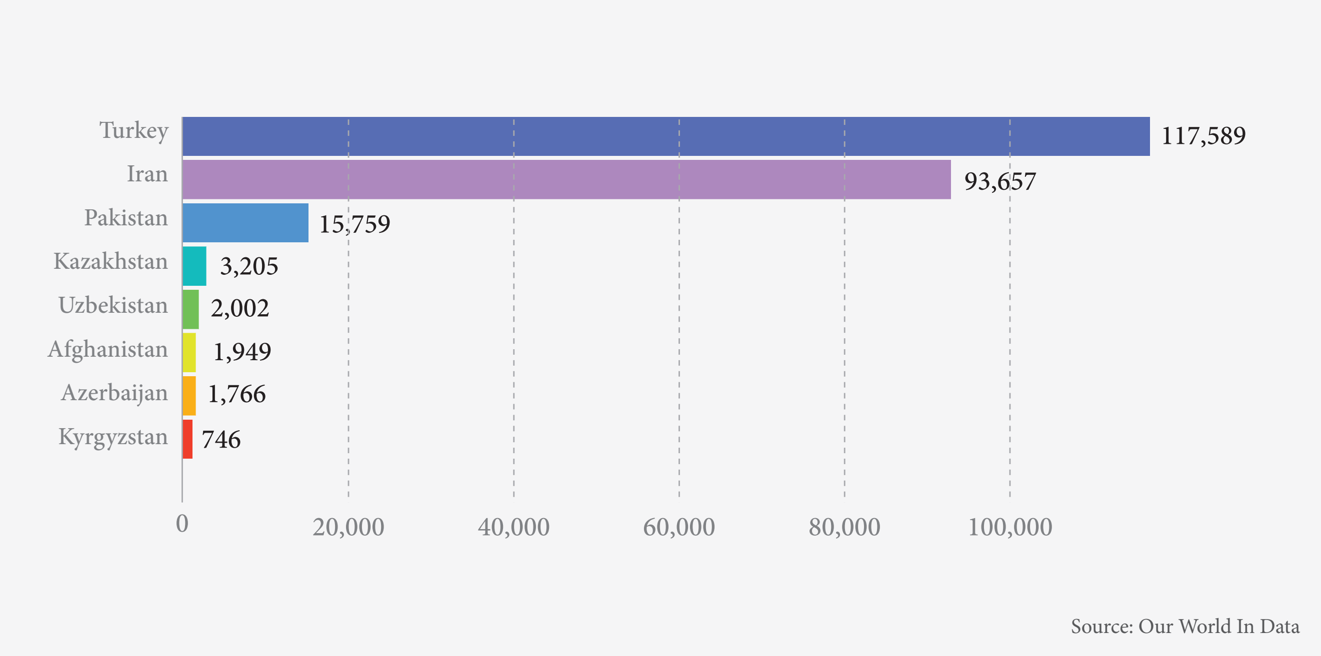
Iran was one of the world's early COVID-19 hotspots and the first country amongst ECO Member Countries to have reported the cases of COVID-19 (Figure 1). Since then the virus has spread rapidly in the country. Soon Iran was declared one of the world's coronavirus epicenters after China, with the death toll surpassing 5,900 and the number of cases topping 93,000. Iran faces serious challenges to respond to the pandemic, amidst the sanctions against global trade, cutting into its crude oil sales, banking and other industries. The coronavirus, coming on top of the economic struggles of the sanctions, is increasingly hitting Iran's already struggling economy.

Presently, Turkey has exceeded Iran and has highest number of confirmed cases of COVID-19[2] (Figure 1). As of May, 2020, the official number of cases in Turkey stands at 117,589, the seventh highest total in the world[3]. However, despite highest rate of infection, Turkey has managed to keep its death rate quite low[4]. The low death rate can be attributed to the Turkey's well developed healthcare system, and aggressive testing capacity along with emphasis on early diagnosis.

Despite the lower confirmed cases than Turkey, Iran has the highest number of confirmed deaths in the ECO region and that is almost double that of Turkey (Figure 2). Meanwhile, Turkish health authorities have signaled that the country is at the peak point of outbreak, as the daily deaths are appearing to slow down[3]. Besides, the recent numbers indicate that Turkey has brought the outbreak under control. The following charts 1 and 2 present the confirmed number of cases and deaths in the ECO Member Countries as of April 30, 2020. Good news is that Tajikistan and Turkmenistan have not reported any case, so far.

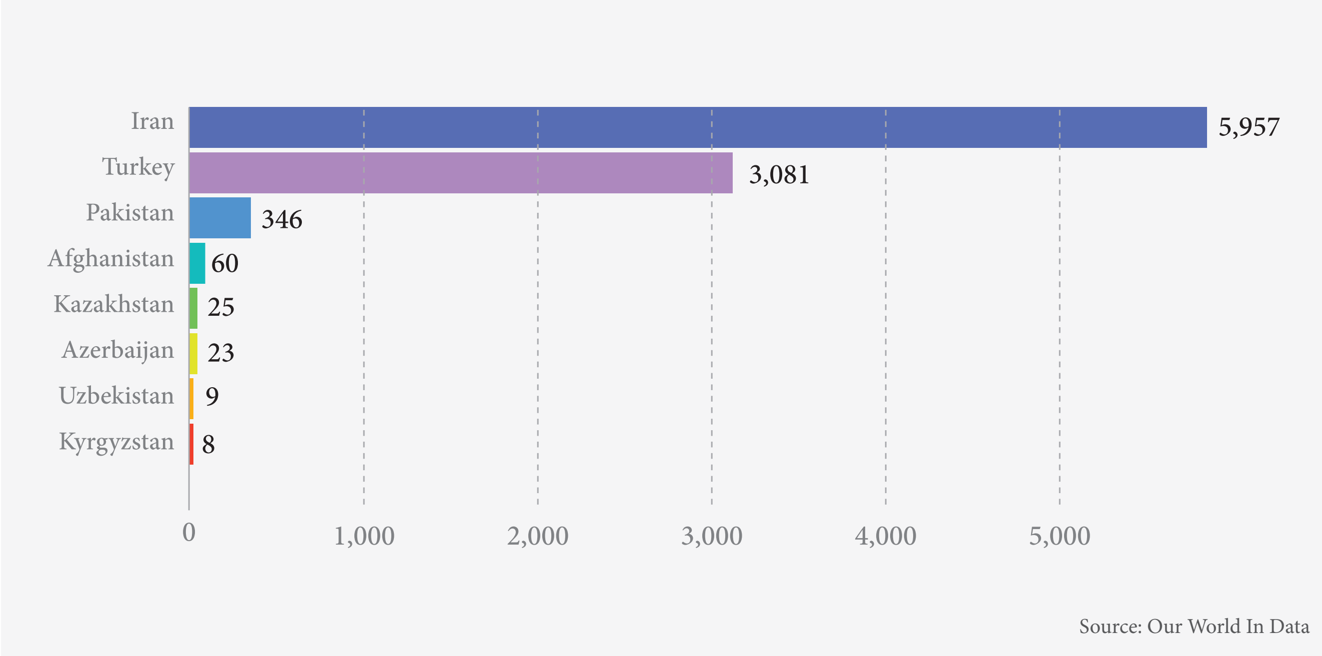
Compared to its high population density in the ECO region, Pakistan has lower cases of COVID-19. As of April 30, the total number of positive and confirmed deaths stood at 15,500 and 340 respectively. Many argue that actual numbers may be significantly high but due to low rate of testing, the positive cases go undetected and hence the low rate of infections in the country[5]. Despite fiscal constraints and struggling economy, the Pakistani government has rolled out a massive social safety net initiative, termed as Ehsaas Emergency Cash Programme[6]. This is intended for many of the country's poorer residents involving direct cash transfers during the lockdown in the country. The economic implications of COVID-19 will be particularly severe in Pakistan. Prior to COVID-19, the country has been observing economic austerity after a balance of payments crisis resulting in loans from the IMF. Whereas, the Ministry of Planning, Development and Reforms has estimated that unemployment in the country could spike, leaving

1) RFE/RL. (2020, April 26). Covid-19: Iran's Rohani Says New Tracking System Could Lead To Mosque Reopenings; Pakistan Extends Suspension Of International Flights. Radio Free Europe Radio Liberty. https://www.rferl.org/a/covid-19-pakistan-extends-suspension-of-international-flights-tajikistan-
2) McKernan, B. (2020, April 7). Turkey's Covid-19 infection rate rising fastest in the world. The Guardian. https://www.theguardian.com/world/2020/apr/07/turkeys-covid-19-infection-rate-rising-fastest-in-the-world?fbclid=IwAR2PvsR6oFv81d5h6G8Zgjt7AvarNLaIXL0ZCLyLh1QE30r2hjM7yGOLC48
3) Ahval. (2020, April 29). Health minister says Turkey at peak point of outbreak, as COVID-19 death toll rises to 3,081 – live blog. Ahval. https://ahvalnews.com/turkey-coronavirus/health-minister-says-turkey-peak-point-outbreak-covid-19-death-toll-rises-3081
4) TRTWorld. (2020, April 23). Why is the coronavirus fatality rate low in Turkey? TRT World. https://www.trtworld.com/turkey/why-is-the-coronavirus-fatality-rate-low-in-turkey-35688
5) Agrawal, R. (2020, April 30). A Coronavirus Mystery: Why Are There So Few Cases in South Asia? Foreign Policy. https://foreignpolicy.com/2020/04/30/coronavirus-mystery-why-so-few-cases-south-asia-india-pandemic-lockdown/
6) Mukhtar, I. (2020, April 29). Ready to open offices for Ehsaas programme verification: NADRA. The Nation. https://nation.com.pk/29-Apr-2020/ready-to-open-offices-for-ehsaas-programme-verification-nadra



[Figure 1] Total confirmed COVID-19 cases in the ECO Member Countries

The number of confirmed cases is lower than the number of total cases. The main reason for this is limited testing.



[Figure 2] Total confirmed COVID-19 deaths in the ECO Member Countries

Limited testing and challenges in the attribution of the cause of death means that the number of confirmed deaths may not be an accurate count of the true number of deaths from COVID-19.

as many as 18.5 million people jobless[7]. Pakistan has developed a dashboard to monitor COVID-19; accessible at http://covid.gov.pk

The ECOSF has also developed a dashboard with real-time statistics on COVID-19 numbers for the ECO Member countries, accessible at http://ecosf.org/covid.aspx.

Afghanistan faces a real challenge in handling this pandemic situation. Currently, the confirmed cases stand at 1949 in the country. With limited healthcare capacity and a population that is more than 70 percent based in rural areas, it will be challenging for the country if the virus continues to spread widely in far-flung areas[8]. The country has already been through wars for decades and now they are bracing for another challenge which could threaten the nation[9].

Likewise in **Azerbaijan**, as the number of infections began to increase, strict measures have been taken[10]. All land borders with the neighbors have closed and education and work related activities have been suspended.

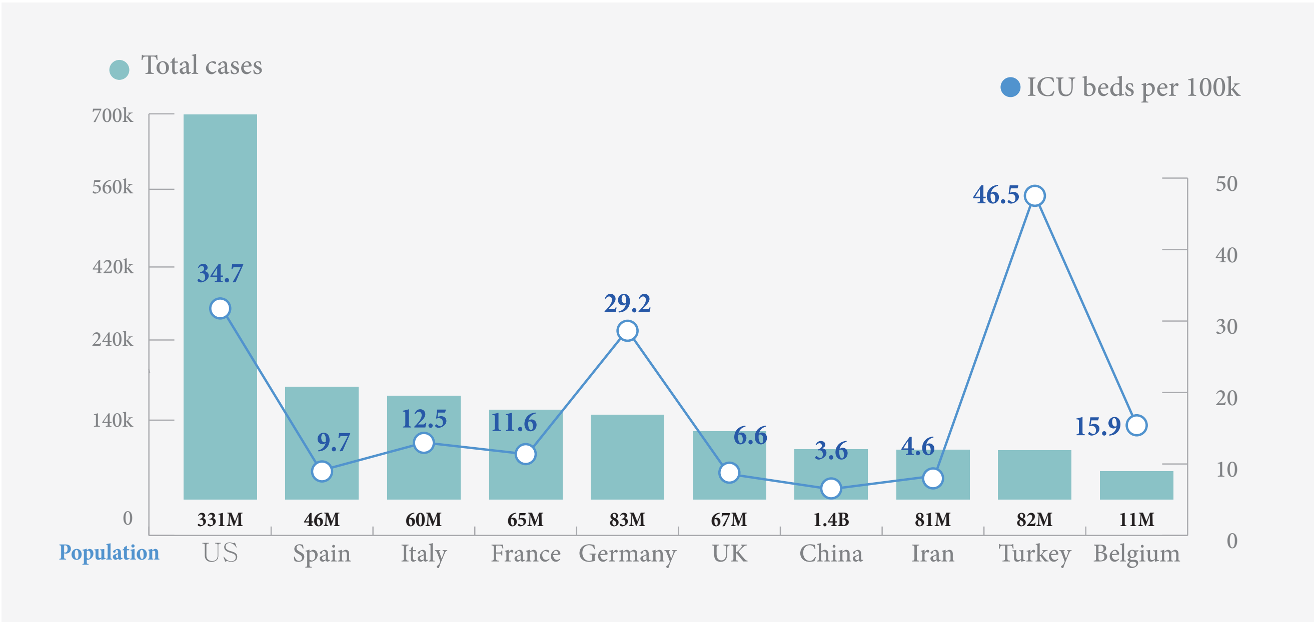
Kazakhstan has taken COVID-19 seriously and so far, it has conducted the highest tests per capita amongst the ECO Member Countries. The country has taken reasonable measures, including closing nonessential business, curtailing travel, and enforcing quarantines.

Kazakhstan also has developed its dashboard with the latest data accessible at https://www.coronavirus2020.kz. Economic implications of COVID-19 will be stern for Kazakhstan as well. Due to low demand of oil, Kazakhstan could see a sharp decline in its revenue generation.

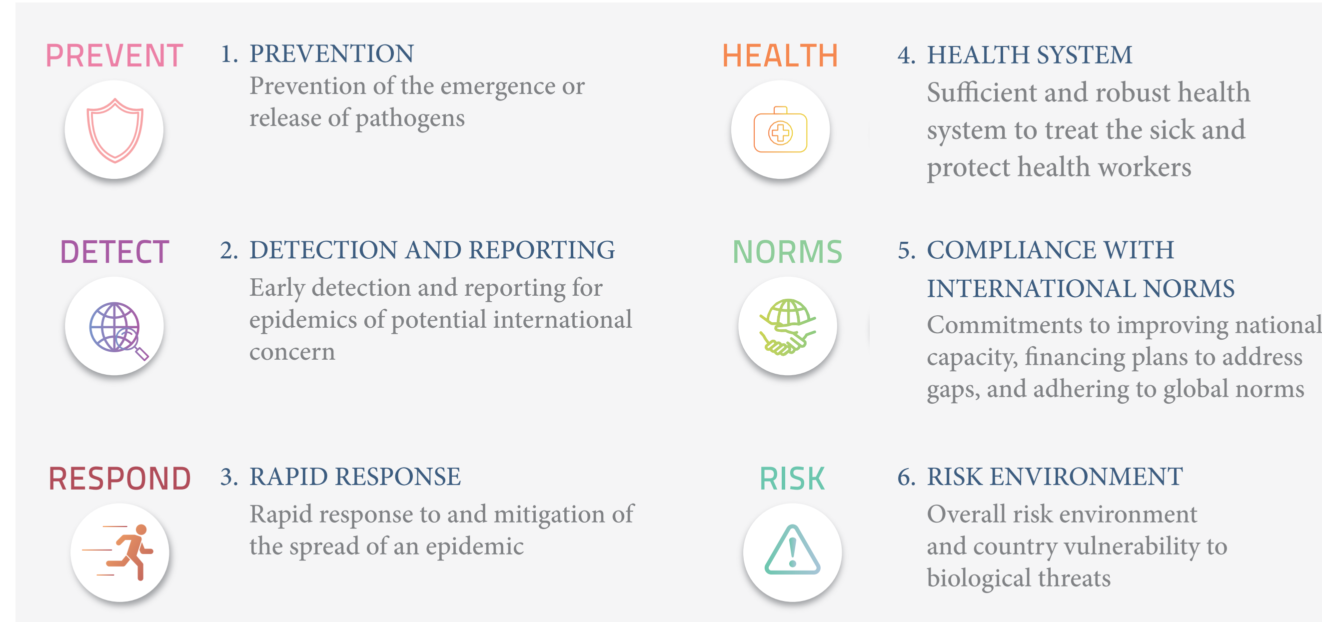
Similarly, with the outbreak, **Uzbekistan** took immediate actions after its first case was reported. Uzbekistan is under a state of emergency; it has closed its borders, worksp aces and schools, while heavy restrictions have been placed on movement within cities. At the same time, Uzbekistan has allowed freight traffic to continue across the region to enable the flow of aid and supplies to transit through its territory.

Kyrgyz authorities also appear to be taking the pandemic seriously. The authorities set up a website with information on the virus and news updates; accessible at https://covid.kg. The economic implications of this pandemic will be severe for the Kyrgyz Republic, as its economy relies heavily on remittances, 33% of GDP in 2018[11]. Thus, the country is expected to get a serious hit on remittances sparked by the pandemic. See supplementary data 1 for more information about government response to COVID-19 of the ECO Member Countries.

7) Rana, S. (2020, April 3). Coronavirus forecast to render 18.5m jobless in Pakistan. The Express Tribune. https://tribune.com.pk/story/2189904/2-coronavirus-forecast-render-18-5m-jobless/
8) Rahim, S. A. (2020, April 11). What the COVID-19 Outbreak Means for Afghanistan's Troubled Economy. The Diplomat. https://thediplomat.com/2020/04/what-the-covid-19-outbreak-means-for-afghanistans-troubled-economy/
9) Ahelbarra, H. (2020, April 15). Afghans brace for COVID-19 outbreak. Asia | Al Jazeera. https://www.aljazeera.com/news/2020/04/afghans-brace-covid-19-outbreak-200415055726150.html
10) Baghirov, O. (2020, April 25). Azerbaijan's response to COVID-19 related economic problems. Modern Diplomacy. https://moderndiplomacy.eu/2020/04/23/azerbaijans-response-to-covid-19-related-economic-problems/
11) OSMONALIEVA, B. (2020, May 1). UNDP assesses Kyrgyzstan's preparedness to respond to COVID-19. 24.kg. https://24.kg/english/151604_UNDP_assesses_Kyrgyzstans_preparedness_to_respond_to_COVID -19/



[Figure 3] Number of ICU beds per 100k -Turkey has the highest number of ICU beds compared to major developed countries



[Figure 4] Six parameters of GHS Index

2. Healthcare infrastructure in the ECO region

As the world struggles to respond to the COVID-19 pandemic, the virus is already pushing hospital and healthcare capacities to critical point. The deteriorating situation exposes lack of critical care infrastructure across different countries, particularly in terms of ICU bed capacity, ventilators and personal protective equipment (PPEs) for the healthcare workers (Figure 3). In addition, the institutional and systematic health inequalities continue to persist in developing countries, and the ECO Member Countries are no different (Figure 7).

With this pandemic, there is a growing recognition that national health security is fundamentally weak in many a developing world[12]. Thus, no country is fully prepared for epidemics or pandemics, and every country has important gaps to address. Under the current scenario, ECO Member countries require flexible and timely measures with adequate financing options to detect and prevent the spread of this virus. It is a high time that all ECO Member Countries must prioritize and exercise the capabilities required to prevent, detect, and rapidly respond to this pandemic.

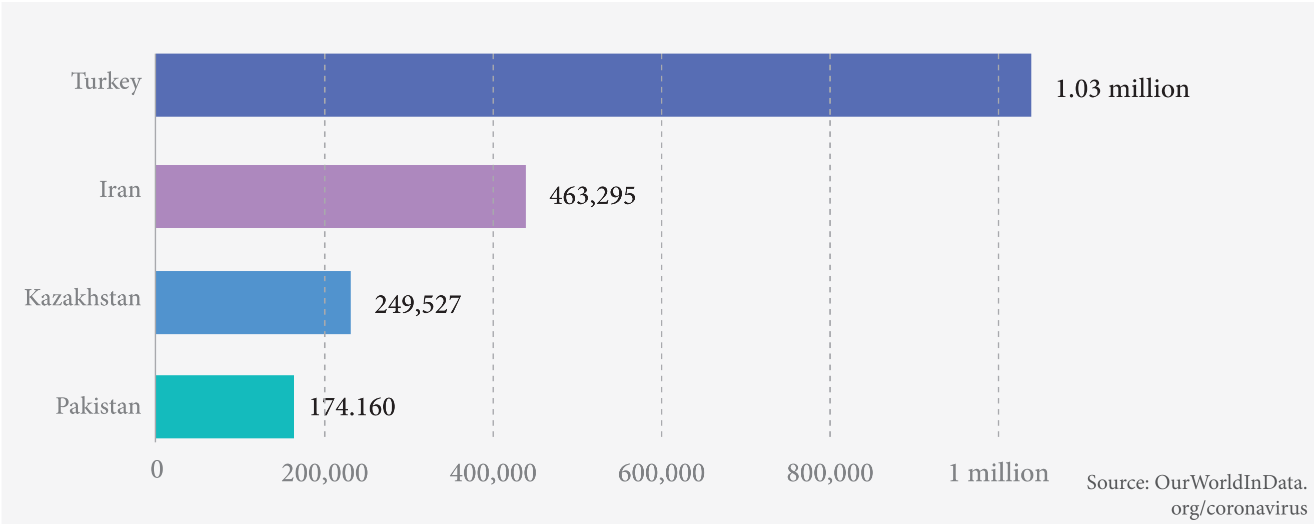
This brief assesses the healthcare capabilities by each ECO Member State against the Global Health Security Index (GHSI)[13]. The GHSI is a comprehensive assessment and benchmarking of health security and related capabilities across the 195 countries to address one of the world's most omnipresent risks: infectious disease outbreaks that can lead to international epidemics and pandemics. A snapshot of ECO Member profiles is provided at the end of this report.

The Global Health Security Index or GHSI underscores that every country must be transparent about its capabilities to assure neighbors it can stop an outbreak from becoming an international catastrophe. The Global Health Security Index measures the capabilities of participating countries using six prime parameters, as listed below: as shown in Figure 4. See supplementary data 2 for more information about GHS Index profiles of the ECO Member Countries.

According to the GHS Index, Turkey appears to be better prepared with adequate healthcare infrastructure to respond to this crisis amongst the ECO Member Countries. Perhaps it is because of this reason that Turkey has been able to steadily ramp up its testing capacity to accurately map out the COIVD-19 outbreak and stop further infections. In addition, Turkey has been among a few countries in the world that carried out more than a million coronavirus tests[14].

Furthermore, the COVID-19 crisis has also sparked a situation to reconsider the existing budget allocations across sectors and within the health sector in particular. The pandemic is forcing countries to reprogram existing expenditures towards the health care response. Therefore, we look at the Current Healthcare expenditure by the ECO Member Countries. We also look at the availability of physicians and hospital beds per 1000 people in each

12) KFF. (2020, February 13). Global Health Security Index Highlights Countries Best Prepared For Health Emergencies. KFF Daily Global Health Policy Report. https://www.kff.org/news-summary/global-health-security-index-highlights-countries-best-prepared-for-health-emergencies-finds-national-health-security-fundamentally-weak-around-world/15) https://www.ghsindex.org
13) NTI. (2020, April 10). The Global Health Security Index. GHS Index. https://www.ghsindex.org/
14) Daily Sabah. (2020, April 30). Turkey completes over 1 million COVID-19 tests; number of patients in critical care declines. Daily Sabah. https://www.dailysabah.com/turkey/turkey-completes-over-1-million-covid-19-tests-number-of-patients-in-critical-care-declines/news



[Figure 5] Total COVID-19 tests conducted in selected ECO Member Countries (As of April 30, 2020)

Note: For testing figures, there are substantial differences erences across countries in terms of the units, whether or not all labs are included, the extent to which negative and pending tests are included and other aspects. Details of each country can be found at Our World in Data website.

Member State to assess the healthcare capabilities in the Member States.

In terms of healthcare expenditure per capita, the average value for the entire ECO region stands at US$ 227 which is much less than the global average at US$ 884 as shown in Figure 6B. Although Iran, Turkmenistan, and Turkey show better capita spending and each one of these country spend twice than the ECO average.

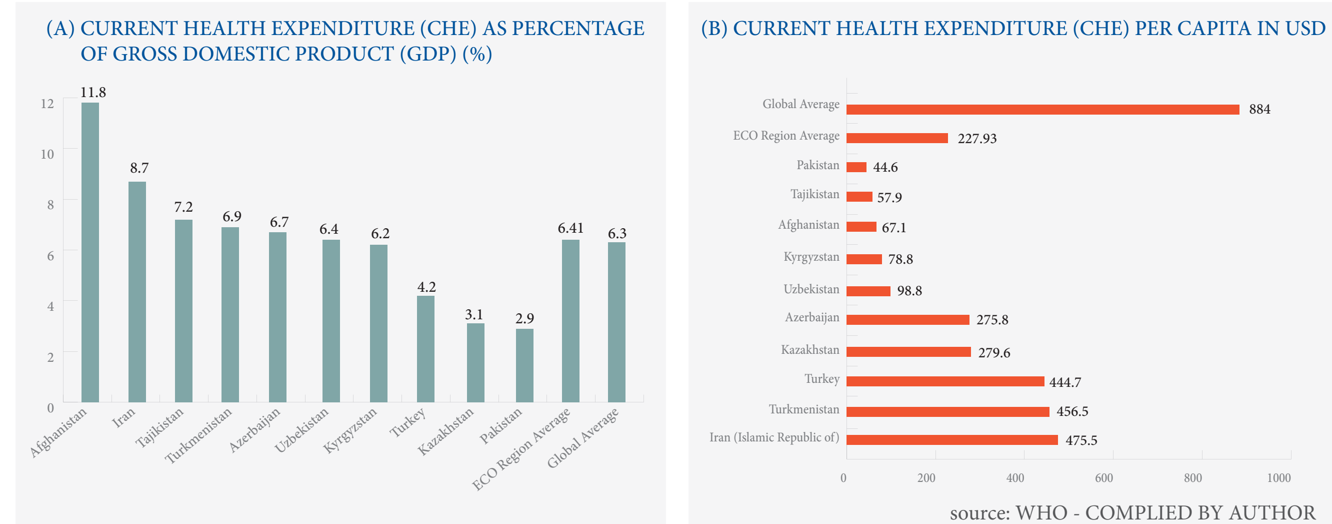
However, it is disappointing to see that Pakistan, Afghanistan and Tajikistan are acutely poor in terms of per capita healthcare spending in the region. Their per capita spending is less than the WHO's benchmark for the low income countries. Although, in terms of healthcare spending as percentage of GDP, the ECO region has a slightly higher standing than world average at 6.4% than the global average at 6.3% as show in the Figure 6A.

The Figure 6 demonstrates also demonstrates that some ECO Member countries will face sever challenges owing to their week national healthcare infrastructure. If the current outbreak continues to spread further, it may highlight persistent health system constraints in addition to lack of adequately skilled health workforce in these Member States.

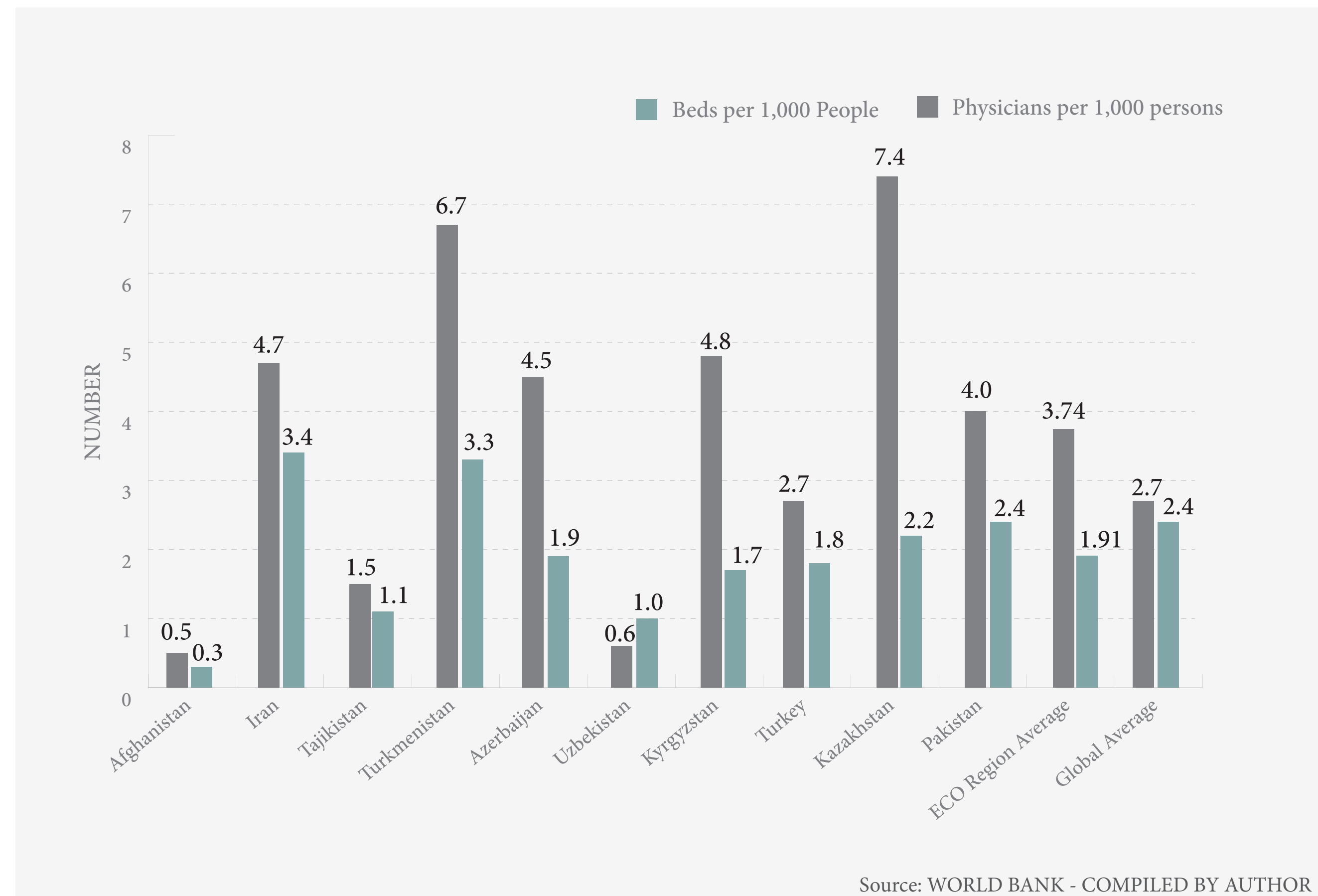
The Figure 7 demonstrates the availability of hospital beds and physicians per 1,000 people in the ECO Member Countries. Pakistan and Afghanistan rank lowest in the region with values less than combined average of ECO and the global average. It could mean that with fast- moving spread of the COVID-19, Pakistan would most likely be on its way to quickly reach its critical limits of healthcare facilities and face severe shortages of both healthcare professionals and hospital beds in the country.

Similarly, this also highlights an urgent need of dedicated epidemiologists in the Disaster.

Management Authorities in the ECO region; whose services would be critical to respond to the COVID-19 pandemic.



[Figure 6] Current healthcare spending in the ECO countries (A) as % of GDP (B) per capita in USD



[Figure 7] Availability of hospital beds and physicians per 1,000 people in the ECO region

3. Scientific and technological responses to the COVID-19

A. Turkey

Scientific and Technological Research Council of Turkey (TUBITAK), which is Turkey's top scientific body, has established COVID-19 Turkey Platform to mobilize scientific resources of 41 scientific institutions develop medicines and vaccines against COVID-19[15]. Under COVID-19 Platform, 7 vaccine and 7 drug development projects are currently being undertaken.

Furthermore, TUBITAK has invested over US$ 300 million for the development of 16 vaccine and other medicine projects over the past five years in Turkey[16].

Due to its advance scientific capabilities, Turkey is now self-sufficient in terms of manufacturing its own testing kits and develops its Polymerase Chain Reaction (PCR) tests. For example, a Turkish firm has recently produced a COVID-19 test that can yield results within five minutes without requiring trained personnel or expensive lab equipment[17].

B. Pakistan

The Higher Education Commission (HEC) of Pakistan has launched a programme supporting applied research in areas including disease surveillance and epidemiology, and in the rapid development and commercialization of products and services that will help the country control COVID-19.

On the product side, the commission is interested in promoting domestic manufacturing of low cost equipment and materials, including diagnostics, ventilators and personal protective equipment. Universities, technologists and researchers are invited to submit proposals. Projects will last for six months or one year, with maximum funding of over US$ 90,000[18].

The Pakistan Science Foundation has opened a Rs20 million (US$ 19.5 Milllion) call for proposals for a public-private collaboration in the fields of technology and material development, infection prevention and control, and epidemiology, to fight COVID-19[19]. Also, the Ministry of Information Technology and Telecom in Pakistan is providing funding support to high-impact and short time-to-market ideas that can be developed to tackle the most pressing challenges by COVID-19 outbreak using the application of Information and Communication Technologies (ICTs)[20].

The International Center for Chemical and Biological Sciences (ICCBS) at the University of Karachi has been actively involved in the diagnostics, research and drug delivery system for the novel corona virus. The Jamil-ur-Rahman Center for Genome Research based at the ICCBS is undertaking the genomic analysis of COVID-19 from Pakistan by using next generation sequencing[21]. This research will help to understand the genetic variations and their correlation with the disease severity, progression and clinical outcomes. The International Center has also been involved in the evaluation of protein-protein contact profiles between CoV2 spike protein and ACE2 to understand the dynamics of the event. The Center has also established largest biosafety level-III (BSL-III) laboratory in the country in response to the pandemic with a potential testing capacity of 2,400 tests per day.

C. Iran

Mustafa (PBUH) Science and Technology Foundation (MSTF) based in Iran have garnered the support from Scientists and Technologists of the Islamic World to contribute towards the detection, prevention, including drug development and vaccines for the COVID-19. In its 7th, Science and Technology Exchange Program (STEP) which will be organized online, will invite leading scientists from the Islamic world to discuss and share the scientific and technological resources to combat COVID-19 on May 28, 2020. MSTF is also collaborating with Sharif University of Technology to develop AI Med; if successful this could be an effective method to detect the COVID-19 cases at a large scale[22].

D. Kazakhstan

The National Biotechnologies Centre and Scientific Research Institute of Biological Security of Kazakhstan is reportedly developing a vaccine against COVID-19[23].

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15) Bicer, A. (2020, February 4). COVID-19: Turkey making headway in vaccine development. Anadolu Ajansı. https://www.aa.com.tr/en/health/covid-19-turkey-making-headway-in-vaccine-development/1789193
16) Daily Sabah. (2020, April 25). Turkey's top scientific body invests TL 2.3 billion on 16 vaccine projects over 5 years. Daily Sabah. https://www.dailysabah.com/turkey/turkeys-top-scientific-body-invests-tl-23-billion-on-16-vaccine- projects-over-5-years/news
17) Daily Sabah, D. S., & AP. (2020, April 23). Turkish firm develops 5-minute COVID-19 test. Daily Sabah. https://www.dailysabah.com/turkey/turkish-firm-develops-5-minute-covid-19-test/news
18) Higher Education Commission, Pakistan. (2020). RAPID RESEARCH & INNOVATION INITIATIVE (RRII). Higher Education Commission, Pakistan. https://www.hec.gov.pk/english/services/RnD/RRIF/Pages/default.aspx
19) Pakistan Science Foundation. (2020). Research Support. PSF. http://www.psf.gov.pk/researchSupport.aspx
20) Ignite. (2020). Ignite - National Technology Fund. Ignite. https://ignite.org.pk/
21) International Center for Chemical and Biological Sciences. (2020). ICCBS's Ongoing Projects on Coronavirus (COVID-19). International Center for Chemical and Biological Sciences . https://www.iccs.edu/page-covid-19
22) Mustafa Prize. (2020). Universal Access to AI-MED Covid-19 Detection System. http://www.mustafaprize.org. http://mustafaprize.org/news/?id=3171
23) Nurmaganbetova, Z. (2020, March 20). Kazakhstan developing vaccine against COVID 19. KAZINFORM. https://www.inform.kz/en/kazakhstan-developing-vaccine-against-covid-19_a3627758

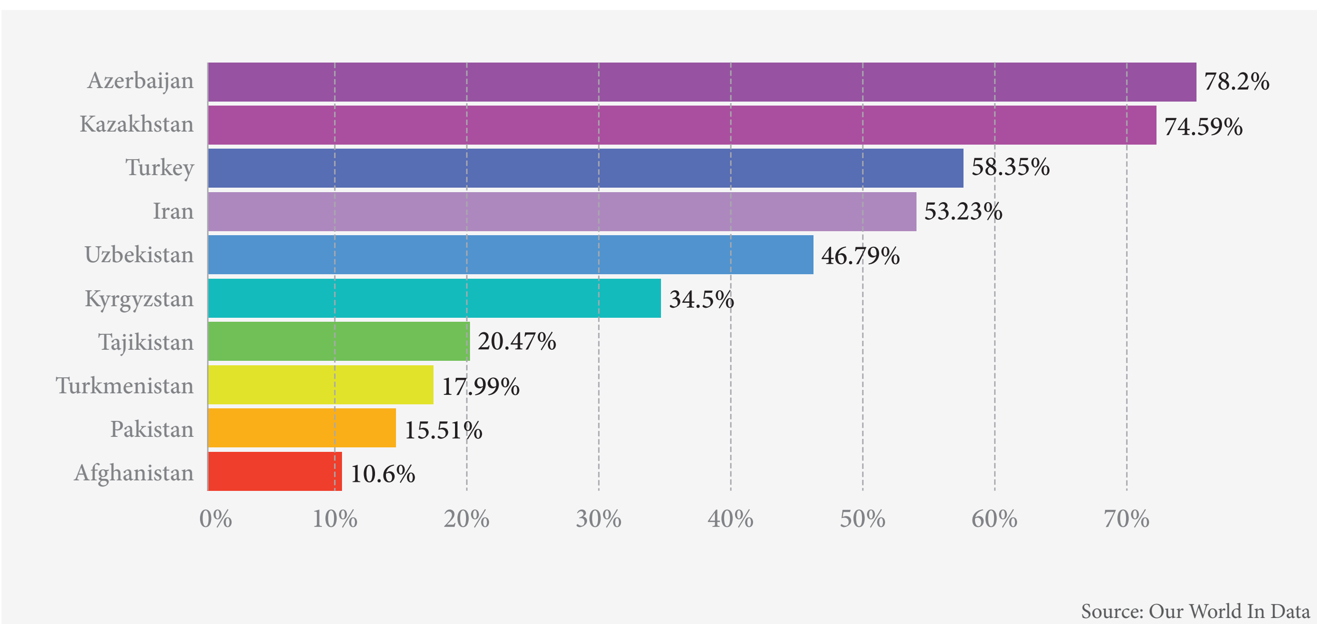
4. ICT in the ECO member countries

In combating the adverse effects of COVID-19 and enhancing societal and economic resilience, digital technology and internet connectivity have emerged as an essential tool and alternative to the physical equivalent. According to the World Bank, over 160 countries have mandated temporary school closures, leaving 1.6 billion children and youth out of school.

Here is the snapshot of internet connectivity in the ECO region. To tackle this challenge, ECO Member Countries need to promote and increase inclusive broadband connectivity to deliver remote learning and critical healthcare facilities during the pandemic.

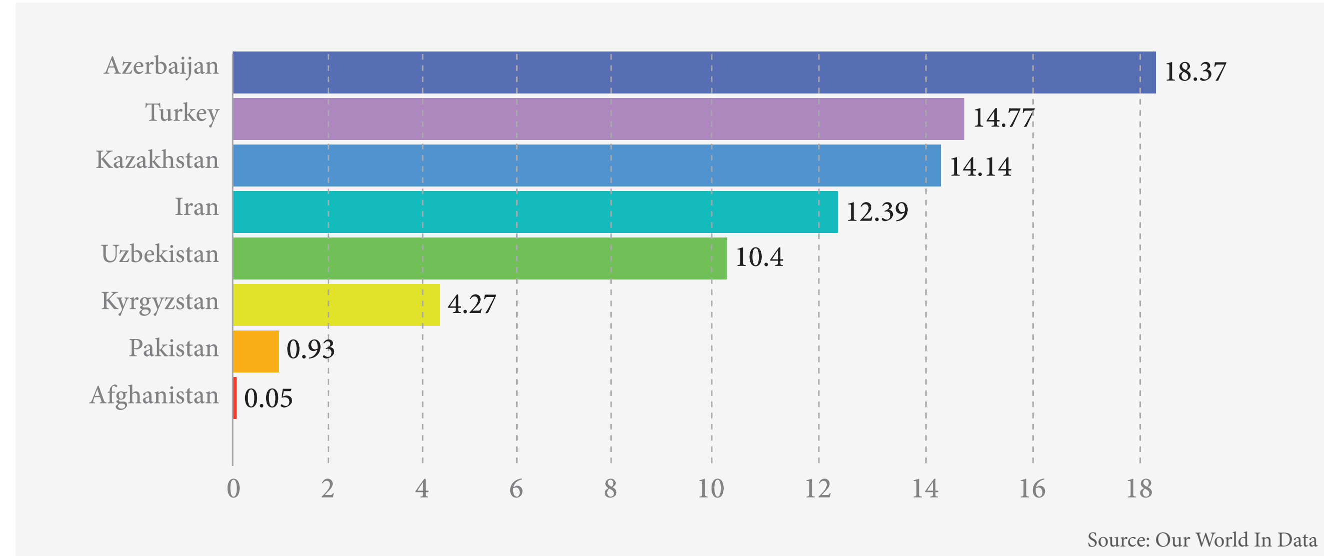
Extended school closures in the Member Countries may cause not only loss of learning in the short-term, but also further loss in human capital and diminished economic opportunities in the long-term. To help mitigate the loss of learning, many countries are pursuing options to utilize remote learning to manage and cope with the crisis. However, without reliable connectivity, this would be a challenge to embark upon remote learning in the region.

Figure 8 and 9 show that there exist serious gaps in internet connectivity in the region. Therefore, it is high time that ECO Member Countries develop a plan to augment the accessibility and connectivity in the region. The relevant Ministries of ICTs could liaise with international development partners such as Information Technology Union of United Nations and UN Broadband Commission to beef up their ICT infrastructure in the respective countries. During this pandemic, the resource availability and connectivity through broadband is critical to respond to the COVID-19 pandemic.



[**Figure 8**] Share of the population using the Internet

All individuals who have used the Internet in the last 3 months are counted as Internet users. The Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV etc.



[**Figure 9**] Broadband subscription per 100 people

Broadband subscriptions refer to fixed subscriptions to high-speed access to the public Internet (a TCP/IP connection), at downstream speeds equal to, or greater than, 256 kbit/s

5. Economic and fiscal measures

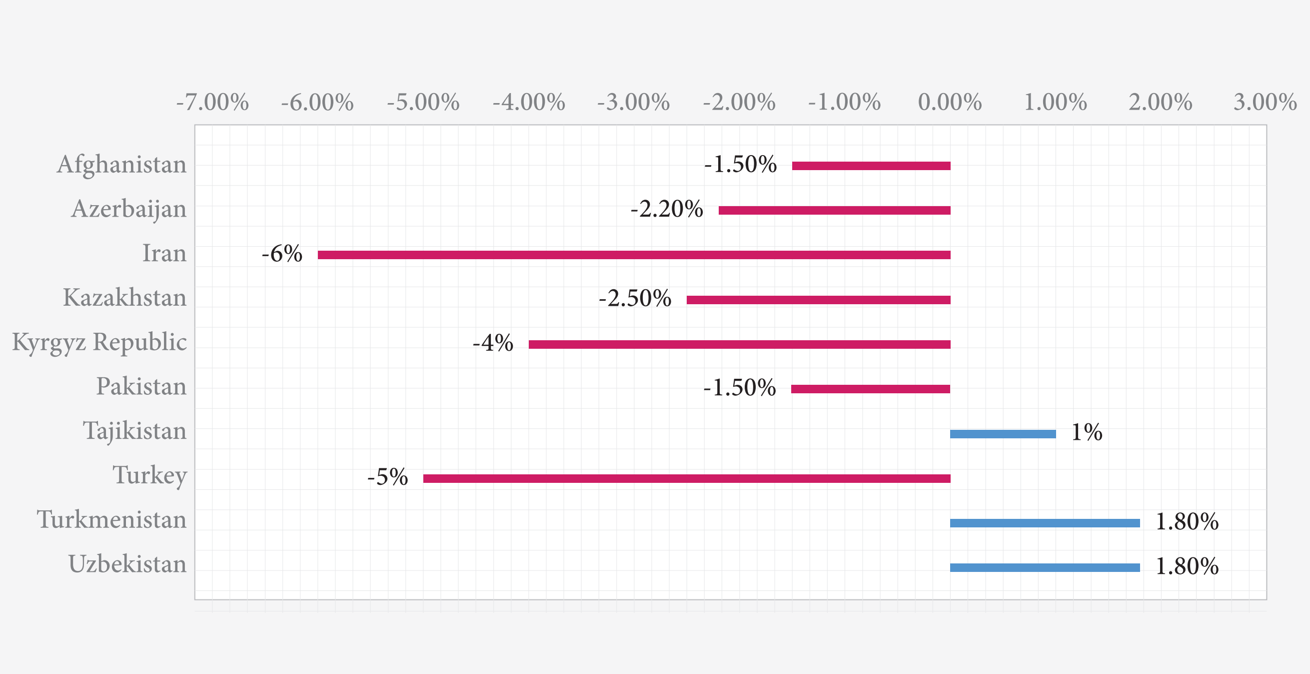
The severity of this pandemic and its impact on economic consequences is unimaginable. No one knows yet exactly how the pandemic further develops and no one knows exactly the future path of economies worldwide. The IMF has revised its Global Economic Outlook for 2020. The following chart shows the impact of COVID-19 on real GDP growth of the ECO Member Countries.

However, in order to save lives and secure most urgent necessities for millions of people, it is important to concentrate on fast-track measures to contain the pandemic and mitigate its adverse impact on livelihood and economies. Virtually all countries in the world have responded to the COVID-19 crisis by implementing some fiscal and monetary measures. Below are the fiscal measures taken by the ECO Member countries. In response to this crisis, nearly all countries have undertaken fiscal and monetary measures to and redirected funds and financing towards healthcare emergencies. This brief considers the fiscal measures undertaken by the ECO Member Countries and their economic outlook for 2020 by the International Monetary Fund (IMF).

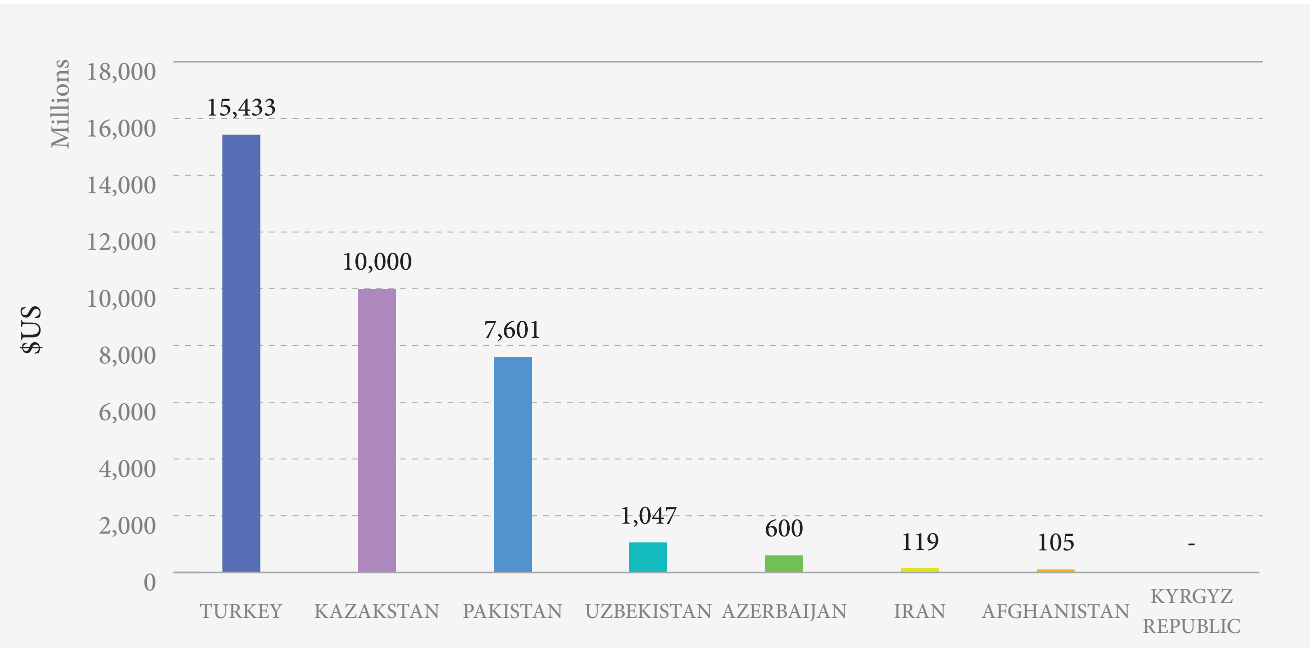
In order to keep the economy running despite lockdowns, to support health systems and other critical infrastructure and to mitigate the adverse economic shocks, ECO Member Countries must come together to support each in the fight against this pandemic.

6. Recommendations for the Member Countries

The COVID 19 pandemic requires decisive and swift actions to respond to this overwhelming challenge. Followings are some recommendations for the ECO Member Countries:



[**Figure 10**] Real GDP growth of ECO Mebmer Countries (annual percentage change)



Source: Oxford Government Response Tracker

[**Figure 11**] Fiscal measures in reponse to COVID-19, by ECO Member Countries

1. Increase the budget allocations for the health sector and provide immediate support for the long-term strengthening of the health sector;

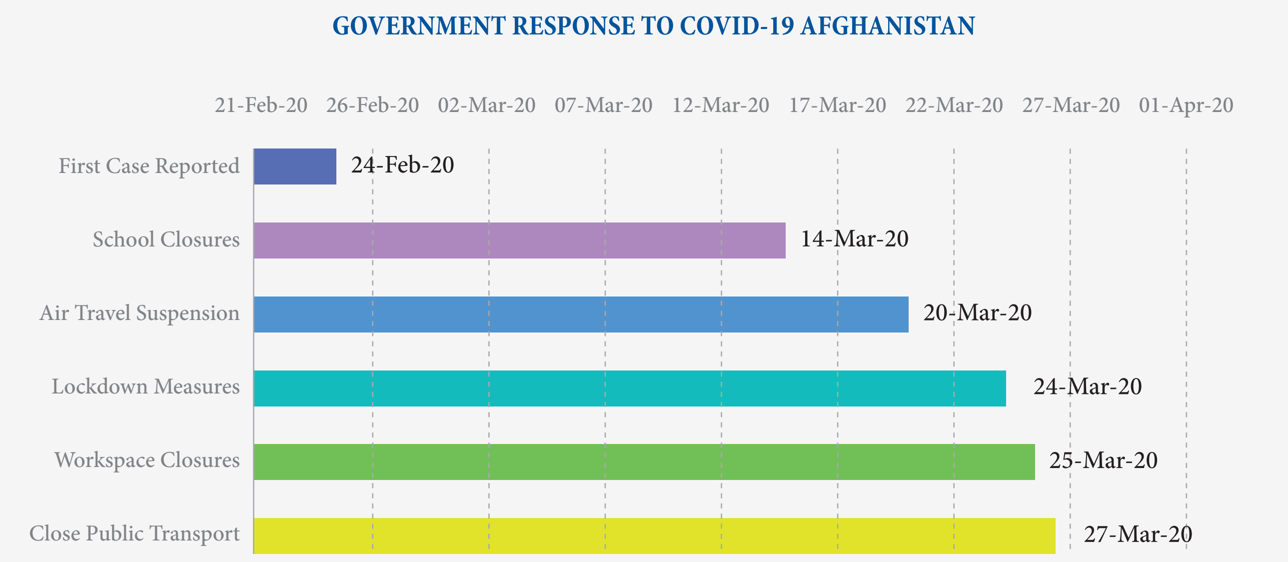
2. Invest signficant more resources on science, technology and innovation, particularly health and science education, so that member states are adequately prepared to prevent any daunting challenge in the future, and

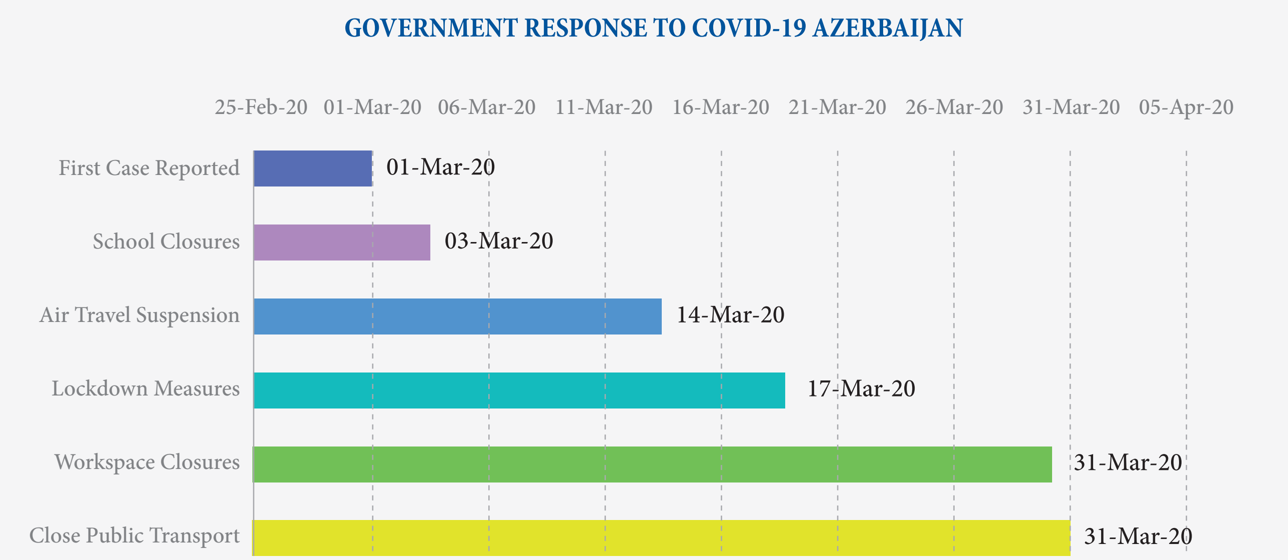
3. Develop and strenghten capacities and capabilities of the scientific communities and development collaborative platforms amongst the universities and laboratories of the member countries to fund and scale up research for medical treatment and vaccine development for corona virus. This will increas the preparedness of the counteries to tackle any future epidemics and calamities as well.

Supplementary Data 1

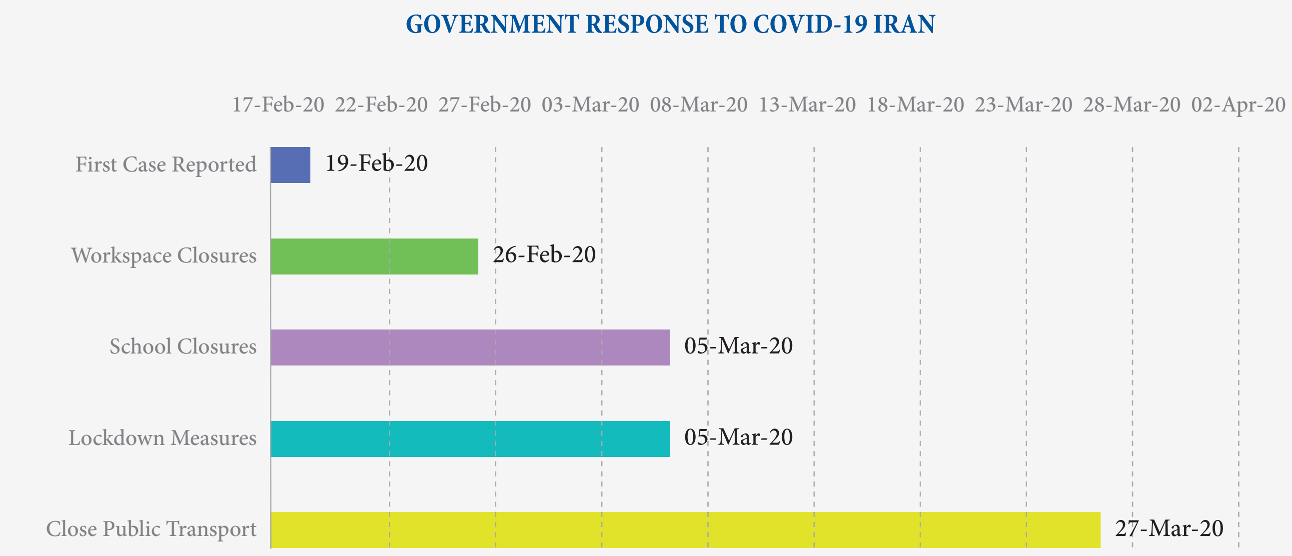
ECO Member Countries Response to COVID-19

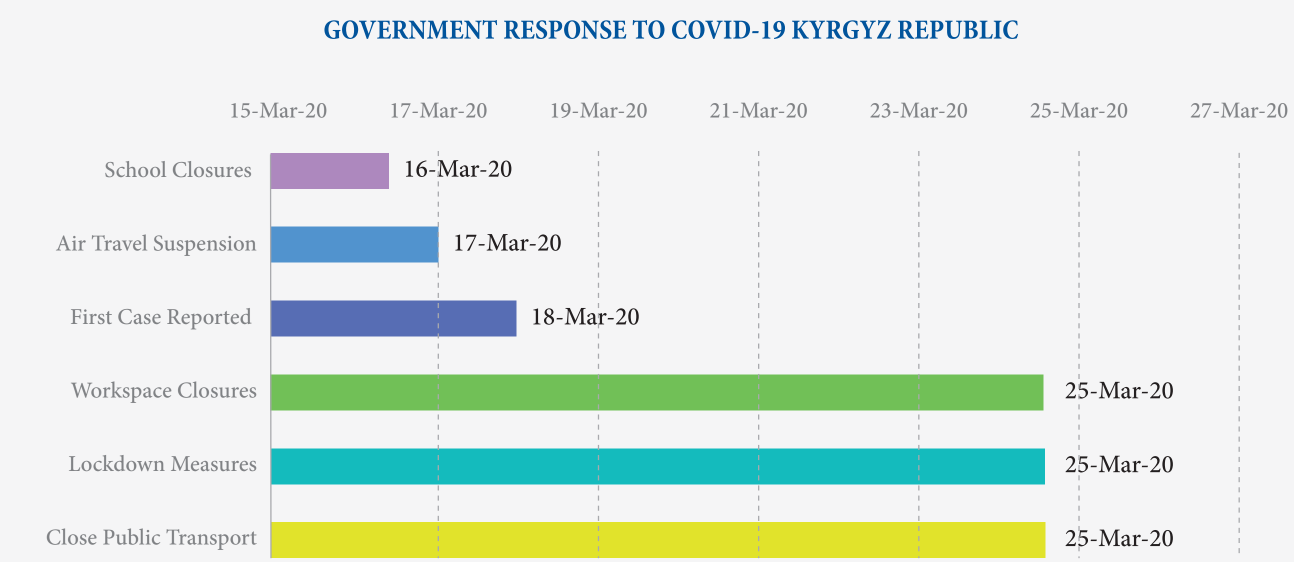
Oxford University Response Tracker for COVID-19 - Complied by Author[24]



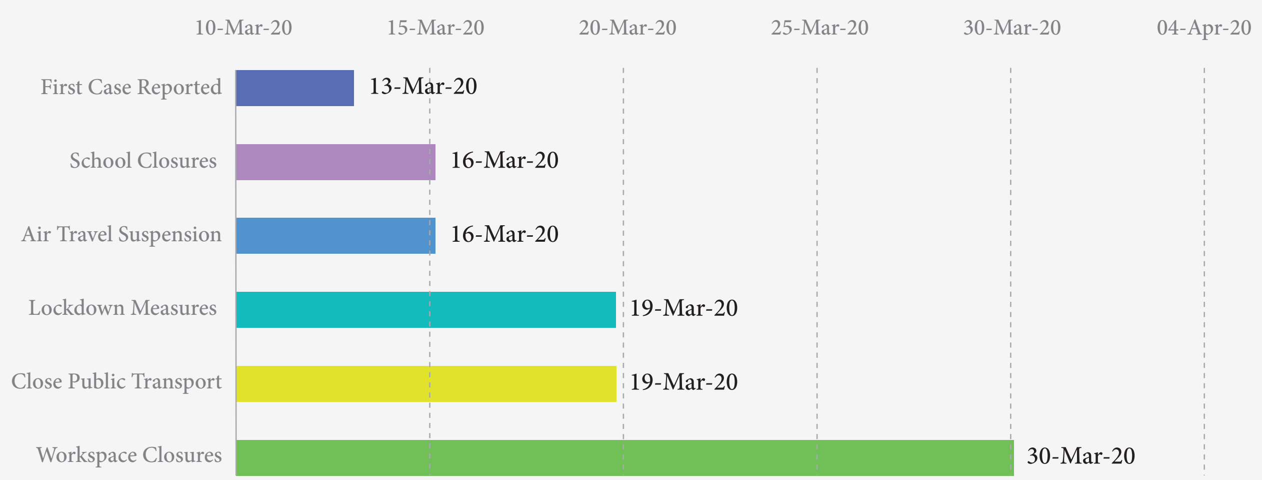


24) Blavatnik School of Government. (2020). OxCGRT. https://covidtracker.bsg.ox.ac.uk/

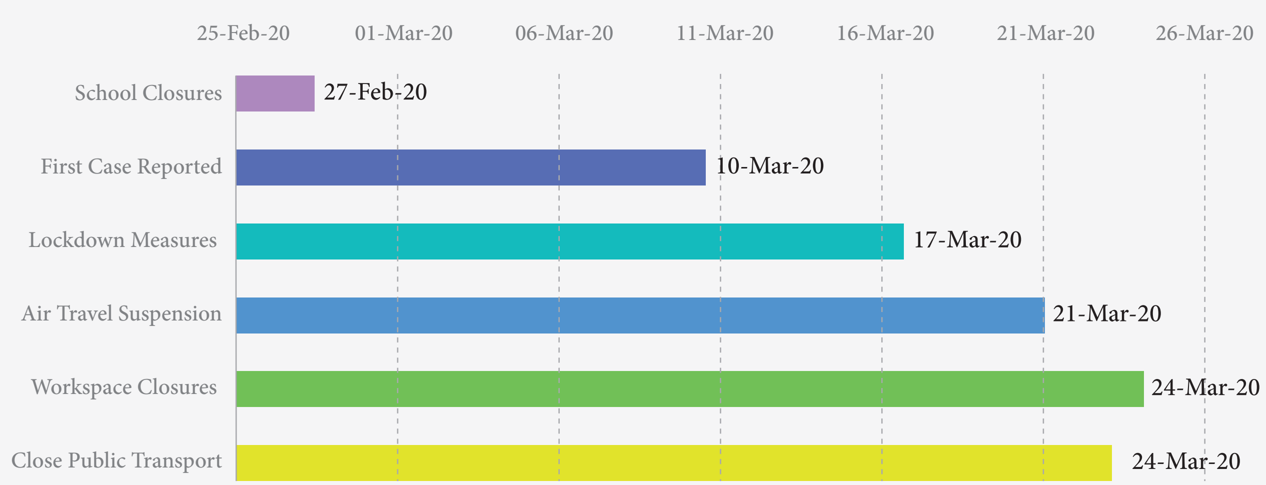




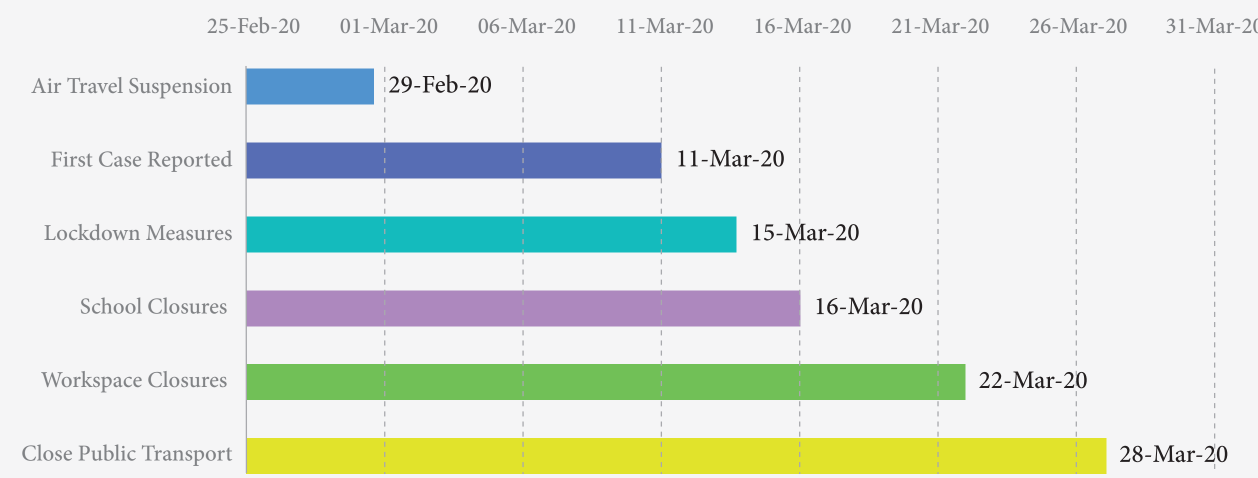
GOVERNMENT RESPONSE TO COVID-19 KAZAKHSTAN



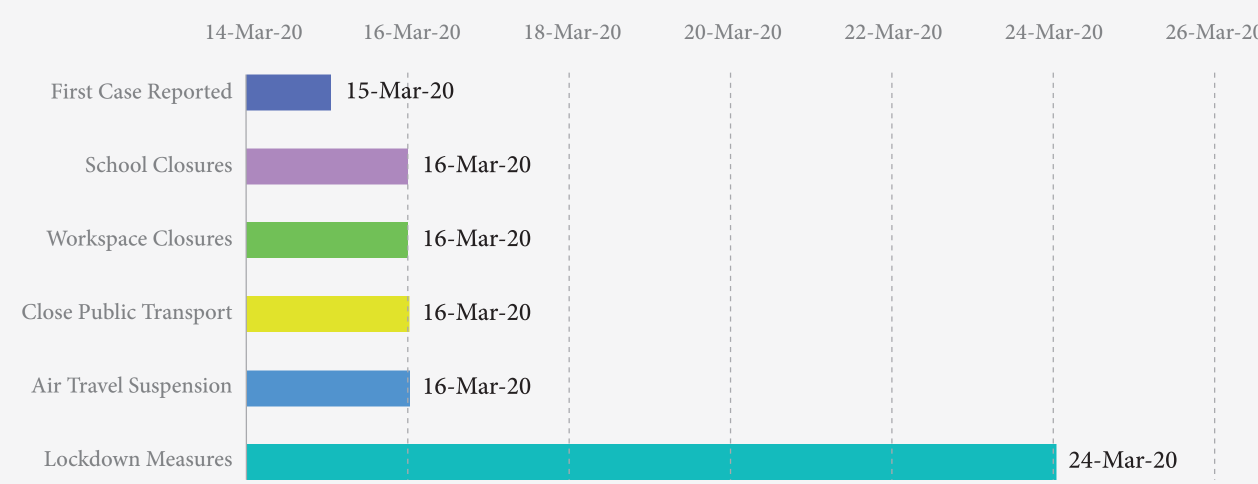
GOVERNMENT RESPONSE TO COVID-19 PAKISTAN



GOVERNMENT RESPONSE TO COVID-19 TURKEY



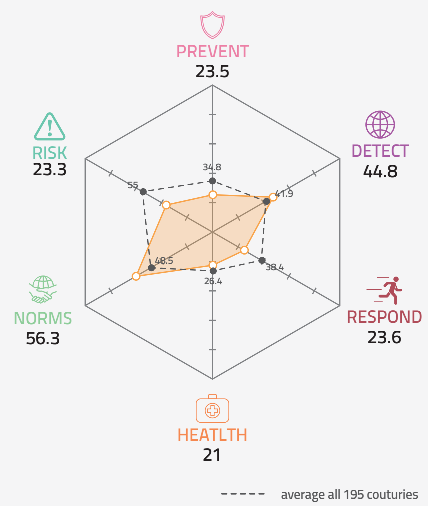
GOVERNMENT RESPONSE TO COVID-19 UZBEKISTAN



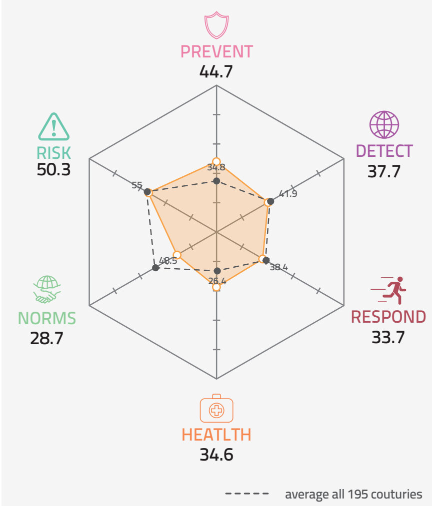
Supplementary Data 2

Global Health Security Index Profiles of the ECO Member Countries

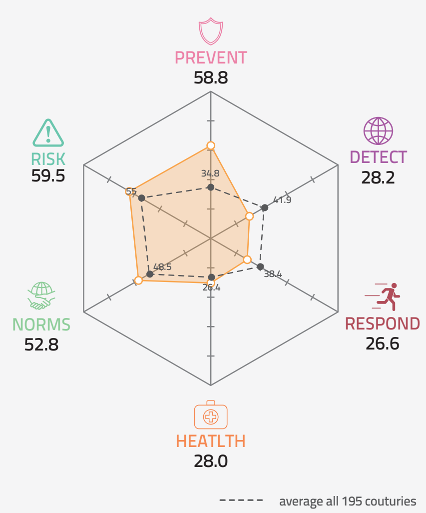
Afghnistan
32.3 Index Socre 130/195



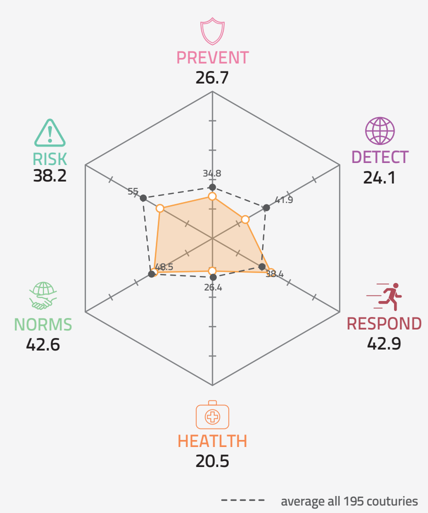
Iran
37.7 Index Socre 97/195



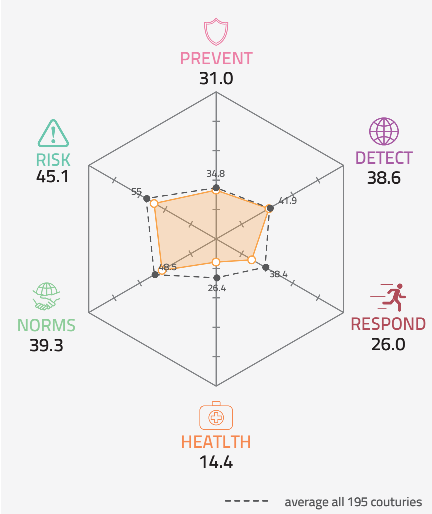
Kazakhstan
40.7 Index Socre 83/195



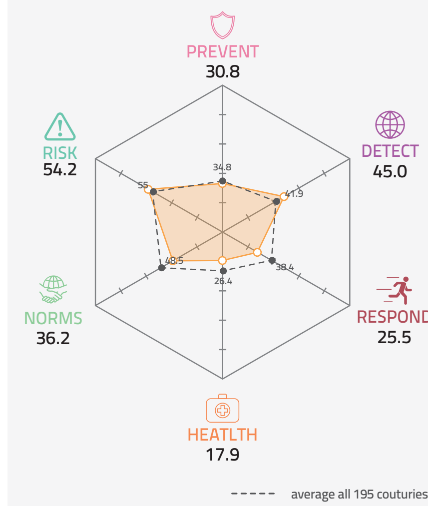
Tajikistan
32.3 Index Socre 130/195



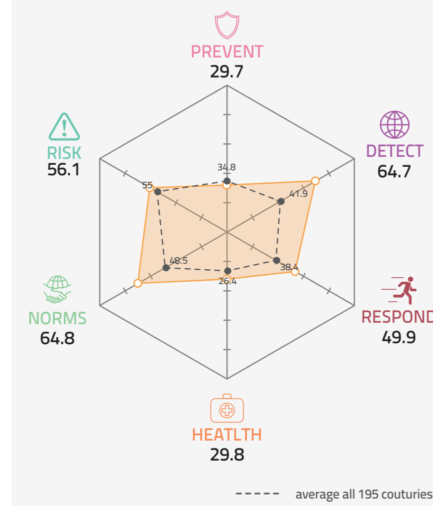
Turkmenistan
31.8 Index Socre 135/195



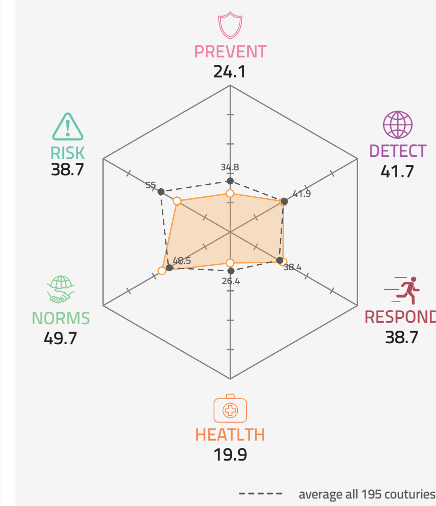
Azerbaijan
34.2 Index Socre 117/195



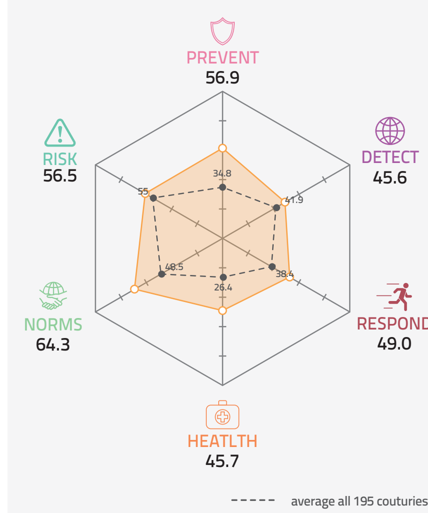
Kyrgyz Repblic
49.3 Index Socre 47/195



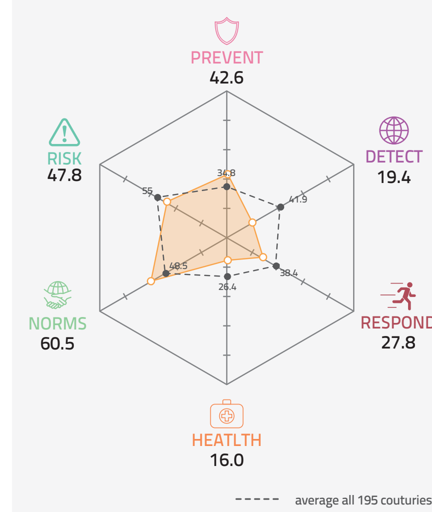
Pakistan
35.5 Index Socre 105/195



Turkey
52.4 Index Socre 40/195



Uzbekistan
34.3 Index Socre 116/195



The Need to Protect Science, Technology and Innovation Funding During and After the COVID-19 Crisis

UNCTAD
United Nations Conference on Trade and Development, Geneva

A. Background

The COVID-19 outbreak has infected more than 2,950,000 people and killed more than 202,000 worldwide to this date[1]. While the overall economic impact of this outbreak is still unfolding, there are strong indications that it will cause the largest economic downturn since the 2008 financial crisis.

This brief makes a case for protecting science, technology and innovation budgets during the COVID-19 crisis and its aftermath, based on the fact that continued investments in STI will be critical to the achievement of the 2030 Agenda for Sustainable Development. Even though developing countries as a group have recorded continued growth in R&D expenditure over recent years, the absolute levels remain small and their STI capabilities limited. It is therefore crucial for developing countries to reinforce their commitments to protect investment in STI and to design recovery packages that leverage technology and innovation for sustainable development.

B. The importance of stable, predictable R&D expenditures at times of crisis

The 2008 financial crisis provides an example of a widespread, profound international economic shock that can be compared to the likely impact of COVID-19. At that time for the countries for which there is a consistent data set for expenditure on R&D and that had in place innovation systems on which changes on the levels of expenditure could have significant impact (mostly those in the OECD), two different sets of trajectories can be observed:

On the one hand, countries with more knowledge-intensive economies and more developed innovation systems suffered less from the 2008 financial crisis and did not impose austerity on R&D expenditures. On the other hand, countries that entered the 2008 financial crisis with weak budgetary efforts in STI and consequently weaker innovation systems showed less macroeconomic resilience, which led to budgetary tightening on R&D expenditure which in turn further weakened their innovation systems and their chances to move to more knowledge-intensive growth patterns. Countries that decreased public R&D expenditures turned to alternative financing mechanisms (loans, guarantees, co-financing, competitive funding, etc.) and undertook consolidation and streamlining of existing policies and programmes, with uneven results given the lower maturity of their innovation systems. Thus a trend of growth in public R&D expenditures was reversed, jeopardizing the results of previous investment and with subsequent impact on private investment in technology and innovation.[2] [3]

Because the outcome of research and innovation investments is particularly subject to uncertainty and risk, maintaining continuity and a long-term perspective in public support to STI is critical. There is evidence that government expenditures to encourage R&D in the business sector are more effective when they are stable over time: firms hesitate to invest in additional R&D if they are uncertain of the durability of government support[4] [5]. Predictability and long-term perspectives in funding are also critical for research undertaken by academic institutions.

Similarly, investment in human capital can suffer from stop-and-go policies and lead to difficulty in retaining skilled human resources. Faced with unstable academic research systems, gloomy career prospects and salary cuts, promising researchers and other skilled workers are likely to switch to other career paths or migrate to countries where STI investments are stable or continue to grow.

C. A Science, technology and innovation policy response to the COVID-19 crisis

The following are some policy considerations for STI funding decisions in response to the COVID-19 crisis:

During the crisis, support R&D activities as part of emergency measures and of recovery packages

Within an overall context of public funding of STI that should remain stable or grow during the pandemic, and considering the nature of the COVID-19 crisis, in the short term it is suggested that priority should be given to measures such as:

Grants for R&D carried out by academic or public institutions as well as by the private sector on vaccines, therapeutics and diagnostics to treat or prevent the spread of the coronavirus, particularly those that focus on the specific needs of developing countries;

Grants for preparedness, response and prevention research, with a particular emphasis on digital technologies;

Prioritize procurement for health system infrastructure, labs, equipment and supplies from firms with a stronger commitment to innovation;

Emergency loans to firms (particularly SMEs)

1) WHO (2020). Coronavirus disease (COVID-19) Pandemic. Available at https://www.who.int/emergencies/diseases/novel-coronavirus-2019 (accessed on 29 April).
2) Izsak K et al (2013). Impact of the Crisis on Research and Innovation Policies. Available at https://ec.europa.eu/research/innovation-union/pdf/expert-groups/ERIAB_pb-Impact_of_financial_crisis.pdf (accessed 6 April 2020).
3) ILO (2020). A review of global fiscal stimulus April. Available at https://www.ilo.org/wcmsp5/groups/public/---dgreports/---inst/documents/publication/wcms_194175.pdf (accessed 6 April 2020).
4) Guellec D and Potterie B van P de la (2000). The Impact of Public R&D Expenditure on Business R&D.
5) Mitchell J et al (2019). Tax incentives for R&D: supporting innovative scale-ups?. Research Evaluation, 29(2), 121–134.

conducting R&D relevant to COVID-19 and that were financially hit by the crisis.

It will be equally crucial that recovery packages include a strong component of fiscal support to STI and to innovation-intensive activities. For instance, smart recovery packages could present an opportunity to prioritize investments in innovation-enabling infrastructure, particularly for the digital economy, and support the transition to renewable energy and more environment friendly manufacturing and services. Along this line, 13 European climate and environment ministers have signed a joint article calling for a European green deal in response to COVID-19[6). Similar considerations would be relevant to other regions, including in the developing world.

After the crisis, revisit and strengthen the budgetary commitments to support R&D

A lesson from the 2008 financial crisis was that countries with weaker innovation systems suffered more from it and that subsequent R&D budget reductions made them unable to build the innovation systems they would need to become more resilient, knowledge-based economies. This is a particularly relevant lesson for developing countries where innovation systems are in most cases nascent and frail. Even though in the decade after the 2008 financial crisis developing countries achieved higher average annual growth rates of R&D expenditures than developed countries (and even faster rates than in GDP growth), their R&D expenditures remain significantly smaller as a percentage of GDP than in developed countries and far below the levels that would be compatible with the ambition of the 2030 Agenda for Sustainable Development (Table 1). Hence the importance of protecting investment in STI should be noted even in the difficult fiscal environment that can be expected after the COVID-19 crisis.

Once the most pressing emergency situations have been addressed, countries need to revisit and strengthen their budgetary commitments to support R&D. In doing so a "forward guidance" approach (committing to a growth path of future government R&D expenditures) can be an effective tool. Already some regional organizations have set targets for R&D expenditure as percentage of GDP such as the European Union's 3 per cent target and the African Union's 1 per cent target[7). Likewise, developing countries could revisit and set their targets and, importantly, establish their spending trajectory towards them. This way, governments can not only treat R&D expenditures as "protected funding lines" but also ensure and signal the continuity and predictability of government R&D support to other stakeholders.

Support a systems approach to policy making that includes natural sciences, engineering and social sciences

While a global public health crisis unfolds, it is inevitable that most attention is focused on medical and public health responses that can deliver solutions

6) Gewessler L et al. (2020). European Green Deal must be central to a resilient recovery after Covid-19. Available at https://www.climatechangenews.com/2020/04/09/european-green-deal-must-central-resilient-recovery-covid-19/ (accessed on 17 April 2020).
7) UNESCO (2019). New UIS Data for SDG 9.5 on Research and Development. Available at http://uis.unesco.org/en/news/new-uis-data-sdg-9-5-research-and-development (accessed 9 April).

[Table 1] Growth of R&D expenditures by development status groups

	R&D expenditures (average annual growth rate, 2007-2017)	GDP (average annual growth rate, 2007-2017)	R&D expenditures as percentage of GDP (average, 2007-2017)
Landlocked developing countries	5.0%	5.8%	0.23%
Small island developing states	2,.5%	0.9%	0.98%
Sub-saharan Africa	4.4%	4.4%	0.37%
Least developed countries	6.2%	5.1%	0.21%
Low income countries	7.2%	4.0%	0.28%
Lower middle income countries	4.5%	5.5%	0.46%
Upper middle income countries	10.2%	5.0%	1.23%
High income countries	2.3%	1.4%	2.34%
World	4.3%	2.6%	1.65%

Source: UNESCO (2020). Science, technology and innovation: Gross domestic expenditure on R&D (GERD), GERD as a percentage of GDP, GERD per capita and GERD per researcher; UNCTAD (2020). UNCTADstat: Gross domestic product
Note: Groups overlap with each other and some countries belong to more than one group.

to the immediate problems of stopping the spread of disease and healing the sick. However, a systems approach that emphasizes multidisciplinary and multisectoral approaches, is likely to be the most effective strategy to improve the preparedness and resilience of societies against future similar threats. This requires sufficient flow of resources to support not just biomedical research and innovation but a much broader range of scientific and technological knowledge and its practical applications.

It has been observed that the resilience and the ability to recover from the COVID-19 outbreak will require capabilities in and coordination among not just medical science and public health but also in a wide range of disciplines. These include data science, sociology, psychology, mass transit systems engineering, supply chain management, ICTs and digital technologies, political science and economics, just to name a few. Public R&D budgets need to support not only the generation of new knowledge in this broad range of disciplines, but also the institutions and mechanisms that enable cross-sectoral, multidisciplinary collaboration among those different communities of practice.

Ensure international cooperation and coordinated policy responses

COVID-19 is now rapidly spreading to the developing world where the capacity of public health systems and the financial resources to address the pandemic are both lower than in developed countries. International cooperation is more critical than ever, and all relevant actors should work together to fund, design and deliver solutions, particularly when it comes to developing science and technology-based solutions.

The United Nations has launched a $ 2 billion global humanitarian response plan to fund the fight against COVID-19 in the world's poorest countries that includes support for R&D[8]. The UN IATT, an interagency group of which UNCTAD and DESA are co-conveners, has issued a call for innovative solutions worldwide to combat COVID-19. UNCTAD, in collaboration with the UN Commission on Science and Technology for Development, has also issued another call for the sharing of COVID-19 related national policies and experiences around which international collaboration can be developed. Calling for a scaled-up global response to COVID-19, several non-profit and private sector organizations are helping speed up the development of COVID-19 treatments and vaccines, while urging international financial institutions and G7 and G20 governments to provide immediate funding to fill urgent gaps[9].

As a vast number of different actors engage in research worldwide to combat COVID-19, the coordination efforts become more critical. In this effort, WHO has set up protocols and roadmaps to identify global research priorities and standards for better alignment of research by different groups[10]. Also, WHO has endorsed the creation of a voluntary intellectual property pool whose content could be shared for developing drugs, vaccines, and diagnostics, which would particularly benefit developing countries[11]. Further, open access to scientific work has been facilitated, where a large number of data and findings related to COVID-19 that are only a few days (or sometimes hours) old, are now made openly available for the community.[12]

A global pandemic is a text-book example of a critical problem where the sum of isolated efforts by national governments provides much inferior outcomes than international collaboration[13]. The positive externalities of STI investments in such a situation could be huge and decisive in the effort to ensure that the most vulnerable members of the international community are not left behind.

8) United Nations Coordinated Appeal (2020). Global Humanitarian Response Plan COVID-19 March. Available at https://www.unocha.org/sites/unocha/files/Global-Humanitarian-Response-Plan-COVID-19.pdf (accessed 6 April 2020).
9) Geulette M (2020). Canada pledges C$275M for coronavirus R&D, adding to global funding rush. Available at https://sciencebusiness.net/news/canada-pledges-c275m-coronavirus-rd-adding-global-funding-rush (accessed 6 April 2020).
10) WHO (2020). WHO Director-General's opening remarks at the media briefing on COVID-19 - 6 March 2020. Available at https://www.who.int/dg/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---6-march-2020 (accessed 6 April 2020).
11) Silverman E (2020). WHO director-general endorses a voluntary intellectual property pool to develop Covid-19 products. Available at https://www.statnews.com/pharmalot/2020/04/06/covid19-coronavirus-patents-voluntary-pool-world-health/ (accessed 24 April 2020).
12) Younes G A, et al (2020). COVID-19: Insights from Innovation Economists.
13) UNCTAD (2020). Coronavirus: Global pandemic amplifies the critical role of international research collaborations in science and technology.

AMED R&D Related to Combating the Novel Coronavirus

AMED
Japan Agency for Medical Research and Development, Tokyo, Japan

I. Outline of the Japan Agency for Medical Research and Development (AMED)

President Mishima
(since April 2020)

1. Objectives

Based on the Plan for Promotion of Medical Research and Development created by the government's Headquarters for Healthcare Policy, AMED engages in research and development in the field of medicine, establishing and maintaining an environment for this R&D, and providing funding, in order to promote integrated medical R&D from basic research to practical applications, to smoothly achieve application of outcomes, and to achieve comprehensive and effective establishment/maintenance of an environment for medical R&D.

2. Established : April 1, 2015

3. Organization

A. Directors
- President : Yoshinao Mishima
- Executive Director : Katsufumi Jo
- Auditor (part-time) : Shingo Majima, Kimiko Murofushi

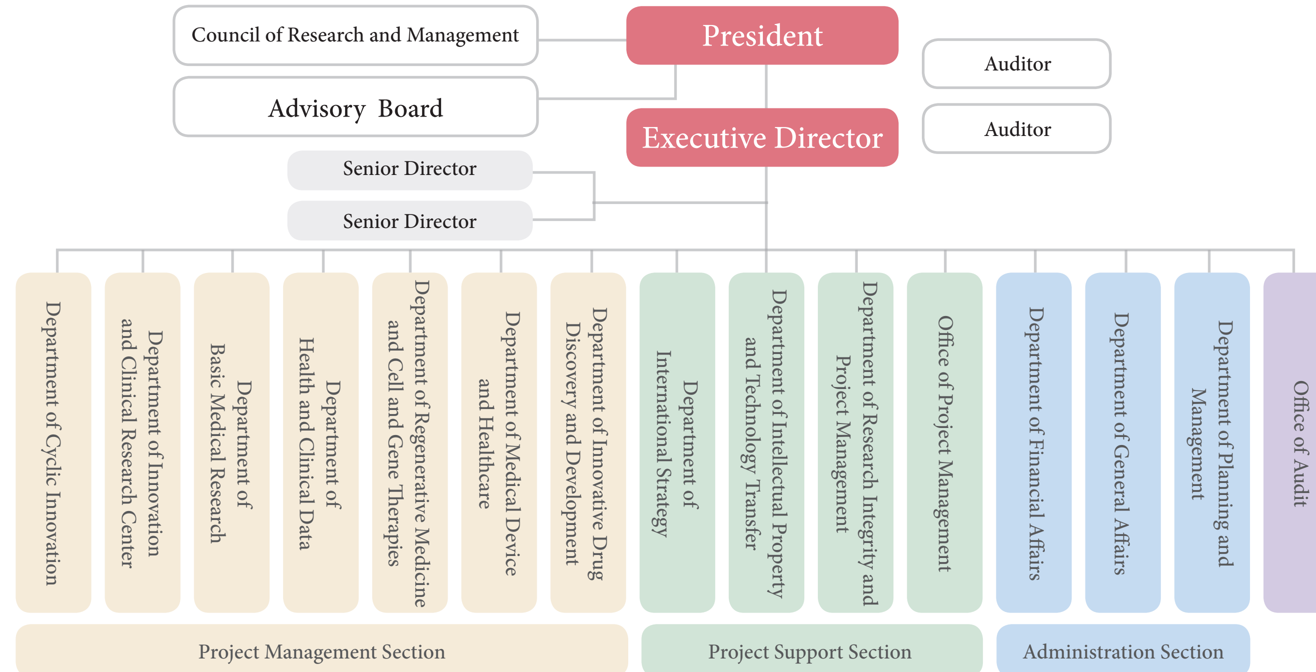
B. Number of staff (as of April 1, 2020)
Number of full-time staff : 387

4. Budget (FY 2020)

Subsidies for AMED : 127.2 billion yen
Adjustment fund : 17.5 billion yen[1)]

5. Address

20-24F Yomiuri Shimbun Bldg. 1-7-1 Otemachi, Chiyoda-ku, Tokyo



[Figure 1] Organization chart of AMED

II. Domestic and international trends regarding the novel coronavirus (COVID-19)

1. Global background

A. Over the past 20 years, there have been three outbreaks involving coronaviruses*.

B. The first was caused by the severe acute respiratory syndrome coronavirus (SARS-CoV) in 2002, which infected more than 8,000 people and caused more than 800 deaths[2)].

C. The second was caused by the Middle East respiratory syndrome coronavirus (MERS-CoV) in 2012, which had a low infection rate but a high mortality rate, with 2,429 infections and a mortality rate of 34.4% as of 2019[3)].

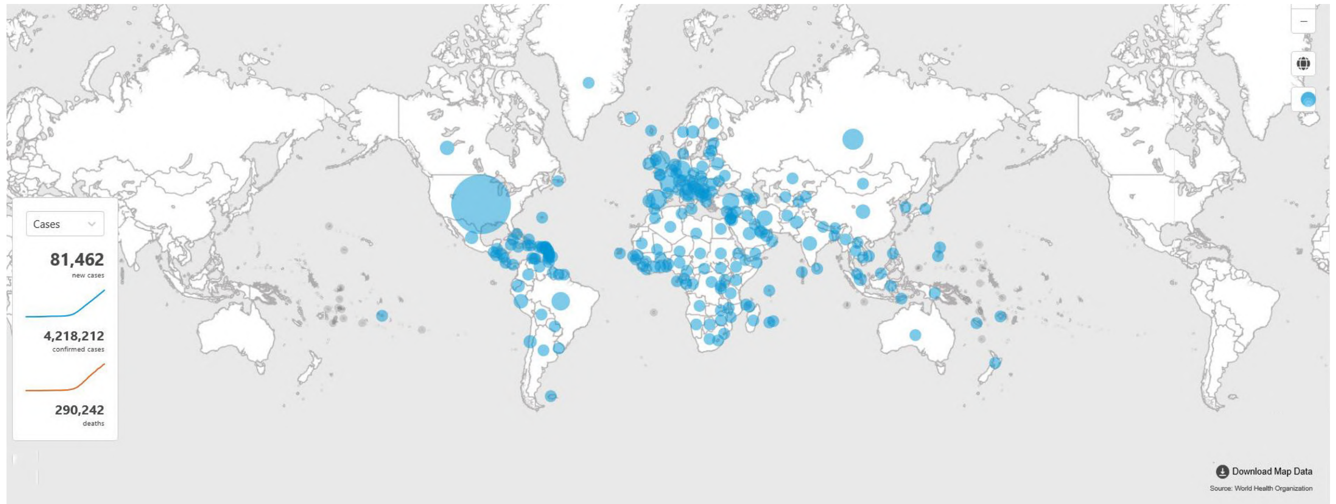
D. The third outbreak has been caused by SARS-CoV-2, which is deemed to have emerged in Wuhan, China in December 2019 and is the cause of the COVID-19 severe respiratory illness[4)].

E. The World Health Organization (WHO) announced on March 31, 2020 that COVID-19 "can be characterized as a pandemic".

F. As of May 14, 2020, 4.21 million people have been infected worldwide, and more than 290,000 have died[5)].

1) Part of SIT promotion funds are allocated.
2) Graham & Baric, 2010.
3) WHO, 2019.
4) Gorbalenya et al., 2020.
5) WHO, 2020.

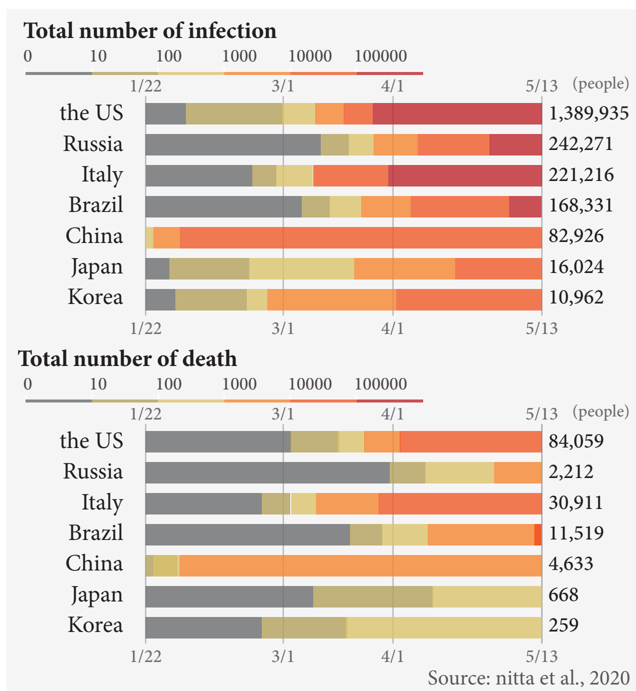
*Covonavirus



[Figure 2] Coronaviruses that infect humans include four types that cause the common cold, and three types – including this novel coronavirus – that originated in animals and cause severe pneumonia[6]

2. Main events in Japan

- Jan 15 — Returnees from Wuhan, China tested positive
- Jan 21 — A ministerial task force for novel coronavirus measures was established
- Jan 28 — Person-to-person infection was reported in Nara Prefecture
- Jan 29 ~ Feb 17 — Japanese nationals were repatriated from Wuhan by government charter flights
- Jan 30 — The first meeting of the Novel Coronavirus Response Headquarters was held
- Mar 13 — Amendment of the Act on Special Measures for Pandemic Influenza and New Infectious Disease Preparedness and Response
- April 7 — Declaration of a state of emergency in 7 prefectures, April 16 : Expanded to all prefectures
- May 4 — The state of emergency was extended until May 31 (including 13 prefectures subject to special precautions)
- May 14 — The state of emergency was rescinded for 39 prefectures excluding Hokkaido, Saitama, Chiba, Tokyo, Kanagawa, Kyoto, Osaka, and Hyogo



[Figure 3] Number of infection and death cases around the world

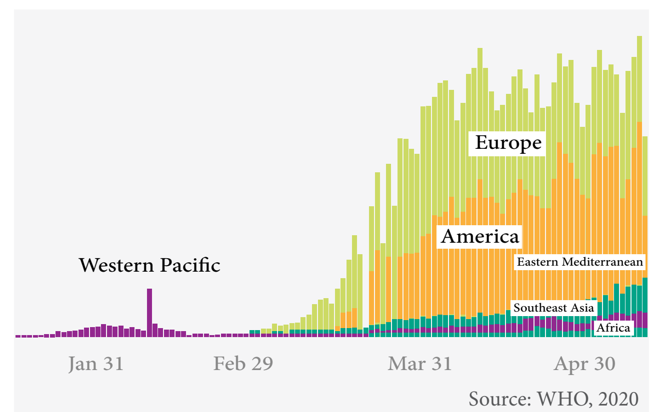
As of May 14, there were a total of 16,079 infected people and 687 deaths in Japan[7].

3. Trends in the numbers of people infected worldwide

- Since March 2020, numbers of infected people have increased sharply in Europe and the U.S.
- According to the genomic epidemiology of the novel coronavirus, the virus that has been circulating domestically and internationally since March is the same as that which spread across Europe.

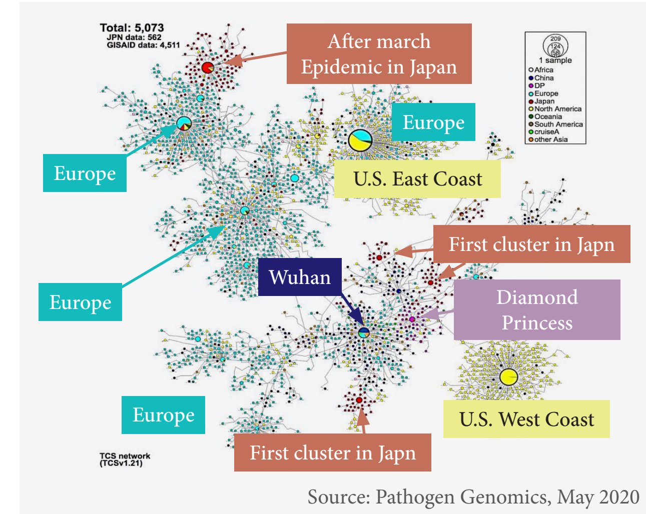
4. Infections in Japan

- Patients are hospitalized for two to three weeks on average. Although more than half the patients in Japan have been discharged, there are still many critically ill patients who need ventilators and ECMO.

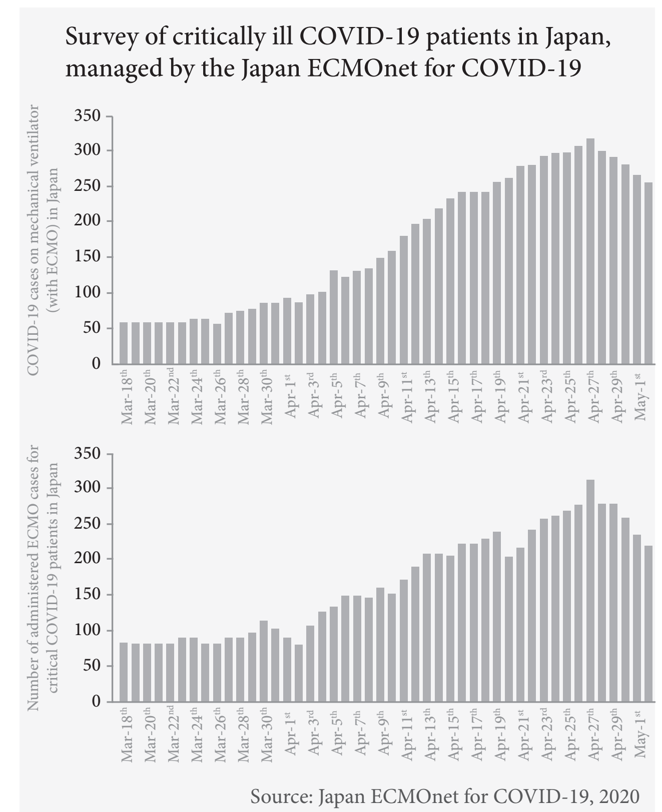


[Figure 4] Trend in the number of people infected worldwide (WHO data)(Regional names are WHO classifications)

6) NIID, 2020
7) WHO, 2020



[Figure 5] Genomic molecular epidemiology of the Genomic molecular epidemiology of the coronavirus



[Figure 6] Trend in the number of confirmed patients requiring a ventilator nationwide (above) Trend in the number of patients on ECMO nationwide (below)

III. AMED's activities related to COVID-19

1. AMED's initiatives in medical R&D

- On January 31, 2020, AMED signed a joint statement committing to rapidly and widely share research results and data related to the novel coronavirus. The joint statement signatories, including research supporting institutions such as AMED and the NIH, are implementing their own sharing policies while also calling for researchers to share their data.
- AMED participated in a teleconference hosted by the U.S. and a G7 scientific leaders' meeting on the novel coronavirus.
- AMED regularly obtains the latest information on COVID-19 research and understanding on the ground from its Washington DC and London Offices, and shares that information in a timely manner with the Headquarters for Healthcare Policy, MEXT, MHLW, METI, the Ministry of Internal Affairs and Communications, and the Japan Patent Office.
- AMED started support for the development of existing and new drugs, as well as a vaccine for the novel coronavirus (detailed on the next page).

[Table 1] Japan's international collaboration on the novel coronavirus

The key points of the joint statement promising to rapidly and widely share research findings and data on the novel coronavirus	Framework for international collaboration to combat the novel coronavirus
We call on researchers to rapidly and widely share their research outcomes and data relating to COVID-19, and to ensure the following: • Research findings relevant to the outbreak are made immediately and freely accessible in academic publications • Research findings are made available via preprint servers before journal publication, or via platforms that make papers openly accessible before peer review, with clear statements regarding the availability of underlying data • Researchers share interim and final research data relating to the outbreak, together with protocols and standards used to collect the data, as rapidly and widely as possible - including with public health and research communities and the WHO • It is made clear to authors that data or preprints shared ahead of submission will not pre-empt its publication in these journals	Regular US-hosted teleconference on the novel coronavirus Main participants Science and technology advisors from about 20 countries including Japan, US, UK, France, and Korea From Japan, CSTI Executive Member Ueyama attended (AMED also participated). Outline Held about once a week since the beginning of March, at the invitation of Dr. Droegemeier, Director of the White House Office of Science and Technology Policy. Participants jointly issued a letter to academic publishers urging them to promptly publish articles and data in WHO databases, etc., and exchange opinions on testing methods and the development status of therapeutic drugs. G7 Science Leaders Meeting (April 30, 2020) Main participants Japan : Naokazu Takemoto (Minister of State for Science and Technology Policy) Takahiro Ueyama (CSTI Executive Member), Yoshinao Mishima (AMED President) U.S. : Kelvin Droegemeier (Director, White House Office of Science and Technology Policy) EU : Mariya Gabriel (Commissioner-designate for Innovation and Youth) Outline Participants exchanged opinions on science and technology relating to COVID-19 and confirmed the importance of international collaboration.

2. Collaboration with related organizations

- Research support organizations and publishers of academic journals around the world jointly singed a statement committing that research data and findings will be shared, and that efforts will be made to ensure that this will not disadvantage researchers' publication records (February 3, 2020)[8].
- It was confirmed that the following three initiatives to combat COVID-19 will be undertaken on a Japan-wide basis through mutual cooperation and by strengthening collaboration among industry, academia and government, including the Japan Pharmaceutical Manufacturers Association and Japanese pharmaceutical companies, as of March 27, 2020
  - A. Provision of low molecular weight compounds (drug repositioning)
  - B. Vaccine development using a BSL-3 facilities
  - C. Research and development of neutralizing antibody drugs[9]
- A web page on AMED support for R&D on the novel coronavirus disease (summary) will be created, where information on calls for research proposals and research findings can be accessed easily, and all information will be updated as necessary (March 17, 2020)[10].

IV. AMED R&D related to comtrol for the novel coronavirus

1. AMED expenses of **109.3 billion** yen out of total government support of 144.4 billion yen

*Figures are rounded up, so totals may therefore differ

- 1st round (February 13, 2020) Total of 460 million yen (FY2019 budget surplus)

<government as a whole : 2.03 billion yen>

The government has put together a list of measures that should be taken immediately, with the highest priority being to protect the lives and health of the people. AMED aims to develop simple diagnostic kits similar to an influenza test, antiviral drugs, recombinantprotein vaccines, etc., and to assist structure-based discovery of efficacious repurposed drugs.

R&D details

A. Development of diagnostic methods and equipment (basic research and development of a rapid diagnostic kit, development of serum antibody detection kits and systems)
B. Development of therapeutic methods (selection of therapeutic drug candidates using in silico analysis, development of antiviral drugs)
C. Vaccine development (development of recombinant protein and mRNA vaccines)

- 2nd round (March 10, 2020) Total of 2.81 billion yen (FY2019 adjustment fund, reserve fund)

<government as a whole : 3.11 billion yen>

In addition to accelerating the research and development started in the 1st round, we aim to carry out clinical research to utilize anexisting drug, Favipiravir (Avigan) for COVID-19, to speed up development of rapid testing equipment, and to establish an R&D platform that can immediately respond to emerging epidemics.

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8) AMED, February 2020.
9) AMED, March 2020.
10) AMED, November 2020.

R&D details

A. Development of infrastructure that supports research (development of analysis infrastructure for pathogens and infectious clinical specimens, and enhancement of drug discovery infrastructure in the field of infectious diseases)
B. Clarification of molecular epidemiology and pathology (genomic analysis of infectious diseases, immune repertoire analysis, and integrated data sharing)
C. Development of methods of treatment (Favipiravir clinical research)
D. Development of diagnostic methods and testing equipments (development of rapid diagnostic equipment)
E. Development of infrastructure to support research (development of new technology infrastructure related to R&D for emerging infectious diseases)

– 3rd round (March 17, 2020) Total of 3.25 billion yen (FY2020 reserve fund)

<government as a whole : 3.25 billion yen>

Given that the development of therapeutic drugs, vaccines, medical devices, etc. is an urgent need, we aim to further accelerate and expand R&D concerning COVID-19 through top-down funding.

R&D details

A. Development of methods of treatment (additional sites for Avigan clinical research, observational studies of Alvesco and Avigan, etc.)
B. Development of infrastructure to support research (installation of cryo-EM at BSL-3)
C. Development of treatment methods (development of new drugs for COVID-19)
D. Clarification of molecular epidemiology and pathology (collection and analysis of samples - blood samples, etc. from Japan and overseas)

– 4th round (April 30, 2020) Total of 46.9 billion yen (FY2020 supplementary budget)

<government as a whole : 75.1 billion yen>

In order to overcome COVID-19 and put the hard-hit Japanese economy back on a growth trajectory, we aim to add measures to accelerate the development of devices and systems in addition to the development of therapeutic methods and vaccines for COVID-19.

R&D details

A. Vaccine (support for preparation of vaccine candidates, animal studies, development of related technologies such as adjuvants, non-clinical trials and clinical trials, and development of supply technologies)
B. Development of diagnostic methods and testing equipment (development of medical equipment in response to various needs at each stage of diagnosis, provision of medical services, treatment, etc.)
C. Development of infrastructure that supports research (strengthening compound library and compound screening functions, building clinical study and clinical trial networks in Asia, etc.)
D. Creation of pharmaceuticals, medical equipment, etc. using government funding

– 5th round (March 17, 2020) Total of 55.9 billion yen (FY2020 second supplementary budget)

<government as a whole : 60.9 billion yen>

While the end of this once-in-100-year crisis is not yet in sight, we aim to accelerate the development of treatment methods and vaccines for infectious diseases in order to prevent the spread of infection, and at the same time to fully restore socio-economic activities.

2. Contents

A. Molecular epidemiology and pathology

- Supporting research to track viral propagation pathways, infection mechanisms, and aggravation mechanisms.
- As there are two strains circulating – one from Wuhan and one from Europe – strain identification will aid analysis of transmission pathways and prevalence, and possibly also vaccine development.

B. Development of diagnostic methods and testing equipment

- Supporting the development and commercialization of inspection technology and equipment with high accuracy, high sensitivity, and high processing capacity for early detection of COVID-19.
- Validation of a PCR detection device able to rapidly detect viruses. Commercialization and insurance coverage from March.
- Development of a testing kit to detect antigens quickly and easily. Manufacturing and marketing approval in May.
- Development of a rapid diagnostic method enabling visual diagnosis, without the need for detection equipment, from samples (such as saliva) within 25 minutes.

C. Development of treatment methods

- Supporting repositioning of existing drugs or development of new drugs for treating patients. Also, supporting development of medical devices to relieve symptoms.
- Through in silico screening (using computer/numerical analysis to identify candidate compounds), identification of 118 hit compounds from about 8,000 compounds in existing drug databases.
- Discovery that an existing drug (Nafamostat) blocks viral entry in the early stages of infection.
- Support for clinical research on existing drugs (Avigan, Alvesco). Support for research and development to improve the performance and safety of ventilators and cardiopulmonary bypass (ECMO).

D. Vaccine development

- Supporting the development of vaccine candidates and technological development for stable domestic supply to prevent the future spread of infection.

E. Infrastructure to support coronavirus research

- Supporting basic research, development of equipment, production of model animals, and establishment of evaluation systems to support the clarification of pathology, treatment, and development of vaccines.

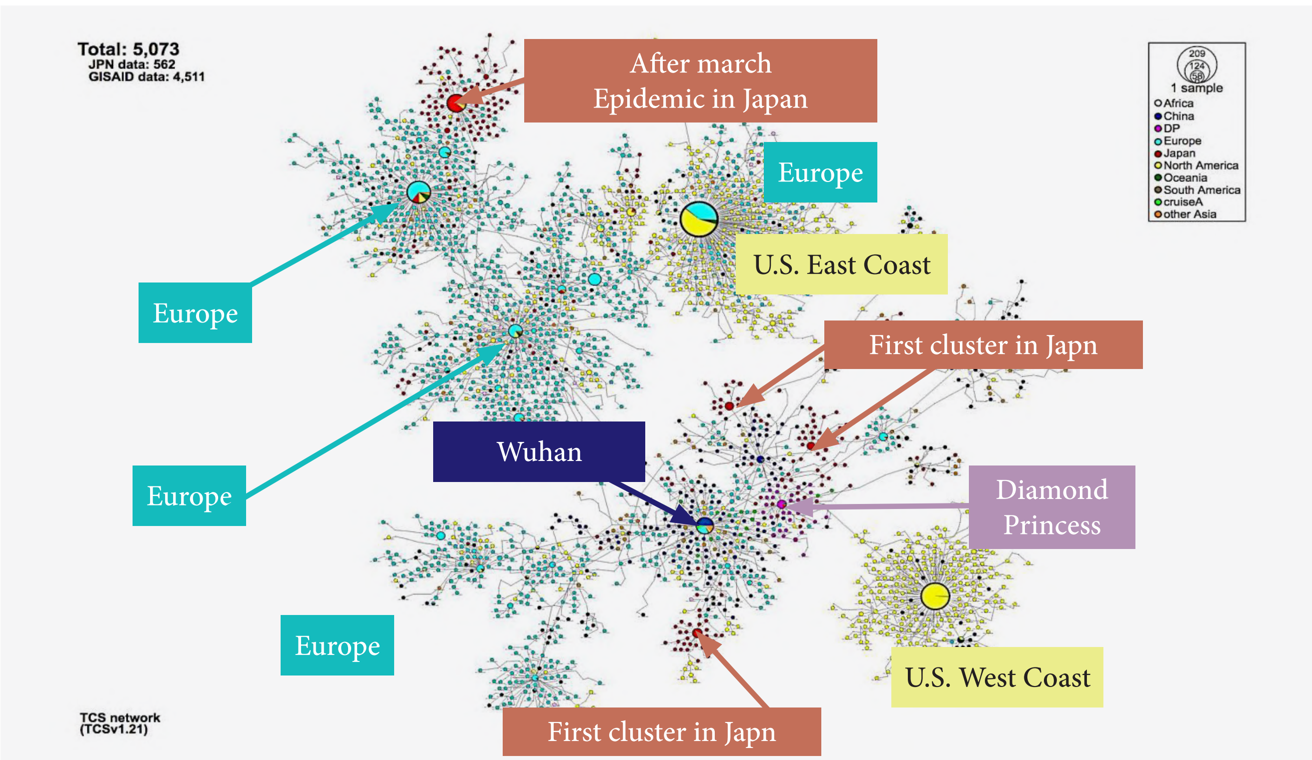
F International cooperation, industrial support, etc.

- Promoting R&D to develop innovative medicines and medical devices, including measures against the novel coronavirus, through collaboration among industry, academia and government.

3. Molecular epidemiology and pathology

- In this field, it is possible to accelerate R&D with real-time genomic analysis by establishing a worldwide virus genome data sharing framework (GISAID)[11].
- Viruses are constantly mutating while growing in human and other cells, and tracking their types may aid analysis of their infection pathways and transmission, and the development of vaccines[12].
- How did the virus spread, how did it mutate, and how did the infection spread? To answer these questions, it is necessary to clarify themolecular epidemiology and pathology of the virus by collecting and analyzing samples (such as blood samples) from Japan and overseas.

A. Genomic epidemiology of the novel coronavirus



Reference: Phylogenetic network analysis of SARS-CoV-2 genomes PNAS first published April 8, 2020

A comparison of the genomes of SARS-CoV-2 isolates in Japan (562) with all GISAID-available genomes (4,511):	1. From the Diamond Princess cruise ship (1) Virus from Wuhan (2) No epidemic in Japan 2. First clusters in Japan (Hokkaido, etc.) (1) Virus from Wuhan (2) Measures against clusters: Effective 3. Increasing spread in Japan since March (1) From people returning from Europe (2) Clusters in various regions

Souce: Pathogen Genomics Center, May 2020

4. Development of diagnostic methods and testing equipment

- In the early stages of the spread of infection, a PCR test kit was developed that can detect the novel coronavirus in about 15 minutes excluding pretreatment time, and some testing is covered by insurance.
- The Japanese Association for Infectious Diseases conducted a preliminary study to evaluate the performance of four types of test kits that are commercially available overseas, concluding that they do not recommended using them for novel coronavirus testing, and that although they may be used for epidemiological studies, further detailed examination is necessary[13].
- Rapid implementation of research and development contributing to infectious disease countermeasures, and development of technologies for conducting rapid, large-scale studies.

A. Progress and achievements

- Kyorin Pharmaceutical demonstrated the performance of GeneSoC, a PCR testerthat rapidly detects viruses, commercialized it, and obtained insurance coverage (approved March 18) (2nd round: Reserve fund).
- Fujirebio has developed a test kit that detects antigens quickly and easily, and it was approved for manufacture and sale on May 13. (1st round: Budget surplus)
- Yokohama City University developed a serum antibody diagnostic technology andhigh-throughput and automation technologies in collaboration with Tosoh (1st round: Budget surplus, 4th round: 2020 supplementary budget).

Image courtesy of KYORIN Pharmaceutical Co. of Japan

Image courtesy of Yokohama City University of Japan

- Call for proposals for the development of equipment relevant to control of infectious diseases, using 2020 supplementary budget.

5-1. Development of treatment methods (therapeutic drugs)

- Since it takes time to develop a new drug or vaccine, it is a top priority to find existing drugs that are effective against the novel coronavirus, with proven basic safety profiles.
- In order to expand the application of existing

11) GISAID, 2020
12) Forster et al., 2020
13) Preliminary study on the performance of four test kits based on the detection of novel coronavirus antibodies (April 23, 2020, Japanese Association for Infectious Diseases)

approved drugs to the novel coronavirus (drug repositioning), we conducted in silico screening of existing drugs and linked the results to an evaluation system using actual viruses.

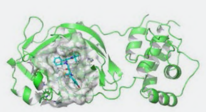
- In addition, since February this year, wet lab research was carried out at the National Institute of Infectious Diseases with the support of AMED.
- Support for clinical studies on existing drugs (Avigan, Alvesco).
- In the future, support for the development of new therapeutic drugs with the practical application of new antiviral drugs in mind (currently applications are being reviewed).

A. Progress and achievements

① In silico screening[14] (AMED/BINDS project, from February this year)
→ 118 hit compounds identified from approximately 8,000 compounds in the existing drug database

▼

② Screening in a wet lab (from February this year, 1st round : Use of the FY2019 budget surplus)
→ (Result) A synergistic antiviral activity was found with a combination of Nelfinavir and Cepharanthine.



Main protease composite structure of Nelfinavir and the novel coronavirus:The findings of BINDS

③ Clinical research on existing drugs (Avigan and Alvesco) (from March this year, 2nd round : 2019 top-down reserve fund)
→ Avigan specific clinical study_Target number of cases 106, Avigan and Alvesco observational study

④ Call for drug discovery research proposals (scheduled to start on June 15) (3rd round, 2020 top-down reserve fund)
→ Accelerate commercialization by setting new projects including industry-sponsored projects

Reference: Status of overseas clinical trials-
A new antiviral drug, Remdesivir, and existing approved drugs, Kaletra,camostat, etc. are being tested

5-2. Development of treatment methods (devices)

- Due to the worldwide spread of COVID-19, it is challenging to secure enough ventilators for the treatment of pneumonia. There may be a shortage of ventilators in Japan[15].
- Undertake R&D to improve performance and safety, and to ensure the availability of ventilators and extracorporeal membrane oxygenation (ECMO) machines for critically ill patients.

A. Progress and achievements

- Nipro and others have developed and commercialized the world's smallest and lightest high-performance next-generation cardiopulmonary assist system (ECMO).
- ECMO can only be used for about 6 hours continuously, so the National Cerebral and Cardiovascular Center, MERA and others will developtechnology to extend the possible duration of its continuous use (4th round : 2020 supplementary budget).

Compared to the existing system
Artificial pump-oxygenator / Existing auxiliary system / Developments

Note
Call for research proposals as part of the Program "Develo p Cou nt erm easure Tech nologies again st Viral an d Oth er In f ect ions" using the FY2020 supplementary budget. There was a total of 113 applications, including proposals focusing on treatments, tests, protection of medical staff, prevention of infection in hospitals, remote monitoring technology, IT, and application development. Research is expected to start in June.

6. Vacccin development

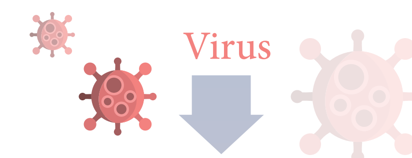
- Vaccines with various molecular mechanisms are being developed internationally (according to the World Health Organization (WHO), there are 110 novel coronavirus vaccine candidates in development around the world)[16].
- Domestic production is necessary to ensure a stable supply of vaccines for the Japanese population.
- AMED has been supporting research on the development of various vaccines since February 2020.

A. Progress and achievements

Research Program on Emerging and Re-emerging Infectious Diseases (460 million yen)
*1st round : FY2019 budget surplus (implemented since February 2020)

- Professor Hasegawa, National Institute of Infectious Diseases : Study on development of vaccines using recombinant protein as antigen.
- Professor Kawaoka, Institute of Medical Science, The University of Tokyo : Research on the development of vaccines and related technical foundations that apply mRNA technology.

Currently, animal models are being developed



Animal model

Program on Development of Vaccines for COVID-19 (10 billion)
*4th round : 2020 supplementary budget.

- Industry-sponsored projects and university-initiated projects will be supported with the goal of rapid development and practical application.
- Support for a wide range of development stages: basic research, non-clinical trials, etc., as well as technical assistance for the supply of vaccines.

14) Narrowing down candidate compounds by computational analysis.
15) Estimate based on: a survey of the number of ventilators by the Japanese Society of Respiratory Care Medicine and the Japan Association for Clinical Engineers, announced on March 6, 2020; the estimate released by the MHLW on March 6 for the peak number of outpatients; and population statistics by prefecture from the Ministry of Internal Affairs and Communications.
16) R&D Blue Print (WHO), 2020

→ The call for proposals closed at the end of April, and applications are currently under review.
→ Start of funding in late May (planned)

B. Reference : Overseas vaccine development (prominent examples)

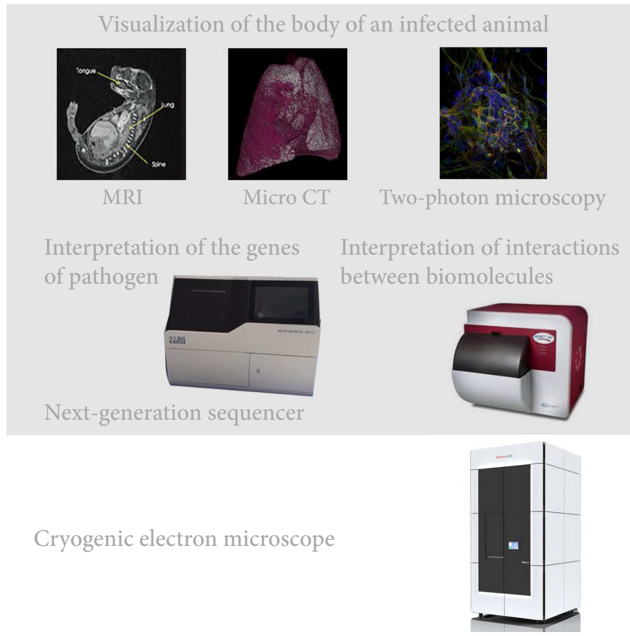
Company (country)	Status of development	Type of vaccine
Moderna (US)	Phase I clinical trial	mRNA vaccine
Inovio Pharmaceuticals (US)	Phase I clinical trial	DNA vaccine
BioNTech/Pfizer (Germany/US)	Phase I clinical trial	mRNA vaccine
GeoVax (US)	Non-clinical testing	Recombinant vaccinia vaccine

7. Infrastructure development to support coronavirus research

- Accelerate COVID-19 R&D and establish an R&D platform that can respond immediately to new infectious disease epidemics.
- Furthermore, in order to accelerate the search for target molecules that may contribute to the treatment of infectious diseasesand the subsequent R&D of therapeutic drugs, provide a cryogenic electron microscope in one of the world's few BSL-3 facilities (rarely seen around the world).

A. Establishment of specific research platform (examples)

① A vaccine and treatment development platform, relevant to infectious diseases and directly linked to clinical practice (2nd round: FY2019 reserve fund)
→ Within-BSL-3 facilities and their associated facilities, establish a platform directly connecting to the clinical frontline in order to analyze and characterize emerging infectious diseases, establish diagnostic methods, develop vaccines, and develop therapeutic methods.



② Cryogenic electron microscope facilities to support pathogen analysis
- Institute for Frontier Life and Medical Sciences, Kyoto University (BSL-2 facility, 2nd round: FY2019 reserve fund)
- Hokkaido University Research Center for Zoonosis Control (BSL-3 facility, 3rd round: FY 2020 reserve fund)

→ Install a 300 keV high-end cryogenic electron microscope at the BSL-3 facility at Hokkaido University, and enhance and expand the search for target molecules in discovery of anti-infective drugs by enabling more detailed structural analysis of viral proteins.

③ A non-human primate experimental infection platform (2nd round: FY2019 reserve fund)
→ Establish an experimental infection platform using non-human primates for analysis of COVID-19 pathogenicity and understanging its behaviour in other contexts. (National Institutes of Biomedical Innovation, Health and Nutrition, Research Institute for Microbial Diseases, Osaka University (BSL-3 facility))

8. International cooperation, industrial support, etc.

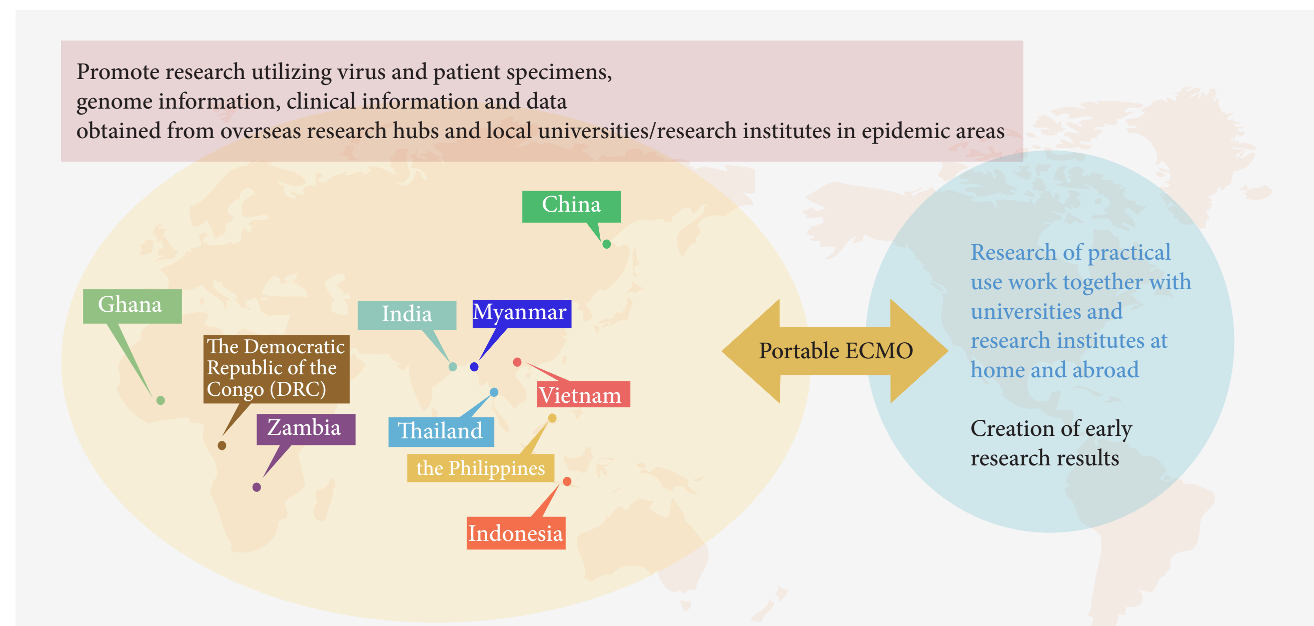
- Promotion of rapid research outcomes, using patient samples and clinical information obtained at overseas research centersin Asia and Africa, that will contribute towards new preventive, diagnostic and therapeutic advances, and towards countermeasures against future epidemics in Japan.
(Strengthening and accelerating research on countermeasures against the novel coronavirus infection)

A. Program overview

- Promotion of joint research using local samples and information obtained in infectious disease endemic areas in Asia and Africa (10 countries), based on a relationship of trust with universities, research institutes and hospitals in those locations and with researchers working there.
- Support for research on the novel coronavirus, leveraging overseas research centers, in order to generate rapid outcomes that will contribute to new preventive, diagnostic and therapeutic advances, and to future infectious disease countermeasures in Japan (using FY2020 reserve fund and primary supplementary budget).

B. Progress and achievements in countermeasures against novel coronavirus infection

- Support for research demonstrating that nafamostat (a drug for treating acute pancreatitis) blocks viral entry during early stages of infection. (FY2019 initial budget, University of Tokyo).



Promote research utilizing samples and information obtained from overseas research hubs (Asia, Africa)

C. Overview of overseas research centers

(year of establishment)

Hokkaido University/ Zambia Research Center (2007)	Collaboration with the University of Zambia School of Veterinary Medicine. Epidemiology of zoonosis, research on drug-resistant tuberculosis.
Tohoku University/ Philippines Research Center (2008)	Collaboration with the Philippines Research Institute for Tropica lMedicine. Features a cohort study of infant pneumonia and diarrhea.
Niigata University/ Myanmar Research Center (2015)	Collaboration with the Nationa Health Laboratory of Myanmar. Epidemiology of influenza and respiratory viruses.
University of Tokyo/ China Research Center (2005)	Collaboration with the Chinese Academy of Sciences and Chinese Academy of Agricultural Sciences. Research on preventive therapeutics and diagnostics for new influenzas, and vira infection control.
Tokyo Medical and Dental University/Ghana Research Center (2008)	Collaboration with the Noguchi Memorial Institute for Medical Research, University of Ghana. Molecular epidemiology of dengue fever and chikungunya.
Osaka University/ Thailand Research Center (2005)	Collaboration with the National Institute of Health of Thailand and Mahidol University. Research on mosquito-borne diseases and drug-resistant bacteria.
Osaka City University/ Democratic Republic of Congo (2020)	Collaboration with the Nationa Institute of Biomedical Research. Feasibility study on establishing the research center this year.
Kobe University/ Indonesia Research Center (2007)	Collaboration with the Airlangga University Institute of Tropical Disease. Research on bird flu and dengue fever.
Okayama University/ India Research Center (2007)	Collaboration with the National Institute of Cholera and Enteric Diseases. Research on new Cholera strains and transmission mechanisms.
Nagasaki University/ Vietnam Research Center (2005)	Collaboration with the National Institute of Hygiene and Epidemiology. Research on dengue fever, bird flu, pediatric respiratory tract infections. Succeeded in the first isolation of the novel coronavirus in Vietnam in 2020.

STI Policy in the Age of COVID: The Chinese Case

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"You never let a serious crisis go to waste. And what I mean by that, it's an opportunity to do things you think you could not do before."

– Rahm Emanuel, then President Barack Obama's Chief of Staff, former Mayor of Chicago

China faces the year 2021 with both many achievements and daunting challenges. It is about to begin its 14th Five-Year Plan which involves significant adjustments to the trajectory of its development. It is also doubling down on its commitments to scientific research and technological innovation as means for attacking the challenges, including the launching of a new medium to long-term plan for science and technology development intended to both secure China's position in the industries of the future and to bring novel technological solutions to major societal problems. China has spent several decades building its capabilities for science, technology, and innovation, and now enjoys a convergence of talent, facilities, and generous funding that can be directed to the fulfillment of goals for the 14th Plan and beyond. Yet, Plan implementation will not be without problems as an examination of the strengths and weaknesses of China's response to COVID-19 illustrates.

The link between crisis and opportunity is recognized by strategic thinkers around the world. Although the Chinese term for "crisis" *(weiji)*, containing the characters for "danger" and "opportunity" is often misunderstood in the West, there is nevertheless a suggestive resonance in the ways in which the crisis-opportunity connection manifest itself in recent developments of Chinese science, technology, and innovation (STI) policies. The appearance of a new SARS like coronavirus in China in early 2020, and the health emergency it produced, has led to new opportunities for promoting China's goals for biomedicine. Developments in biomedicine, however, are best understood in terms of a wider array of crises and opportunities for strategic science policy responses. The current moment in Chinese STI policy development is therefore especially interesting since it comes at an inflection point where crises have intensified, but where Chinese capabilities for seizing opportunities have reached new levels.

While not all of the serious challenges China faces can be regarded as crises, the difficulties they present nevertheless have been recognized by China's top leaders who are attempting to fashion opportunistic responses which build on and expand advances in science and technology. These are evident in current discussions about the 14th Five-Year Plan and in the development of a new long-term plan for science and technology. When we consider the various severe challenges facing China, we can begin to appreciate why the Chinese leadership now talks increasingly about the need to introduce and implement a new national development model, "innovation driven development" (IDD), with research and innovation playing central roles.

These challenges include some that have been with China for some time, while others - taking on more of a crisis importance - are more recent. The environmental degradation that has accompanied China's rapid growth over the past four decades has now become a matter of intense concern, especially when problems such as air pollution reach crisis levels. China's aging population, a function of its one child policy introduced four decades ago, is canceling out the economy's "demographic dividend" provided previously by a young workforce. Key forces of economic growth - the youthful workforce, inexpensive labor, and the ability to access markets and know how in a benign international environment - are no longer available as the workforce ages, labor has become more expensive, export markets have shrunk as a result of pandemic-induced limits on economic growth. Opportunities to capture advanced technologies are closing off as countries in the OECD world become increasingly concerned over the competitiveness and security implications of China's rise and adopt measures to limit technology transfers to China. To this list, of course, should be added the domestic impacts of the coronavirus, the deteriorated relations with the United States as it affects access to US science and technology, and fears that some combination of the above will lead China into a "middle income trap."

It is in this context that plans for a new Five-Year Plan, the 14th, are being developed. Along with plans for the 14th FYP is a longer-term outlook for Chinese development through the year 2035 as reflected in an outline for a new 15 year "Medium to Long Term Plan for the Development of Science and Technology." In addition Chinese planners have laid out a series of major programs under the rubric of "Science, Technology, and Innovation 2030 Mega Programs."

Past efforts to build STI capabilities: a snapshot

The IDD builds on several decades of efforts to upgrade Chinese technologies through international technology transfer and the modernization of the system for indigenous, domestic research and development (R&D). A major effort in support of the latter was the introduction in 2006 of the "Medium to Long-Term Plan for the Development of Science and Technology, 2005-2020" (MLP), a key foundation stone for the introduction of IDD policies some 10 years later. The MLP promoted the idea of "indigenous innovation" and provided for a series of major R&D projects which were intended to reduce dependency on foreign technologies through expanded support for China's domestic research and innovation. The MLP included a series of engineering "megaprojects"

- Core electronic components
- High-end generic chips
- Basic software
- Extra-large IC manufacturing technology
- Next generation wireless telecommunications
- Advanced numeric controlled machinery and manufacturing technology
- Large-scale oil and gas exploration
- Advanced nuclear reactors
- Water pollution control and treatment

- Genetically modified organisms
- Drug innovation and development
- Major disease control
- Large aircraft
- High definition observation systems, and
- Manned aerospace and moon exploration.

Megaprojects in science, included protein science, quantum research, nanotechnology, and developmental and reproductive biology.

In the 15 years of the program, the MLP has been modified and a variety of new national plans and projects have been introduced including the "Strategic Emerging Industries" program and "Made in China 2025" during the 13th FYP. While some of the megaprojects have been disappointing (in particular the work on integrated circuits, large aircraft), one can see that many of the areas where Chinese accomplishments are now attracting attention (e.g. 5G, quantum research) enjoyed support from the MLP and its follow-on programs. China thus approaches the initiation of the 14th Plan period having achieved pockets of excellence in:

- 5G telephony
- Advanced computing
- Artificial intelligence
- Brain research
- Catalysis and chemical engineering
- Fuel cells
- Life sciences/biotechnology
- Manned space
- Materials science/nanotechnology
- Mathematics
- Microsatellites
- Physics
- Rare earth chemistry, and
- The Internet (Cao, 2020a).

The story of China's current innovation system necessarily requires reference to several decades of reforms. China entered the 1980s with systems for research and innovation that were manifestly unsuited for meeting China's national aspirations and for catching up with scientific and technological advances in the world beyond its borders. Thus began an iterative process of reforming research, higher education, and general economic institutions which continues to the present. While this reform experience has produced fundamental changes in the ways China approaches research and innovation, it has failed to solve some enduring problems and, in some cases, have created new ones - reforms have engendered problems requiring further reforms (Cao and Suttmeier, 2017). As a result, the efforts to harness science and technology to address the kinds of problems identified above call for a new reform agenda, especially with regard to:

- The administration of research funds;
- Finding the right balance between market forces and state policy in promoting innovation;
- Clarifying the roles of state owned enterprises and private firms in the innovation system;
- Defining the ongoing engagement with international science and technology in comparison to greater self-reliance, and
- Finding the right balance between policies and institutions focused on national needs and mission oriented solutions and those for curiosity driven basic science.

The 14th plan and the new MLP

The two key themes of the 14th Plan are the stimulation and restructuring of the domestic economy and the doubling down of the idea of the IDD, first introduced in the 13th FYP beginning in 2015. The former, referred to as the "dual circulation" concept, is intended to complement an export led international trade agenda ("international circulation") with more rapid growth in domestic demand ("domestic circulation") in order to compensate for weaknesses and uncertainties in the international economy. The IDD is intended not only to push Chinese products into higher levels of sophistication and value-added (for both exports and domestic consumption), but is also intended to enhance a broader ecosystem for innovation that reinforces the "dual circulation" objectives and enables China to "leapfrog" into leadership positions in the science-based industries of the future. Programmatic manifestations of current STI deliberations can be seen in the major programs identified for inclusion in the "STI 2030" strategy. These include:

- Aviation Engines and Gas Turbines
- Deep-Sea exploration
- Quantum Communication and Quantum Computing
- Brain Science and Brain Inspired-intelligence
- National Cybersecurity
- Deep Space Exploration
- Independence of the National Seed Industry
- Clean and Efficient Use of Coal
- Smart Grid
- Integrated Space-Earth Network
- Big Data
- Smart Manufacturing and Robotics
- Research and Applications of New Materials
- Beijing-Tianjin-Hebei Integrated Environmental Management
- Healthcare
- Artificial Intelligence 2.0 (Cao, 2020a)

As China attempts to craft new STI policies for the 14th Plan and beyond, it's policymakers are guided by several main considerations:

S&T Breakthroughs

The first of these is the challenge of capturing a leading position in areas of cutting-edge science and technology, such as those noted above. Success in these areas requires increasing spending on R&D - perhaps to 3% of GDP from the approximately 2.18% in 2018 - and the re-examination of the managerial approaches that served China well in catching up to, or approaching, international frontiers. A new emphasis on basic research requires intellectual risk-taking, tolerance of failure, a willingness to accept extended time horizons for assessing the success of a projects, and flexibility in approaching interdisciplinary and inter-institutional cooperation. Chinese policy makers recognize the need to focus on a broad ecosystem of research and innovation incorporating new approaches to institutions and policies, and changes in research culture (Suttmeier, 2020).

Pressing societal problems

A second consideration is the need to bring science and technology resources to bear on societal problems. In areas of medicine and public health (discussed further below), for instance, emphases will be placed on brain science (including work on neurodegenerative diseases affecting an elderly population) and public health and medical applications of artificial intelligence, including the development of new medicines, and the prevention and treatment of serious diseases. Agricultural research will focus on crop improvement and innovations in the seed industry, driven in part by concerns that China's seed stock depends too heavily on foreign technologies.

The need to address problems with environmental degradation will be addressed with new projects focused on water pollution, on domestic environmental governance, and on approaches to global climate issues. China's energy profile is central to both climate change and to the domestic economy and environment. Its heavy reliance on coal calls for ongoing R&D on clean coal technologies and its growing attention to clean energy sources requires further work on applying AI and other technologies to smart grid development.

Reform

As noted above, the ongoing need for institutional reforms will focus attention on the institutional infrastructure for research and innovation. China's research system is composed of a vast collection of science and technology-related institutions. Over the past four decades these have been reformed and added to in order to meet then current needs. Going forward, though, many of these may not be suitable for the IDD, as envisioned. For instance, Xi Jinping has repeatedly called for the creation of multidisciplinary "national laboratories," but progress has been slowed in part, one suspects, because of the existence of major big science facilities which might be considered as national labs, the extensive system of institutes within the Chinese Academy of Sciences (CAS), hundreds of "state key laboratories" and engineering research centers, some of which resemble national labs. However, these legacy institutions, even when they are doing world-class, or near world-class, work, tend to be narrowly discipline-focused rather than multidisciplinary centers suitable for responding to the new national missions. In addition, there are numerous national and local high-technology parks, incubators, etc. which often promote commercial activities but are not necessarily linked to cutting-edge research centers. Hence, the need to rethink the creation of modernized platforms for innovation focused on critical national needs.

Research geography

As China reconsiders its STI institutions and platforms, increased attention has been given to the spatial distribution of research and innovation activities. China's provinces, especially the wealthier eastern provinces, have become important players in the development of the national innovation system, with provincial and city governments becoming important providers of funding for research and S&T infrastructure (land, facilities, etc.). As these activities have expanded, options for institutional cooperation and synergies transcending political and administrative boundaries have increased. Hence, the growth of interest in regional cooperation in the building of local innovation systems. Regional coordination and development in the Beijing-Tianjin-Hebei, the Yangtze River Delta, and the Guangdong-Hong Kong-Macau regions have received particular attention.

Research-user linkages

A long-standing problem of the Chinese innovation system, now partially ameliorated by past reforms, is the failure to ensure the effective transfer of research results into commercial products and more generally effective connections between researchers and users. Efforts to make these connections have characterized reform efforts since the 1980s and have gradually shown some results. Progress has resulted from the gradual marketization of the economy and the resulting incentives for enterprises to innovate, the notable expansion of R&D spending by business units and the addition of research personnel to the workforce, the establishment of high-tech zones, university science parks, incubators, etc. and the introduction of favorable laws and policies (including for intellectual property protection), and new funding schemes including venture capital mechanisms to support innovative activities in enterprises. Nevertheless, problems remain. Enterprises, for instance, have often preferred to acquire proven technologies from abroad instead of working with the domestic R&D system. China's research culture has historically had more of an academic, rather than a commercial, orientation and universities and research institutes often lack the institutional mechanisms for effective technology transfer. While one can clearly document some dramatic improvements in the connectedness of the research system with the economy, Chinese policy documents and the words of Chinese leaders continue to note disappointments in the ways in which Chinese research is not delivering on the kinds of advanced commercial innovations expected from the large agenda of reforms.

International cooperation issues

A final concern in preparing for the 14th Plan and beyond is finding the right strategy for international cooperation and engagement with the international technical community. Over the course of the reform era, China has developed strategies for exploiting the many science and technology resources in the international environment, and has benefitted greatly from international technology transfers of one sort or another, and from access to training and cooperative research with the world's leading universities. In the process, China has experienced the growth of a cadre of scientists and engineers capable of understanding, and working at, the international frontiers. China has also learned a great deal about international best practices for STI policies, institutional models, and innovation management, all of which have been adapted to Chinese conditions and contributed to the acceleration of China's progress in science and technology.

The continued success of this engagement has now been thrown into doubt. The deterioration of relations with the United States, for instance, is strongly conditioned by science and technology issues. While concerns over IPR violations are often cited as central to US concerns, China's overall progress in science and technology is seen by the US, and increasingly by other OECD countries, as a more fundamental competitive economic threat and national security concern. China's efforts to forge a high-technology military through its policies of "civilian-military fusion" adds to these concerns. As a result, the US under the Trump administration has introduced severe limitations on China's access to critical technologies and have raised alerts among US universities about the dangers of knowledge transfers in sensitive fields. The kinds of concerns seen in the US are beginning to appear in Europe, Australia, and parts of Asia as well.

The Chinese response to this altered international environment, in declarative terms, has been to reiterate a strong commitment to international cooperation and, as discussed below, has been developing a strategy to link its science and technology resources with foreign policy to achieve diplomatic ends. At the same time, criticisms of China's dependencies on foreign, especially US, technologies have increased along with calls for much greater self-reliance through enhanced indigenous research efforts, and the strengthening of national self-confidence in moving towards the goals of IDD. In spite of policy statements in support of international cooperation, China is also experiencing policies which reflect a growing national security consciousness that is in many ways antithetical to the spirit of international cooperation. For Xi Jinping, the challenge - indeed crisis - of being denied access to US technology is seen as an opportunity to overcome problems with China's national innovation system in ways that incremental reforms of the past did not.

COVID-19, Biomedicine, and biotechnology aspirations

China's response to the coronavirus (SARS-CoV-2) outbreak provides insights into the operation of the STI system and resonates with a number of issues affecting STI policies and platforms noted above. When China experienced the outbreak of a new coronavirus in late 2019, it quickly confronted a public health crisis, seemingly out of control. As with the United States, China began to experience both failures in the public health system and the rewards of past efforts to develop its biomedical capabilities. The latter enabled China to quickly sequence and characterize the viral agents, but initial public health decision-making, as we know, was characterized by failures. Following the SARS (SARS-CoV-1) outbreak of 2003, China made considerable efforts to build a infectious disease reporting and decision-making system, including the creation of a Chinese version of Center for Disease Control. The initial failures of the system in late 2019 in early 2020, driven largely by a lack of transparency in sharing information and concerns for secrecy, demonstrated ongoing problems with the system developed after 2004. These centered on bureaucratic fumbles and concerns for political interests in China's complex system of local government-national government relations, As we know, these initial failures were followed by draconian measures to shut down much of the country, measures which ultimately proved successful in limiting contagion. In this sense, China's ability to manage the crisis was less a matter of science and technology than of political will and power.

On the other hand, we can also see that the crisis did, and continues to, provide opportunities for the pharmaceutical industry and biomedical research community to serve the management of the crisis and, in the process, take advantage of the commercial, scientific and political opportunities it offered. While virologists, immunologists, epidemiologists, microbiologists, etc. have all been active in response COVID-19, so too have China's drug companies and Chinese diplomats. The advent of China's "virus diplomacy" has involved making Chinese diagnostic and therapeutic technologies available to the international community in the hopes of overcoming the damage done to China's reputation by the early failures to control the spread of the virus. As noted, China's response to COVID-19 reflects many of the features of the broader STI landscape including the crisis-opportunity dynamic noted at the outset.

Research

The Chinese research system has responded aggressively to the Covid-19 pandemic. Chinese funding agencies have made it a priority, by establishing well-funded emergency programs, and have encouraged researchers to focus in on Covid-related topics (Murphy, 2020). Reportedly the Natural National Science Foundation of China (NSFC) has invested roughly US$ 60 million in largely investigator initiated responses to program calls. The Ministry of Science and Technology has also initiated special projects in cooperation with the National Health Commission, as have local governments and pharmaceutical firms. (Private communication). Given such supportive policy attention and the the sense of crisis-driven opportunity, it is not surprising that there has been a vast outpouring of papers and preprints from the research community. Chinese authors quickly came to dominate the number of published papers in the early stages of the pandemic; interestingly, they became less dominant in percentage terms as the pandemic was brought under control in China. As of early October, 2020, Chinese authors had produced some 9223 papers (17.5%) of total papers relating to Covid. In the first phases of the pandemic, on the other hand, Chinese papers constituted almost 48% of the total. Subsequently, the total number of Chinese papers has continued to rise, but the explosion of work in countries more subject to crisis conditions, especially from the U.S. and Europe, has reduced the percentage of Chinese papers in the total. (Fry, et. al., 2020a, 2020b).

Vaccine and drug development

China's work on developing a vaccine for COVID-19 began early in the pandemic. Reportedly there are now at least 11 candidate vaccines under development although five seem to be further along in terms of phase III trials. These include two from Sinopharm, a large state owned enterprise and one from Sinovac Biotech, a private firm which has been building on unused vaccine work done for the SARS outbreak in 2003. These candidates employ the more conventional technologies using inactivated viruses. CanSino Biologics, another private firm with roots in Canada, and which collaborates with The Chinese Academy of Military Medicine in developing its candidate, is a third leading prospect, Its effort involves the insertion of an RNA segment of the coronavirus protein into a weakened adenovirus. A fifth candidate developed by Anhui Zhifei Longcom Biologics, in cooperation with the Institute of Microbiology of the Chinese Academy of Sciences, is based on bioengineered units of the spike protein. (Murphy, 2020).

Beginning in July, widespread vaccinations were given in China on a "emergency use" basis prior to full phase 3 trials. Due to the success of suppressing the virus in China, though, clinical trials are also being conducted in other countries. In the case of Sinopharm, these are taking place in the United Arab Emirates, Bahrain, and Egypt. Mexico is hosting trials of the CanSino candidate. Trials are also being conducted in Turkey, Indonesia, Chile and Brazil where the SinoVac trial has gotten tied up in Brazilian politics after an individual died (from causes apparetly unrelated to the vaccine) after being inoculated. Results from the phase 3 trials in the UAE, reported in early December, 2020, indicated that the Sinopharm vaccine was 86% effective.

In addition to vaccines, of course, China's pharmaceutical industry has also been active in exploring the efficacy of therapeutics. (Li, et. al. 2020). This includes interest in the uses of traditional Chinese medicines (TCM) from the Chinese pharmacopeia. TCM enjoys political support in China and has been subject to increasingly sophisticated analytical work at such centers as the CAS Institute of Materia Medical in Shanghai, Jinan University, and elsewhere (Wang, 2020).

The broader context

Not surprisingly, given the domestic and global impacts of the pandemic, China's experience with Covid has elicited a broad range of discussions having to do with the broader STI ecosystem. The public health failures in the early phases of the outbreak has forced China to re-examine its mechanisms for controlling infectious diseases. Clearly, in late 2019 and early 2020, the mechanisms developed following the SARS outbreak in 2003 were shown to be seriously defective. In addition, the outbreak has called attention to problems of medical education, especially its emphasis on specialization, and its neglect of generalist medical education (Shao and Zhao, 2020).

The discovery of the virus in Wuhan has led to widespread attention to the coronavirus research at the CAS Wuhan Institute of Virology and to the Chinese CDC's Wuhan Center for Disease Control and Prevention. Although there have been extensive denials from Chinese political and scientific leaders that the virus did not escape from a Wuhan laboratory, it is notable that Xi Jinping called attention to the need to strengthen biosafety/bio security in his discussions of "holistic view of national security" in February 2020, and that China's National People's Congress finally enacted a long-delayed biosafety/bio security law in October (Cao, 2020b).

Public health reporting mechanisms and concerns over biosafety/bio security involve complex questions of information controls, data availability and data sharing. The pandemic has brought these issues into sharp focus both as matters of public policy and of research culture. The Chinese political system is biased towards tightly controlling information, affecting both public health and research. It is not surprising, therefore, that policies have been introduced to require the vetting of certain types of Covid-related research prior to making them public. At the same time the Chinese research system has often been lax in ensuring quality and integrity in research reports and publications, as problems of fraud and misinformation illustrate. Hence, some degree of vetting is being welcomed in the research community (Silver and Cryanoski, 2020). While many Chinese scientists recognize the need for sharing research findings, there is also a recognition that the norms of the research culture often work against data sharing as Chinese scientists strive for priority publications in high-impact journals and for "quick success and short term gains" (jigong jinli). (Wu and Poo, 2020; Suttmeier, 2020).

The foreign policy dimension

In recent years, China has sought to project its economic and political interests well beyond its borders. This has been especially true since the financial crisis of 2008, when China concluded that its model of governance and development had international appeals in the face of problems encountered by the capitalist democracies of the West. The efforts to project influence have involved diplomatic initiatives to project Chinese "soft power" around the world, expansion of foreign investment and penetration of foreign markets, and increasingly generous forms of foreign assistance. Much of these efforts are tied up with Xi Jinping's signature "Belt and Road Initiative" (BRI) initiative. China's stumbles in the early stages of the Covid outbreak, and the subsequent global pandemic, clearly set back these influence-projecting efforts. To compensate, China has attempted to use the lessons learned in controlling the virus, and especially the progress made in vaccine development and research more generally, to recover aspects of its reputation lost in its failure, at the outset, to control the virus.

Through what some have called "virus diplomacy," China has offered to make vaccines available to countries hosting clinical trials and more generally, to participate in international efforts to ensure the availability of vaccines as seen, for instance, in its agreement to join the WHO-supported COVAX vaccine aliance. Chinese voices have called for greater international cooperation in Covid - related research and vaccine development, and has attempted to highlight China's own efforts in support of international cooperation (Zhou, 2020). China has also sought to use it science and technology capabilities to enhance its role in BRI through research cooperation, biomedical foreign assistance, the promotion of Chinese standards, and the expansion of commercial opportunities for Chinese firms.

An especially interesting case of China seizing opportunities from the pandemic crisis is seen in the activities of BGI, a world leader in gene sequencing which has now diversified into a major player in genomic research and commercialization. In a recent report, BGI is said to have sold 35 million rapid COVID-19 testing kits around the world and built "…58 labs in 18 countries." BGI maintains a philanthropic arm which has helped pay the associated costs and has enjoyed support from China's embassies in the recipient countries as an extension of China's virus diplomacy. (Needham, 2020). These initiatives also help BGI to capture genomic data from around the world, an opportunity furthered by the establishment of the BGI "Global Initiative on Open-source Genomics," a platform which invites the international sharing of virus data. That BGI also hosts the China National Gene Bank and several government supported "key laboratories" for genomic research highlights the ways in which foreign policy initiatives combined with domestic research and industrial policies help advance China's aspirations for cutting-edge research and technology (cf., Needham).

The transformation of biomedicine

China's response to the COVID-19 pandemic points to the interesting challenges it faces with regard to its drug industry and its aspirations for biomedical research more generally. As suggested by the BGI story, China is attempting to combine advanced technologies and major commitments of government and corporate resources to advance China's biomedical aspirations. While China's drug and medical device industries have been characterized as being largely dependent on contract research and the production of generics and active pharmaceutical ingredients (APIs) for large international firms, there is a growing recognition that Chinese companies are on a steep learning curve toward a more innovative future (Wang, 2020). Drug companies had been limited by low R&D budgets, lengthy drug approval processes which discouaged investment and innovation, and generally weak opportunities for clinical research. In recent years, government and industry have attempted to turn these problems around with reforms in the drug approval procedures and major investments in biomedicine, including programs for the construction of translational medical centers (Normile, 2017).

The Chinese pharmaceutical industry is hoping to move to new levels of innovation beyond derivative combinations of chemical molecules toward the development of biologics and strengths in synthetic biology employing biomedical applications of advanced biotechnology. While still working its way through the "first generation" of biotechnology ("tools and methods based on the capability to modify and move genes from one organism to another"), China is moving rapidly towards establishing "second-generation" biotech capabilities which allows for the "engineering" of biology. Through the application of "digital design methods" and "modern engineering concepts" biological materials can be synthesized by drawing on "…large, high-quality data sets, digitalization, and automation," and the "reading and writing DNA." Such is the stuff of "leap frogging" - the opening up new frontiers of research and medical practice (Carlson and Wehbring, 2020).

The creation of a biotech sector with "second-generation" capabilities is a major objective of Chinese STI policy, made all the more pressing by the pandemic. It builds on a biotechnology foundation developed over the past three decades but is now led by promising young scientists, many trained at the world's leading universities, who are working at the frontiers of relevant fields. The researchers are supported by favorable national policies, by new financial mechanisms including venture capital, and by new facilities and institutional arrangements intended to encourage interdisciplinary cooperation. They enjoy

China's data-rich environment (albeit, still not properly formatted) and possess high levels of competence in biological understanding, computer science, artificial intelligence, big data, and engineering design for the kinds of scientific convergence that is becoming characteristic of frontier research. Goals associated with successful transformational medicine, which effects the linkage of basic medical science and critical practice has been hindered by inherited weaknesses in clinical research. These have been recognized, however, and are now being addressed by encouraging hospitals to become more research oriented and by the introduction of new institutions including the National Research Centers for Translational Medicine and the Institute of Cancer and Basic Medicine at the CAS, the first institute of medicine at the Academy (Zhao, 2019; cf. Normile, 2017).

Conclusion

Louis Pasteur's famously observed that *Fortune favors the prepared mind*. Chinese STI initiatives in relation to the Covid pandemic show that the "prepared minds" were not functioning properly when the coronavirus first appeared. The regime for responding to infectious diseases developed after the SARS crisis of 2003, which was intended to prepare China for such health emergencies, failed to perform as planned due to the persistance of the daunting problems of local-national government relations.

Yet, after China's initial fumbling in response to the outbreak, it did demonstrate institutional and scientific responsiveness that indicates that preparation was not entirely absent. Leaving aside for the moment the political realities contributing to the control of the pandemic, from the point of view of STI policies, we can see that the building up of capabilities in research and technology over four decades has prepared China to achieve a degree of fortune from crisis situations. Since the early 1980s, when the "Four Modernizations" policy identified "the modernization of science and technology" as the key to "the modernization of industry, agriculture, and national defense," China has pursued STI policies that,in spite of abundant waste and inefficiencies, have been remarkably successful. China's exploitation of technologies and advanced research and educational opportunities available from abroad has aggressively moved the country toward long sought after "wealth and power." But the payoffs from exploiting the knowledge assets in the international system would be considerably fewer had there not been robust efforts to build domestic research and educational institutions characterized by national vision and increasingly generous material support.

China's current plans for the 14th FYP and beyond, discussed above, build on this 40 year history. During much of this four decade period, China was excessively dependent on foreign technologies and much of its research was derived from original work done elsewhere. China recognized it was in a catch-up phase, but all the while anticipated opportunities to move beyond catch-up into leadership positions of cutting-edge research and innovation. The key was to prepare the human and institutional resources to seize those opportunities, once they arrived. The BGI case noted above, points to how "preparation" can point to opportunistic success. Preparations through the 14th FYP and the new Medium to Long-Term Plan indicate that China sees long sought opportunities to go beyond catch-up with its science and technology, and is preparing to seize them.

As the 14th Plan begins to take shape, China is experiencing the convergence of ample funding, world-class facilities, and a large science and engineering workforce, an increasing share of which is working at the frontiers of research. What adds to the special circumstances of this convergence of national assets is the convergence of fields of research and technologies reflected in revolutionary discoveries in science and technology and the revolutionary ways in which research is done, as seen for example, in such breakthroughs as "quantum advantage" and AI-enabled protein folding. These kinds of developments, given the convergence of the human and material assets that China brings to its STI platforms, makes China's interests in "leapfrogging" to leadership positions in the sciences, technologies, and industries of the 21st century a plausible aspiration.

China, of course, is not alone in having the assets and aspirations to exploit the opportunities offered by research breakthroughs. Nor is it alone in having institutional and cultural impediments to realizing its STI goals. But, as we consider the ways in which such strengths and weaknesses affect research and innovation in different countries, we can no longer ignore the question of whether China's centralized national purpose and mobilization of resources, its synoptic visions and policy instruments, offer an intriguing STI paradigm for success.

References

Cong, C. (2020a) "China." Forthcoming in UNESCO Science Report 2020.

Cong, C. (2020b). "China's Evolving Biosafety/BioSecurity Legislative Regime." Unpublished manuscript.

Cong, C and Suttmeier, R.P. (2017), Challenges of S&T System Reform in China. Science, 355 (6329), 1019–1021.

Carlson, R. and Wehbring, R. (2020), Two Worlds Two Bioeconomies: The Impacts of Decoupling US-China Trade and Technology Transfer. In Measure Twice, Cut Once: Assessing Some China-US Technology Connections. Johns Hopkins, Applied Physics Laborator (5).

Murphy, F. (2020), Inside China's Response to Covit, Nature. 588. December, S49-S51.

Fry, C., Cai, X., Zhang, Y., Wagner, C. (2020a), Consolidation in a Crisis: Patterns of International Collaboration in Early COVID-19 Research. PLoS ONE 15(7): e0236307. https://doi.org/10.1371/journal.pone.0236307).

Fry, C., Cai, X., Zhang, Y. and Wagner, S. (2020b), Consolidation in a Crisis: Patterns of International Collaboration in Early Covit-19 Research. PLOS ONE. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0236307; "International Collaboration During the Covit-19 Crisis: Autumn 2020 Developments." (Preprint).

(Shao, L., and Zhao,W. (2020) Challenges for Chinese Medical Education In the Coming Post-Covid-19 Era, National Science Review, 7, 1617-1621.

Li, H., et. al. (2020), Overview of Therapeutic Drug Research for Covit-19 in China, Acta Pharmacologica Sinica, 41, 1133-1140. https://www.nature.com/articles/s41401-020-0438-y.

Needham, K. (2020), Special Report: Covit Opens New Doors For China's Gene Giant, Reuters. 2020.https://www.reuters.com/article/us-health-coronavirus-bgi-specialreport/special-report-covid-opens-new-doors-for-chinas-gene-giant-idUSKCN2511CE.

Normile, D. (2017), Medical Center Spearhead China's Pharma Push, Science, 358 (6364), 709.

Silver, A. and Cryanoski, D. (2020), China Is Tightening Its Grip on Coronavirus Research Findings, Nature, 580, 439-440.

Suttmeier, R. (2020), Chinese Science Policy at the Crossroads, Issues in Science and Technology, (Winter), 58-63

Wang, L. (2018), Drug Discovery in China: Challenges and Opportunities, National Science Review. 5, 768-773.

Wu, C., and Poo, M. (2020), Moral Imperative for Immediate Release of 2019-nCoV Sequence Data, National Science Review, 7, 719-720.

Zhao, W. (2019), An Interview with Feng Shao and Weihong Tan: Chemistry Intertwines with Biology and Medicine, National Science Review, 6, 1163-1168.

Zhou, Q. (2020). "International Collaboration for Global Accessibility of Covit-19, National Science Review, 7, 1269.

An All-of-Science Approach to Public Health

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Previous pandemics in the modern era were never long, severe or widespread enough to stimulate an all-of-science approach to beating them. SARS essentially ended after only several months in 2003[1], H1N1 caused approximately 18,000 deaths in 2009~2010[2], and Ebola was concentrated in West Africa in 2014~2016 and in the Democratic Republic of Congo in 2019~2020[3]. During these pandemics, the medical sciences fought back through genomic research, vaccine development and new treatments, but their limited nature did not trigger a response from non-medical branches of science.

COVID-19 is a much more severe pandemic, with no end in sight, more than a million deaths already, and affecting every country in deep ways. As a result, more branches of science are getting involved in the pandemic response, such as transport engineering[4], fluid mechanics[5], mathematical modelling[6] and even astronomy[7]. While politicians close borders to curb the spread of COVID-19, researchers in the medical and non-medical areas are breaking borders by communicating and working on the solution for COVID-19. This is on top of the decade-long partnership in pandemic responses between economists, sociologists and behavioral psychologists with public health experts and doctors.

This all-of-science response is both necessary and admirable. However, such energetic responses can and should be harnessed in several ways to fully maximize the benefits. This article proposes three over-arching principles for country-level governments and the self-governing global science community to consider.

1. Include health into the scientific research agenda

Historically and traditionally, scientific research has multiple objectives, such as human progress, creation of economic opportunities, or to increase national prestige. Health has always been important, but national research agendas may deprioritize health in favor of the applied sciences, manufacturing, or artificial intelligence. Now, in the post-COVID era, there are several strong reasons to include health into the national research agenda as a high-priority item.

One, there is a need for the best brains in a country to focus on inventions and innovations that literally save lives during pandemic and non-pandemic times. Two, the global healthcare industry is expected to grow to nearly $ 12 trillion in 2022[8], which is a huge economic and job-creating opportunity. Three, this pandemic has sharpened the focus on the timeless truth that healthy populations require more than just doctors delivering oxygen or vaccines, but all scientists and researchers playing their own roles working in collaborative ecosystems.

Placing health higher on the scientific research agenda is more than just increasing funding to biomedical or clinical research, although newer antibiotics and more heat-resistant vaccines will be helpful. The core philosophy of research should emphasize on impactful research to add a new dimension of human health and development, instead of the more prosaic aims of intellectual properties, academic achievements or economic progress. It is time to ensure knowledge brought a sustainable change toward a healthier society.

In practical terms, this means several things. The metrics of scientific research should gradually evolve from just the hard statistic of patents and publications to the softer statistic of Disability-Adjusted Life Year (DALY) and Health-Related Quality of Life (HRQOL). Governments should create more inter-disciplinary grants for non-medical scientists and researchers to partner their medical and health colleagues. A centrally led research agenda can be powerful in converging the multiple disciplines together, in a research world that tends towards divergence.

2. Integrate research vertically

More innovations are needed to strengthen public health in several broad categories, and vertical integration can achieve greater impact. These include the use of disruptive technologies in the development of better vaccines, therapeutics and test kits. Their inclusive availability, affordability and accessibility to the poor and marginalized will be an added advantage. Provision of new solutions to increase the effectiveness of non-pharmaceutical interventions, such as tools to increase compliance to physical distancing, make handwashing a pleasant habit or comfortable yet safe fabrics for face masks also need attention. Better solutions combined with predictive analytics and block-chain are also needed to improve the effectiveness of quarantines, contact tracing and isolation.

1) CDC. (2013, April 26). CDC SARS Response Timeline. Centers for Disease Control and Prevention. https://www.cdc.gov/about/history/sars/timeline.htm.
2) WHO. (2015, June 21). Pandemic (H1N1) 2009 - update 112. World Health Organization. https://www.who.int/csr/don/2010_08_06/en/.
3) WHO. (2020, February 10). Ebola virus disease. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/ebola-virus-disease.
4) Hendrickson, C., & Rilett, L. R. (2020, May 5). The COVID-19 Pandemic and Transportation Engineering. Journal of Transportation Engineering, Part A: Systems. https://ascelibrary.org/doi/10.1061/JTEPBS.0000418.
5) Mittal, R., Ni, R., & Seo, J.-H. (2020). The flow physics of COVID-19. Journal of Fluid Mechanics, 894(F2).
6) Panovska-Griffiths, J. (2020). Can mathematical modelling solve the current Covid-19 crisis? BMC Public Health, 20
7) Korsaga, M. (2020). Role of astronomy in the fight against the COVID-19 pandemic. IAU Office of Astronomy for Development. http://www.astro4dev.org/role-of-astronomy-in-the-fight-against-the-covid-19-pandemic/.
8) Wood, L. (2019, June 25). The $11.9 Trillion Global Healthcare Market: Key Opportunities & Strategies (2014-2022) - ResearchAndMarkets.com. Business Wire. https://www.businesswire.com/news/home/20190625005862/en/The-11.9-Trillion-Global-Healthcare-Market-Key-Opportunities-Strategies-2014-2022---ResearchAndMarkets.com.

One COVID-19 success story is South Korea's test-kit diplomacy[9]. There was an accelerated yet safe and robust pathway from bench scientists to regulatory approvals to mass production, allowing South Korea to supply more than 100 countries in the early stages of the pandemic[10]. Such vertical integration of health research to healthcare services is a model for other scientific disciplines. These can be done in several ways.

Firstly, there are three broad datasets for science and technology researchers to embed into their research as they intersect with health and healthcare. These three datasets mirror the historical expansion of medical research aims over the past 50~70 years. Scientists and researchers can begin in any order of preference or familiarity, with clinical outcomes (such as improvement in average blood pressure readings), health economic outcomes (such as the cost savings or cost-effectiveness of a new innovation) or patient-reported outcomes (such as the Migraine-Specific Quality of Life scoring[11]). Clinical outcomes will persuade doctors, economic outcomes will persuade payers and insurers, and patient-reported outcomes will persuade the end-users of the innovation; all are important components of the healthcare system. Randomized controlled trials are the gold standard, but emerging use of real-world evidence (RWE) may be a necessary decision for researchers in the near future.

Secondly, governments can create collaborative networks of inter-agency task forces that combine researchers from multi-disciplines with lawyers (for patents and liability clauses), manufacturers (for iteration and mass production), commercial leaders (for commercialization and scale-ups) and end-users (like doctors, nurses or patients). These task forces will foster greater purpose, faster collaboration and seamless efforts, because researchers no longer work in a silo only to hand-off their finished work to another group of experts.

Thirdly, all researchers must embrace digital technology (eg 5G/6G) to remain relevant, especially in health. Artificial intelligence, bioscience technology, data analytics, block chain and the Internet of Things are only a few examples of the disruptions in science and research. These advances intersect with health through portable lifetime electronic health records[12], pharmacogenomics[13] and wearables, as only three examples. A vertically integrated and built-in digital capability will help take-up as well as increase impact of any innovation.

3. Embed research into systems, not as standalone products

Public health systems have undergone decades of under-investment. For example, the OECD spends only 7% of their health expenditure on preventive care and public health[14], but approximately 80% on curative services and pharmaceuticals. COVID-19 will change all that, with increasing amounts of money now being committed to public health, health systems strengthening, health policies and health services research.

This is welcome for several reasons. One, a better understanding of systems and services can improve population health by allocating resources more accurately and addressing systemic flaws. Two, a stronger and more resilient system can respond better to emergencies, disasters and pandemics. Three, governments can mount all-of-government and all-of-society responses to pandemics, instead of only relying on hospitals and health agencies to carry the entire burden of good health.

The broader science and technology community can respond to this emerging trend by embedding themselves within systems, instead of building and then handing over standalone products for the healthcare system's use. There are several ways to embed into health systems.

Firstly, researchers can include a health systems, services or policies expert. This can begin as early as the grant application process, which can increase the chances of success because multi-disciplinary teams are in increasingly higher demand. During the research process, a health systems, services or policies expert can introduce relevant outcomes to the research, monitor progress for these outcomes, and bring a real-world evidence component to the research. After the research is completed, this expert can advise on the relevant policy applications of the research.

Secondly, researchers should interact more closely with regulators and their agencies. Healthcare is more regulated than many other branches of science, with research outcomes undergoing rigorous scrutiny before and after approval for human use. However, the line between regulated products and consumer items can be unclear. For example, there is debate about whether a smartphone app can be considered a medical device[15] regulated by specialized agencies. Governments can help by creating "regulatory sandboxes" for researchers to innovate.

Thirdly, research into health systems, health services and public health will be demand-led for the foreseeable future. Governments, major funders, development banks and international aid agencies have started building or implementing research, investment and capacity-building agendas in these areas. The broader science and technology community can follow this trend by shifting their intellectual and organizational resources towards integrating with health systems in the first instance, not merely providing finished products to the end-users.

4. Health, not growth, is the ultimate metric

The post-1945 political economy emphasizes growth as the ultimate metric of a nation's success. That is reflected in the priorities of the world's research agenda, which aims in large part to advance a nation's competitive edge. Delivering economic growth and a competitive edge was necessary then, but is not viable in the 2020s and beyond.

Shifting research priorities towards improving public health is not only ethical and desirable, it is also necessary for governments to maintain their political legitimacy by providing stronger health services. The broader science and research community now has a historic opportunity to evolve their priorities, by leading an all-of-science approach to improve the health of all *Homo sapiens*.

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9) Mokhter, S. (2020). Time for New southern policy to deliver. Focus, (14).
10) Khaliq, R. ul. (2020, April 22). World turns to South Korea for virus testing kits. Anadolu Ajansı. https://www.aa.com.tr/en/asia-pacific/world-turns-to-south-korea-for-virus-testing-kits/1814419.
11) Wagner, T. H., Patrick, D. L., Galer, B. S., & Berzon, R. A. (1996). A New Instrument to Assess the Long-term Quality of Life Effects From Migraine: Development and Psychometric Testing of the MSQOL. The Journal of Head and Face Pain.
12) CDC. (2013, April 26). CDC SARS Response Timeline. Centers for Disease Control and Prevention. https://www.cdc.gov/about/history/sars/timeline.htm.
13) U.S. Department of Health and Human Services. Pharmacogenomics. National Institute of General Medical Sciences. https://www.nigms.nih.gov/education/fact-sheets/Pages/pharmacogenomics.aspx.
14) OCED. (2018, November 22). Health expenditure by type of good and service. OECD instance. https://www.oecd-ilibrary.org/social-issues-migration-health/health-at-a-glance-europe-2018/health-expenditure-by-type-of-good-and-service_health_glance_eur-2018-31-en;jsessionid=7rMw1Juga0c9mrnkuHcD3kK1.ip-10-240-5-151.
15) Kamerow, D. (2013, October 19). Regulating medical apps: which ones and how much? BMJ. https://www.bmj.com/bmj/section-pdf/749048?path=/bmj/347/7929/Observations.full.pdf.

ASEAN's Response to COVID-19 and the Case of Vietnam

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Abstract

The Coronavirus (COVID-19) has been leaving its imprints and implications on almost every corner of the globe. In the combat against it, while national response proves to be of determining significance, international coordination and cooperation is of increasing demand and necessity. The pandemic has, therefore, brought to the fore the question of resilience - national, regional, and global, particularly in terms of effective policy response. This article analyses the COVID-19 response by the Association of Southeast Asian Nations (ASEAN) and Vietnam as the ASEAN Chair in the year 2020. The argument is that COVID-19 has served as a reminder of the importance of science, technology and innovation, the real necessity for science-based policies, and the greater demand for national and regional resilience and good governance to deal with emerging challenges. For Southeast Asia, the spirit of cohesiveness and responsiveness that Vietnam demonstrated and promoted in its ASEAN chairmanship year 2020 has been and will be determinant in the response to COVID-19 and sustaining the relevance and resilience of the ASEAN Community further beyond.

The COVID-19 pandemic

The world has been in the prolonged combat against the Coronavirus (COVID-19) for almost one year with encouraging results in some parts and ensuing challenges in others. Being one of the first regions of the world to be affected by the pandemic, and currently suffering its new waves, Southeast Asia is still facing a surge in infectious cases. By end of November 2020, over one million confirmed cases of COVID-19 and more than 27,000 total deaths had been reported regionwide, with the Philippines, Indonesia, Malaysia, and Myanmar being the most heavily infected countries (Dezan Shira & Associates, 2020). COVID-19 is leaving its imprint on all aspects of life and raising multiple cross-cutting questions, domestic and international, in Southeast Asian countries and elsewhere. It has highlighted, among others, the significance of national resilience, particularly in terms of scientific capacity and policy, and necessitated regional cooperation in science, technology and innovation for epidemic combat and economic recovery. In essence, effective national and regional policy responses are in increasing demand.

COVID-19: A powerful reminder of the decisive role of science, technology, and innovation

The COVID-19 pandemic brought to the fore the question of resilience, at all levels - national, regional, and global. They go hand in hand. The traditional emphasis of Southeast Asian politics on 'national resilience' as a prerequisite for 'regional resilience' sits well in this battle against COVID-19 (Dang, 2020). The pandemic has tested the cross-cutting issues of efficiency, relevance, and resilience of institutions - nationally and internationally. Good governance and institutional efficiency have been in high demand. Without them, critical existing problems could not be resolved while new ones would emerge, further undermining the national and international institutions' relevance and resilience as a result. In this sense, COVID-19 has been a powerful reminder that the standing of national, regional, and global institutions and players depends above all else on their performance - especially with regards to sustainable development and crisis management.

A key to sustainable development and epidemic management is science and technology. During normal times, science and technology has, for the past several decades, become an increasingly important determinant of national, regional and global socio-economic development. Unprecedented achievements have resulted from advances of the fourth technological revolution and the rapid growth of the knowledge economy. It is more so during such crisis circumstances as the COVID-19. New technologies such as big data, artificial intelligence, and 5G have been widely used by countries across the globe in epidemic trend forecast and epidemiological investigation, which has contributed greatly to identifying infected cases and their close contacts. In countries including the Republic of Korea, Singapore, and Vietnam, technology has been used extensively to verify home quarantine and to trace contacts. Most popular was text and mobile-based software and a new serological test that can establish links among infected patients, which allows the authorities to map out the chain of transmission. COVID-19 has testified that digital inclusion and secure resilient digital infrastructure is essential for not only supporting disease controlling measures and smart health systems, but also enabling the new normal way of life - wherein physical social distancing, tele-working, and online studying have become part of everyday habits, by facilitating remote learning and working, minimizing workforce disruptions, promoting job upskilling and reskilling programmes to build up post-COVID-19 workforce preparedness. With the promotion of science and technology, the dual task of sustaining economic growth and controlling the pandemic is believed to be within reach.

As such, COVID-19 has born several implications in terms of science, technology, and innovation. Being a health crisis, it has presented a test to the capacity of national public health systems, the efficiency of research and development, and the effectiveness of scientific policies and institutions in

The views expressed are the author's own and do not necessarily reflect those of the institution she works for.

responding to crises. With tremendous economic and social consequences, the pandemic has necessitated greater emphasis on research and development and cooperation in science, technology, and innovation within and among countries. "Where international cooperation works and countries come together, lives will be saved. Where the lessons of science are respected, lives will be saved," said U.N. Undersecretary-General Fabrizio Hochschild at a digital conference on science and technology in the fight against COVID-19 (Fueh, 2020). The crisis, according to UNESCO Director-General Audrey Azoulay, also demonstrated the urgency of accelerating information sharing through open science (UNDGC, 2020). Upon this awareness, the United Nations and other international institutions have been mobilizing international cooperation to harness the power of science to tackle the coronavirus pandemic, while also working with partners to explore innovative crisis response tools. In short, the actual responses to COVID-19 have illustrated with real time daily examples that adopting science-based policies and harnessing frontier technologies can make the difference between life and death (UNCTAD, 2020).

Lessons have been drawn under COVID-19 impacts on the inter-relatedness among science, policy, and society in managing, and recovering from, the pandemic and the important contribution of science towards further sustainable development goals. They included enhancing national capacities for science-based decision making, raising public trust in science and government policies, bolstering public health cooperation measures through sharing information, experience and best practices, enhancing collaborative research and development of vaccines and antiviral medicines through sharing knowledge and data, harnessing the entrepreneurial spirit of the private sector to invest in research and development focusing on developing innovations to address social and environmental challenges and provide economic opportunities, ensuring regional and universal access to solutions, and acting with greater urgency on regional and global scientific assessments (UNDESA, 2020; UNESCAP, 2020). Calls for and commitments to greater collaboration in science and technology have been made within the framework of major global and regional cooperative institutions, including the UN, G7, EU, Inter-American Development Bank, ASEAN, and ASEAN-led mechanisms, and by leading scientific institutions and expert groups. Response to COVID-19 and its implications has, in its turn, reflected the relevance and effectiveness of cooperative mechanisms. "This outbreak is a test of solidarity - political, financial and scientific. We need to come together to fight a common enemy that does not respect borders, ensure that we have the resources necessary to bring this outbreak to an end and bring our best science to the forefront to find shared answers to shared problems. Research is an integral part of the outbreak response," said WHO Director-General Dr Tedros Adhanom Ghebreyesus at a two-day forum held at the World Health Organization's Geneva headquarters in February 2020 (WHO, 2020). Indeed, science, technology, and innovation serve as drivers and facilitating factors in finding solutions to the health and medical problems and to short, medium, and long-term economic and social challenges brought about by the pandemic. They also help improving preparedness of national and regional communities for future risks and crises. In short, scientific research and development proves to be of great importance in responding to COVID-19, individually and collectively.

Fostering collective actions: the response of ASEAN

ASEAN members have taken science seriously. Specific R&D measures adopted by Southeast Asian countries included sharing experience and best practices in epidemiological research and development, clinical treatment, joint research and development of vaccines and anti-viral medicines, bolstering national and regional epidemic preparedness and response including through the possible setting up of a network of experts on public health emergencies. The new waves of the disease spread highlighted the urgent priority for research and integration of social sciences and others into the crisis response.

In a broader context, cooperation in science and technology has long been promoted by ASEAN. The grouping is one of the regional cooperation bodies in the world having regionalism served as a platform for cooperation in science and technology so early as in 1978, when the ASEAN Committee on Science and Technology was established. Since then, a series of ASEAN Plans of Action in Science and Technology (APASTs) have been developed, the most recent being the Action Plan of Action on Science, Technology, and Innovation (APASTI) 2016-2025 endorsed by the ASEAN Ministers for Science and Technology at the 16th ASEAN Ministerial Meeting on Science and Technology (AMMST) held on November 6, 2015 in Vientiane, Lao PDR. ASEAN leaders shared a common recognition that science and technology is a key factor in sustaining economic growth, enhancing community well-being, and promoting regional integration. They envisaged that by 2020, ASEAN would be technologically competitive, competent in strategic and enabling technologies, with an adequate pool of technologically qualified and trained manpower, and strong networks of scientific and technological institutions and centres of excellence (ASEAN, 1997). Recognizing the crucial role of science and technology to development, strong emphasis has been placed by ASEAN states on the measures that need to be implemented to bolster science and technology cooperation in the ASEAN Community Blueprints. In the ASEAN Community Blueprint for the period 2008-2015, ASEAN science and technology cooperation was under the pillar of the ASEAN Social Cultural Community. In the period 2016-2025, it was moved to the ASEAN Economic Community pillar to support economic cooperation within the Community. Current science and technology cooperation in ASEAN focuses on nine programme areas, namely food science and technology, biotechnology, meteorology and geophysics, marine science and technology, non-conventional energy research, microelectronics and information technology, material science and technology, space technology and applications, and science and technology infrastructure and resources development. From a whole-of-Community approach, science, technology, and innovation has featured high in the dual-track approach of mitigating risk and minimizing transmission while gradually restoring socio-economic activities to normal and sustaining growth that ASEAN has taken in recent months in response to COVID-19.

While COVID-19 highlighted that national, regional, and global resilience are mutually reinforcing, it also drew attention to a widening gap between the demand for, and the supply of, regional and global governance and leadership. This stemmed, to a certain extent, from the fact that countries have been dealing with the pandemic largely on a national basis, which presented an implicit recognition of the inefficiency of regional and global institutions. Like many other regional cooperative mechanisms, the Association of Southeast Asian Nations (ASEAN) has been under scrutiny on crisis management efficiency and relevance to its member states in the hour of need. As observed by Charles Santiago, Malaysian Member of Parliament and ASEAN Parliamentarians for Human Rights Chairperson, almost all the countries in Southeast Asia have taken a nationalistic approach over a prosper-by-neighbour one (Demetriadi, 2020). At the onset of the crisis, Southeast Asian countries, similarly to those in other regions, responded to the pandemic with various national policy decisions. The relatively slow and lack-of-coherent response of ASEAN members in the early phase of the pandemic could be partly explained by the unexpectedness of the pandemic outbreak, uneven infections, and different risk perception based on different impacts of the disease among countries (Hoang, 2020). However, the argument on the nexus between national resilience and regional resilience would suggest that extensive early measures taken by each member state are essential to curb the spread of the virus at the national level and, therefore, contributed to regional collective efforts in later phases.

As the pandemic widely hit the region, there has been an increasing policy convergence and ASEAN quickly forged a more united regional response based on consensus on the need for collective efforts to tackle COVID-19 and its impacts on member states. On February 14, 2020, ASEAN issued the Chairman's Statement on ASEAN Collective Response to the Outbreak of Coronavirus Disease 2019, which emphasized the importance of ASEAN solidarity and reaffirmed ASEAN's commitment to collectively respond to the outbreak of the COVID-19 through utilizing and strengthening regional mechanisms for coordination and cooperation (ASEAN, 2020a). ASEAN Defence Ministers on February 19, 2020 issued their Joint Statement on Defence Cooperation against Disease Outbreak. The 26th ASEAN Economic Ministers Retreat on March 10, 2020 in Da Nang, Viet Nam, issued a statement calling for collective action to mitigate the impact of the virus, with a particular focus on leveraging technology, digital trade, and trade facilitation platforms to foster supply chain connectivity and sustainability. ASEAN Health Ministers on April 7, 2020 convened video conference to encourage regional cooperation among various stakeholders and accelerate measures to control the spread and mitigate the pandemic. On April 9, 2020, ASEAN Foreign Ministers held an ASEAN Coordinating Council meeting on COVID-19 to discuss and exchange views on ASEAN collective response to the rapid outbreak of the COVID-19. They called for a Special ASEAN Summit, which was held five days later with a Declaration of the Special ASEAN Summit on Coronavirus Disease 2019 (COVID-19). The Declaration appreciated the extensive measures undertaken by each ASEAN member states and reaffirmed their determination to remain united, act jointly and decisively to control the spread of the disease, and address its severe and multi-faceted challenges (ASEAN, 2020b). At the proposal made by the Summit, the ASEAN COVID-19 Response Fund, the ASEAN Regional Reserve of Medical Supplies, and the ASEAN Regional Centre on Public Health Emergencies and Emerging Diseases were formally established at the 37th ASEAN Summit held in November 2020. Statements of sectoral bodies of ASEAN were also issued, including those of ASEAN Ministers on Agriculture and Forestry to ensure food security, food safety and nutrition in ASEAN (April 16, 2020), the ASEAN Tourism Ministers on strengthening cooperation to revitalise ASEAN tourism in the context of COVID-19 (April 29, 2020), the ASEAN Labour Ministers on response to the impact of COVID-19 on labour and employment (May 14, 2020), and the ASEAN Ministerial Meeting on social welfare and development on mitigating impacts of COVID-19 on vulnerable groups (June 10, 2020). Accordingly, practical cooperative measures and initiatives have been put forward across various sectors of the ASEAN Community to strengthen regional capacity in pro-active response to the challenges of COVID-19. As Hoang Thi Ha argued, the value of raising the ASEAN flag high is to make sure that while exercising national responsibility, member states will not indulge national selfishness. Rather, national resilience is comprehended in the larger picture of regional resilience (Demetriadi, 2020).

The issued declarations and agreements reflected the coherent, comprehensive, multi-sectoral, multi-stakeholder, and whole-of-Community approach taken by ASEAN to regional cooperation on COVID-19. Practical cooperation focuses on further strengthening public health cooperation measures; prioritizing the well-being of people and providing appropriate assistance and support to the nationals of ASEAN member states affected by the pandemic in each other's country or in a third country; enhancing effective and transparent public communication including updates of relevant government policies, public health and safety information, strengthening cooperation in countering misinformation and fake news, and developing a set of guidelines and possible platforms to facilitate timely sharing of information; taking collective action and coordinating policies in mitigating the economic and social impacts from the pandemic (ASEAN, 2020b).

The collective actions taken by ASEAN in tackling COVID-19 also demonstrated the relevance and effectiveness of existing intra-grouping cooperative mechanisms. Response to the health crisis falls into the realm of the social and cultural pillar, while managing its general impacts belongs to the political-security and economic pillars of the ASEAN Community. Under the ASEAN Social and Cultural Community, the most relevant existing mechanisms are the ASEAN Health Ministers, the ASEAN Emergency Operations Centre Network (ASEAN EOC) for public health emergencies, the ASEAN Coordinating Centre for Humanitarian Assistance (AHA Centre), and the ASEAN Bio-Diaspora Virtual Centre (ASEAN BVC) for big data analytics and visualization. The advantages of ASEAN in forging cooperation against COVID-19 lay in the fact that these platforms for cooperation in the health security sector have been in existence and tested, as ASEAN had experience in utilizing these mechanisms in battling real-time epidemics like SARS, H1N1 and MERS-COV in the past.

Dialogue partnerships between ASEAN and key players in the Indo-Pacific region also provided the former with opportunities to mobilize support and assistance from the latter in the joint efforts to tackle the crisis. Since the outbreak of the pandemic, ASEAN has held many ministerial meetings and summits with its dialogue partners via video conference to exchange views and explore areas and measures of cooperation to mitigate, control and respond to the impacts of COVID-19. Major areas and measures included joint collaborations on scientific research and development of vaccines and medicines, building and maintaining resilient, open, and connected supply chains and utilizing ASEAN-led regional mechanisms to put forward people-centred healthcare, treatment, and consular assistance policies in responding to pandemics and supporting a sustained economic recovery (ASEAN, 2020c).

Specifically, ASEAN and EU agreed to boost the sharing of information, experience, and policy coordination, especially in disease diagnosis, prevention and treatment, vaccine research and development, make greater joint efforts to minimize the socio-economic impacts of the epidemic on their respective member countries, maintain trade and investment, and work out long-term economic restoration measures. ASEAN Plus Three (China, Japan, and the ROK) issued statements of health ministers and economic ministers on April 7 and June 4, 2020 respectively, committing to enhancing cooperation on COVID-19 response and mitigating the economic impact of the pandemic. A contribution of US$ 300,000 has been made from the ASEAN Plus Three Cooperation Fund to the ASEAN COVID-19 Response Fund. Bilaterally, the Republic of Korea provided ASEAN with practical assistance in COVID-19 response, including the contribution of medical supplies and equipment and the conduct of in-country training for laboratory officers under the US$ 5 million project on Enhancing the Detection Capacity for COVID-19 in ASEAN Member States, launched on June 16, 2020 and funded by the ASEAN-Korea Cooperation Fund (AKCF), and the COVID-19 Comprehensive Rapid Response Program. ASEAN and the Republic of Korea also adopted the ASEAN - ROK Joint Initiatives on Bolstering the Economic Connectivity in response to the COVID-19 outbreak. Japan pledged to provide over US$ 200 million worth of assistance to secure medical supplies and equipment and technical assistance to research institutions in ASEAN countries. For economic revitalization, Japan granted a total of US$ 2.5 billion in budget support loans to Southeast Asian countries upon their request and investment to build resilient supply chains and promote the digitalization of the industry under the ASEAN - Japan Economic Resilience Action Plan. China was also committed to providing US$ 5 million to support ASEAN - China public health cooperation and donated medical supplies to the ASEAN Secretariat for COVID-19 prevention (Hoang, 2020). At the ASEAN-Australia meeting on November 14, 2020, Australia announced an AU$ 550 million injection of aid to Southeast Asia, including hefty dollops of coronavirus aid with AU$ 21 million for the ASEAN Regional Centre on Public Health Emergencies and Emerging Diseases, and AU$ 70 million for recovery efforts. Washington contributed US$ 87 million to combat the coronavirus in Southeast Asia, including providing ventilators and personal protective equipment (Strangio, 2020). The U.S. government, through the U.S. Agency for International Development (USAID), also supported the ASEAN Committee on Science, Technology, and Innovation and the ASEAN Foundation in organizing annual ASEAN Science and Technology Fellowship workshop with the aim to provide opportunities for scientists in Southeast Asia to apply their knowledge and analytical skills in solving public policy challenges. One of the highlights of the 2019/2020 fellowship was the active involvement of the participants in COVID-19 mitigation efforts, from developing a thermal temperature scanner and low-cost ventilator, to volunteering in producing - and distributing - hand-sanitizer and other safety equipment (USAID, 2020). At the 15th East Asia Summit, leaders of 18 participating countries expressed their commitment to working together inclusively at the regional and global levels, in consultation with the United Nations and the World Health Organization, to address the health, economic and security implications of the COVID-19 pandemic (EAS, 2020).

Assistance from dialogue partners has been encouraging to ASEAN in its effort to jointly respond to COVID-19, given the fact that inadequate infrastructures and resources present a formidable challenge for Southeast Asia countries in the struggle. The existing health care infrastructure in many ASEAN member states, epitomized by long waiting queues and low-quality care, will need significant ramping up to cope with the pandemic. The average ratio of doctors is estimated at only 0.8 for 1,000 people, and out-of-pocket expenditure for healthcare is at 44% in the region's five most populous nations, namely Indonesia, Philippines, Vietnam, Thailand, and Malaysia (Mercado, 2020). If the disease prolongs, growing numbers of patients, shortage of protective equipment for health workers and limited facilities to provide intensive care will increase the risk of a contagion in the region that would be hard to control. However, the difficulty is that many of ASEAN dialogue partners have also been heavily hit by COVID-19, which would make their assistance to ASEAN limited and uncertain. Another obstacle to ASEAN's intra- and extra-regional cooperation lies in the considerable existing gaps in the level of development among its member countries, particularly in terms of science, technology, and innovation. These gaps might be further widened by the economic crisis that regional countries are facing when new phases of COVID-19 keep spreading in the region.

Emphasizing cohesiveness and responsiveness: the experience of Vietnam

Vietnam has been responding to COVID-19 by deploying a whole-of-political-system and whole-of-society approach with early action, prompt, firm, and comprehensive epidemic management measures. As of the first week of December 2020, Vietnam confirmed a total of 1,366 COVID-19 infected cases, with 35 deaths in total, among whom 1,220 have recovered and been discharged from hospitals. Vietnam ranks among the top 20 countries by COVID-19 safety, according to a report by the Deep Knowledge Group based on 130 quantitative and qualitative parameters and over 11,400 data points in categories like quarantine efficiency, monitoring and detection, health readiness, and government efficiency (Koetsier, 2020). The International Monetary Fund has revised up Vietnam's growth of 2020 to 2.4%, among the highest in the world, from its previous forecast of 1.6%. Vietnam was also anticipated to be one of the only four economies in the world that maintained growth in 2020 amid the COVID-19 pandemic (Hoang Nam, 2020).

Vietnam has had several favourable, largely science-and-technology-related, conditions to respond to COVID-19 effectively. Firstly, Vietnam has been long pursuing policies to develop science, technology, and innovation as key drivers of national development. During the renovation (known as Doi Moi) process which started in 1986, Vietnam has adjusted its science and technology perception and policy agenda to better meet the need for national development in the era of extensive international integration. Vietnam's science and technology policy formulation and implementation has been transformed from sectoral to multi-sectoral approach involving all the stakeholders as to deal with the inter-sectoral issues, and from a centralized and isolate decision-making process among policy makers to broader involvement of and greater participation by stakeholders in a more open process of policy dialogue, discussion, and realization. The most recent Law on Science and Technology approved in 2013 created several breakthroughs, particularly renovation of policies on the use and remuneration of human resources and the application of research results and dissemination of scientific and technological knowledge. Usage and management of the State budget for research were also renewed, while investment in science, technology, and innovation, including from the private sector - both national and international, encouraged. Vietnam's science and technology policies focus on raising awareness and responsibility of sectors and localities in charting the development of science and technology, while continuing to improve the legal framework and the national innovation system with enterprises acting as a centre, as well as promoting close links between research institutes and universities with enterprises to accumulate intellectual property and create new sources for fast, inclusive, and sustainable economic growth (Decision No.418/QD-TTg, 2012).

Against this general context, science policies and institutions provide fundamental premises for the country in dealing with the COVID-19 epidemic, in terms of both curbing the spread of the disease and economic recovery. For example, Vietnam has utilized technology to maintain robust systems to collect and aggregate data from public health entities and shifted to a nearly real-time, web-based system since 2009. Since 2016, hospitals in Vietnam have been required to report notifiable diseases within 24 hours to a central database, ensuring that the Ministry of Health can track epidemiological developments across the country (Balajee; Estoundi; et al, 2020). As early as in late January 2020, the Ministry of Science and Technology of Vietnam hosted a meeting with virologists to encourage the development of diagnostic tests. In the following three months, Hanoi University of Science and Technology, Vietnam Academy of Science and Technology, and Vietnam Military Medical University respectively developed local-made test kits that were validated by the Ministry of Defence and the National Institute of Hygiene and Epidemiology, manufactured, and commercialized in coordination with private companies. Under COVID-19, the public has also been exhorted to download BLUEZONE, a COVID-19 contact-tracing app developed by Vietnamese technology firm BKAV and the Ministry of Information and Communications. While only about 390,000 had downloaded the app by mid-July (right before the third wave started), government figures showed a total of 17 million downloads by mid-August (The People's Daily, 2020). This is reflection of the technology-based focus on epidemic preparedness and response in Vietnam's science and technology policy and explanation for the achievements attained in the country's fight against COVID-19. With regards to economic recovery, on October 5, 2020, Hanoi launched a national programme to boost the founding of start-ups in information technology and other high-tech businesses with a view to energizing the country's growth potential under the negative impacts of COVID-19 on the economy.

Secondly, Vietnam shows potential for the vaccine production industry. Vietnam is among 39 countries that meet WHO's strict vaccine standards. It has been registered for National Regulatory Authority (NRA) standards since 2001. In May 2013, the national vaccine management was strengthened with the participation of four agencies under the Health Ministry - the Drug Administration, the Administration of Science, Technology and Training, the General Department of Preventive Medicine, and the National Institute for Control of Vaccine and Biologicals. During the past decade, vaccine manufacturers in Vietnam have been producing and supplying tens of millions of doses of various vaccines serving local needs and for export (VNS, 2015). In response to COVID-19, Vietnam has had four COVID-19 vaccines under research and test, produced by NANOGEN, VABIOTEC, POLYVAC, and the Institute of Vaccines and Medical Biologicals (IVAC) (Le, 2020). The country was invited by the Vaccine Alliance to join in research and production of vaccine against COVID-19.

Thirdly, Vietnam had practical experiences in successfully managing the outbreak of fatal epidemics like SARS, MERS-COV, and H5N1 bird flu. They helped providing the country with both empirical lessons and institutional infrastructure to respond rapidly and operate the crisis management system flexibly and effectively, thereby sustaining national resilience in the current fight against COVID-19. Vietnam's experience with epidemic preparedness and management also served as an important factor to guarantee greater willingness among people in the country to trust, support, and comply with a central public health response.

Fourthly, Vietnam has been actively participating in international cooperation in science and technology, with special regards to public health and epidemic management. In 2014, Vietnam was one of the first to join the Global Health Security Agenda, a group of 67 countries committed to strengthening global efforts in prevention, detection, and response to infectious disease threats. The Centres for Disease Control and Prevention (CDC) started working with the government of Vietnam and local organizations in 1998 to build effective and sustainable public health systems. CDC provides technical expertise for evidence-based decisions to strengthen the capacity and infrastructure of Vietnam's national health systems and works closely with Vietnam to address HIV, tuberculosis, and influenza, as well as strengthening laboratory, surveillance, and workforce capacity to respond to disease outbreaks including COVID-19. Most recently, for its unique health system experiences and expertise, including its effective COVID-19 response, Vietnam has been the only Asian country to be selected by the World Economic Forum for the Partnership for Global Health System Sustainability and Resilience (PHSSR) to apply a framework developed by the London School of Economics to conduct a review of the country's health system sustainability and resilience, and identify practical solutions to strengthen them. The review would be focusing on hospital quality management during COVID-19 and healthcare provision at the grassroots level, with a view to helping highlight lessons and experience from Vietnam and share them with other countries (Phan Anh, 2020).

As the ASEAN Chair in 2020, Viet Nam has been working closely with other ASEAN member states in promoting a whole-of-community, multi-sectoral and multi-stakeholder approach to respond to COVID-19 as a cohesive and responsive Community. Neither COVID-19 nor any clear forecast of a possible global pandemic might have been taken into consideration when the theme "Cohesive and Responsive" for the ASEAN chairmanship year 2020 was proposed by Vietnam and supported by others. Yet, the relevance of the theme has been well showcased by the outbreak and impacts of COVID-19. The pandemic presented an empirical test to the cohesiveness and responsiveness of ASEAN, while putting huge pressure on Vietnam to prove its capacity to lead the grouping towards greater cohesiveness and responsiveness as the Chair in an unprecedented context.

Through to the end of the year, ASEAN and Vietnam proved to have taken the test rather well. Vietnam demonstrated a high level of responsiveness by working hard, including behind the scenes, to bring all ASEAN members and external partners from various time zones together, making digital diplomacy a new normal of ASEAN business (Tung, 2020). At the initiatives and proposals of Vietnam, the agendas were promptly adjusted, ASEAN community-building commitment and momentum was sustained, and ASEAN cooperation within the region and with dialogue partners was forged in combating COVID-19 and post-pandemic recovery. The cohesiveness and responsiveness of ASEAN was reflected by the shared determination to jointly respond to COVID-19 and consensus reached on creating new impetus to improve its competitiveness in the post-pandemic world, optimizing intra-bloc cooperation opportunities, applying cutting-edge technologies and sciences, improving digital transformation capacity, and developing high-quality human resources in ASEAN so as to establish its new position in the global and supply chain in the post-COVID era.

ASEAN responsiveness also resulted in the establishment of the ASEAN COVID-19 Response Fund and the ASEAN Regional Reserve of Medical Supplies to which Viet Nam has respectively committed to contributing US$ 100,000 and US$ 5 million worth of medical supplies. Vietnam also set an example of cohesiveness and solidarity by taking the initiative in assisting other ASEAN members, and other countries in Asia, Europe, the U.S., and South America, with masks, protective gears, and medical equipment. This was where the mutually reinforcing nexus between national resilience and regional resilience came again into the picture of COVID-19 response in Southeast Asia and ASEAN. "Vietnam has demonstrated strong leadership of ASEAN in spearheading a collective regional response to the COVID-19 pandemic", said ASEAN Secretary General Dato Lim Jock Hoi (Pham, 2020).

Conclusion

COVID-19 has served as a reminder of the real necessity for science-based policies as well as greater demand for national and regional resilience and good governance to deal with emerging challenges which are growing in both ferocity and scale, and with which no country can successfully contend on its own. Under its protracted spread and impacts, countries worldwide have been compelled to make their utmost domestic effort to curb, and overcome the social and economic consequences of, the pandemic. The "self-help" measures should be contributing to and complemented by collective response, given the high contagiousness of the disease and the close interconnectedness among countries in the world today. For Southeast Asia, the cohesive and responsive spirit has been and will be determinant in the response to COVID-19 and sustaining the relevance and resilience of the ASEAN Community further beyond.

References

ASEAN, Chairman's Statement on ASEAN Collective Response to the Outbreak of Coronavirus Disease 2019, February 14, 2020a

ASEAN, Declaration of the Special ASEAN Summit on Coronavirus Disease 2019 (Covid-19), April 14, 2020b

ASEAN, Chairman's Statement of the 36th ASEAN Summit, June 26, 2020c

ASEAN Vision 2020, Kuala Lumpur, December 15, 1997

Balajee S, Pasi OG, Etoundi AM, et al. Sustainable model for public health emergency operations centers for global settings. Emerging Infectious Diseases, 23(13), 2017

Bui, Thi Thu Ha., La, Ngoc Quang., Mirzoev, Tolib., Nguyen, Trong Tai., Pham, Quang Thai., Phung, Cong Dinh. "Combating the COVID-19 Epidemic: Experiences from Vietnam," International Journal of Environmental Research and Public Health, 17 (9), 2020

Chairman's Statement of the 15th East Asia Summit, November 14, 2020

Dang, Cam Tu. "The State is Back While the Virus is In," Asialink Insights, May 20, 2020

Decision No.418/QD-TTg, Approving the Strategy for Science and Technology Development for the 2011-2020 Period, The Prime Minister, The Socialist Republic of Vietnam, Hanoi, April 11, 2012

Demetriadi, Alexi. "ASEAN's Covid-19 response: United in name, divided in practice," Southeast Asia Globe, May 15, 2020

Dezan Shira & Associates, "The Coronavirus in Asia and ASEAN - Live Updates by Country," ASEAN Briefing, November 2020

Fueh, Sara. "Enlisting Science and Technology in the Fight Against Covid-19 - and the Ongoing Struggle for Sustainable Development,"

The National Academies of Sciences Engineering Medicine, May 20, 2020

G7 Science and Technology Ministers' Declaration on Covid-19, May 28, 2020

Han, Emeline; Tan, Melisa Mei Jin; Turk, Eva; Sridha, Devi; Leung, Gabrien M.; Shibuya, Kenji, et al. "Lessons learnt from easing COVID-19 restrictions: an analysis of countries and regions in Asia Pacific and Europe," The Lancet, September 24, 2020

Hoang Nam, Báo châu Á nêu động lực tăng trưởng của kinh tế Việt Nam và lợi thế khiến các nước "ghen tị", Thế giới & Việt Nam (World & Vietnam), November 23, 2020

Hoang, Thi Ha. "Flying the ASEAN Flag in a Pandemic Year: Vietnam's 2020 Chairmanship," ISEAS Perspective, No.17, Yusof Ishak Institute, 2020

Koetsier, John. "The 100 Safest Countries in The World for Covid-19," Forbes, June 5, 2020

Le, Chi. "Vietnam may begin human trials of Covid-19 vaccine this month," VN Express International, November 3, 2020

Mercado, Lan. "To tackle COVID-19, a United ASEAN must deliver urgently," Oxfam, (https://vietnam.oxfam.org/latest/stories/tackle-covid-19-united-asean-must-deliver-urgently)

Minh Vu and Bich T. Tran, "The Secret to Vietnam's COVID-19 Response Success," The Diplomat, April 18, 2020

Pham, Linh. "How Vietnam has lead ASEAN in a year of turbulence," The Hanoi Times, November 11, 2020

"Số lượt cài ứng dụng tăng mạnh, Đà Nẵng bắt đầu truy vết qua Bluezone," Nhân Dân (The People's Daily), August 13, 2020 (nhandan.com.vn/thong-tin-so/so-luot-cai-ung-dung-tang-manh-da-nang-bat-dau-truy-vet-qua-bluezone--612690/)

Phan Anh, "Vietnam sole Asian country in WEF global healthcare initiative," VN Express International, November 19, 2020

Strangio, Sebastian. "COVID-19 Recovery Dominates Weekend of Asian Summits," The Diplomat, November 16, 2020

The People's Republic of Myanmar, Ministry of Information, Global forum on COVID-19 pins down research priorities: WHO, February 14, 2020

The Role of Science and Technology in Society and Governance: Toward a New Contract between Science and Society, Executive Summary of the Report of the North American Meeting held in advance of the World Conference on Science, November 1-3, 1998

Truong, Dao Thanh. Perspectives on Vietnam's Science, Technology, and Innovation Policies, Palgrave Macmillan, 2019

Tung, Nguyen Vu. "Has the pandemic disrupted Vietnam's chairmanship of ASEAN?", ISIS Malaysia Focus, May 26, 2020

UNCTAD, UN to explore the role of science and technology policies in Covid-19 recovery, June 9, 2020

United Nations Department of Economic and Social Affairs (UNDESA), "The Covid-19 pandemic: a wake-up call for better cooperation at the science - policy - society interface," Policy Brief 62, April 22, 2020

United Nations, Department of Global Communications, UN mobilizes global cooperation in science-based COVID-19 responses, Apr 7, 2020

UNESCAP, "UN Forges Technological Cooperation to Tackle Covid-19 in Asia and the Pacific," Press Release, Bangkok, August 20, 2020

USAID, ASEAN Science and Technology Fellowship Workshop Showcases ASEAN Scientists' Contributions During COVID-19, Press Release, October 8, 2020

"VN vaccines can be exported: WHO," Viet Nam News, April 22, 2015

Challenges and Opportunities for Health Research During the COVID-19 Pandemic

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Abstract

The COVID-19 pandemic has disrupted almost all areas of daily lives, including research. While the pandemic has clearly posed many significant challenges to the research world, it has also presented great opportunities for research to improve moving forward. Key challenges for health research include: erosion of public trust on clinical trials due to concerns that procedures are being cut with regard to safety and efficacy; difficulties to conduct research due to pandemic circumstances; and distortion of health research priorities and funding. Key opportunities for health research include: extra time to conduct pending studies, data analysis, manuscript writing as well as to pursue new research ideas and acquire new skills; increased public appreciation of research; and momentum for universities to change. Researchers and research institutions should draw more attention to opportunities and shift to a more positive narrative to mobilise for change. Now is the time to reconstruct research models and paradigms to fit a world where crisis is the new normal.

1. Introduction

There have been 66,729,375 confirmed cases of COVID-19 globally, including 1,535,982 deaths, reported to WHO as of 8 December 2020 (WHO, 2020a). The novel coronavirus (SARS-CoV-2) was first identified in Wuhan, China on December 31, 2019 and has spread extensively through Asia and the rest of the world since then (Du et al., 2020). The COVID-19 pandemic has wreaked multiple shocks on the region: the pandemic itself, the economic impact of domestic economic shutdowns, and aftershocks from the global recession triggered by the pandemic (World Bank, 2020). Almost all areas of daily lives have been disrupted, and research has been no exception (Rosales-Mendoza et al., 2020). Notwithstanding, while the COVID-19 pandemic has clearly posed many significant challenges to academic research in the region, it has also presented great opportunities for research to improve moving forward. This paper aims to highlight key challenges and opportunities to health research posed by COVID-19 pandemic.

2. Challenges

Scientists across the world are currently racing to produce effective and safe COVID-19 vaccines. There are 51 candidate vaccines in clinical evaluation and 163 candidate vaccines in preclinical evaluation reported by WHO as of 2 December 2020 (WHO, 2020b). At the head of the line waiting for the vaccine, are the populations of wealthy countries (Maslog, 2020). Pfizer has already sold 82 per cent of its vaccine stocks to some of the world's wealthiest countries (Lovett, 2020). These countries represent just 14 percent of the global population. The remaining 86 percent of the world's population, including those in less developed Asian countries, have to wait. These countries have very limited capacity for vaccine research and development, thus some opted to be testing grounds for the vaccines developed by wealthy countries in order to secure access (Maslog, 2020). In August 2020, China's Sinovac Biotech Ltd initiated Phase-3 clinical trial in Indonesia involving 1,620 patients in Indonesia for a COVID-19 vaccine candidate known as CoronaVac (Widianto et al., 2020). The Philippines is expecting to join by end of 2020 Phase-3 clinical trials of Russia's Sputnik V vaccine, which reportedly has 92% efficacy rate in preventing COVID-19 (Sayson, 2020). Clinical trials need to follow strict protocols and adhere to Good Clinical Practice standards to ensure safety, ethic and quality. The current pace of vaccine trials, particularly in less developed countries, has thus triggered concerns that essential procedures are being cut, compromising safety and efficacy (Schwarz, 2020). Only if the public is convinced that available vaccines are safe and effective, COVID-19 vaccination programs will succeed. Thus, there is a real risk that rushing clinical trials procedures could erode public trust on health research and set back research in less developed countries by many years.

The COVID-19 pandemic has hindered other essential health research in the region. In Nepal for example, almost all non COVID-19 health research has been stalled and some studies that are due to begin have been delayed (Basnyat et al., 2020). Across the world, most clinical trials have been halted, and most continuing trials are now closed to new enrolment (Weiner et al., 2020). COVID-19 mitigation efforts in general interfere with critical aspects of successful clinical research (McDermott and Newman, 2020). These mitigation efforts typically include self-isolation and avoiding academic medical centers, where COVID-19 patients are treated and where clinical research are commonly conducted. Thus, recruitment into clinical research is increasingly difficult due to reduced mobility because of restrictions and the general fear of contracting COVID-19 (Basnyat et al., 2020). Many intervention and observational studies requiring contact with research participants have thus been deferred because of the need for physical distancing (Gnanavel et al., 2020). When the patients do access academic medical centers and willing to be recruited, they still need to be tested to rule out SARS-Cov-2 infection. COVID-19 rapid antibody and antigen tests are currently less reliable than PCR test, and not yet widely available (Gill and Ponsford, 2020; Guglielmi, 2020). Recruitment into non COVID-19 clinical research consequently requires expensive PCR tests and advanced laboratory facilities that are only available in few centres in resource constrained settings (Basnyat et al., 2020). This problem has been further aggravated as research institutions enacted strict procedures for research operations, requiring researchers to follow social distancing guidelines in the laboratory, facility closures, and minimizing laboratory activities (Termini and Traver, 2020).

The pandemic has also distorted health research priorities and substantially disrupting funding streams for non COVID-19 health research (Gnanavel et al.,2020; Pai, 2020a). Governments, pharmaceutical industries and academic institutions have turned nearly their entire focus to COVID-19 research (Venkatesan, 2020). Billions of euros have been rapidly infused for COVID-19 research by multinational support (Harper et al., 2020). Some funding agencies are making such funding available for COVID-19 research at the cost of postponing or cancelling regular grant competitions (Pai, 2020b). Allocation of funds by different grant agencies to research projects for COVID-19 thus could further impede already under-resourced research areas (Gnanavel et al., 2020), such as Neglected Tropical Diseases. Resources and funding have already been diverted away from malaria, HIV/AIDS and tuberculosis towards COVID-19 research, indirectly increasing the risks of these diseases transmitting, undetected and untreated (Venkatesan, 2020). Ethics approval for non COVID-19 studies has also been delayed with a fast track provision available only for studies on COVID-19 (Gnanavel et al., 2020). Research groups working in areas not directly related to COVID-19 are lured away from their area of expertise to COVID-19 research (Pai, 2020b). These groups are spending a great amount of energy shifting their work to the pandemic response. Research-related hiring has been halted because of travel restrictions and junior researchers might soon find themselves out of a job if their research focus is not related to the COVID-19 pandemic (Harper et al., 2020). Academic institutions are struggling with significant financial challenges due to reduction in philanthropic support and revenue, leading to slowdowns in hiring and salary reductions, which may persist for many years to come in resources constrained settings (Levine and Rathmell, 2020). Some institutions are preparing to lay off staff in response to disrupted funding, posing risks that highly skilled researchers will drift away, while institutional relationships and skills will fade away (Reidpath et al., 2020). Medical research bodies funded by governments have declared that they are committed to maintain the breadth and continuity of medical research, however research funding that relies on public fundraising is expected to drop considerably, thus researchers will see a decrease in funding opportunities (Harper et al., 2020). All of these challenges are global, however evidently less developed countries are particularly vulnerable.

3. Opportunities

Despite many challenges posed by COVID-19 as outlined above, for many researchers, the pandemic has actually provided extra time to pause, reflect and even improvise ongoing research (Gnanavel et al., 2020). Daily academic life has changed dramatically as meetings and teaching has been shifted to online platforms (Peters et al., 2020). Academics under these extraordinary circumstances can conduct pending experiments or data analysis, work on manuscripts left behind, and pursue new research ideas (Rosales-Mendoza et al., 2020). Postdoctoral fellows and graduate students can also take advantage of the halt in lab/field work to analyze data left behind, review literatures, write articles or dissertations. These junior researchers now also can take advantage of increasing opportunities to acquire new skills and ideas through online conferences, webinars and courses, which keeps growing in number and scope. This may range from courses in new analysis software, bioinformatics to computational biology (Termini and Traver, 2020). Many academic institutions are already hosting online courses and workshops on using bioinformatics tools and learning coding languages.

The public has never been as appreciative of research as they are during the COVID-19 pandemic (Levine and Rathmell, 2020). The pandemic has evidently boosted appreciation of research as the public witness a golden age of scientific discovery, with diagnostics, drugs and vaccines developed/repurposed in warp speed (Gostin, 2020). The frequently cited timeline for a coronavirus vaccine to come to market is 12 to 18 months, while most vaccines commonly take at least a decade (Roush, 2020). High-quality research aligned with top priority societal goals that produce credible data and actionable information is critical for pandemic response and preparedness. For the public, the pandemic thus highlights the importance of research and solid research infrastructure (Weiner et al., 2020). Lessons learned from research during this pandemic on balancing high-quality, time-efficient, cost-effective research and multiple novel approaches could also benefit the research enterprise beyond the pandemic. This has been addressed by innovative study design, transdisciplinary collaboration, artificial intelligence and adaptation of regulatory approval processes for crisis situation (Weiner et al., 2020). Science has also become more open, while countries, cities and universities are being locked down (Xu, 2020). Since the outbreak of COVID-19, researchers are sharing databases (including genome sequences) openly, rapidly and broadly. This has enabled a quick start worldwide to rapidly develop diagnostics, treatments and vaccines against COVID-19. The pandemic has thus also provided an opportunity to reimagine the research world.

The COVID-19 pandemic has also pushed universities to the forefront of public discourses. Experts in public health, epidemiology, mathematical modelling and infectious diseases are central for news media and decision making; academic clinical research has been vital to improving COVID-19 management; and academic laboratory has been crucial for COVID-19 diagnostic testing (Lancet, 2020). In the meanwhile, these academic institutions have also been pressured to consider new ways of doing things that are better for everyone involved and rethink traditional academic structures in response to the pandemic (Guzman, 2020). Universities now need to be much more deliberate to dismantle disciplinary silos, boundaries and borders (Kupe, 2020). As the pandemic has starkly demonstrated, societal challenges are highly complex, thus do not fit neatly into disciplinary paradigms. In embracing transdisciplinary research, universities also need to reimagine international collaboration. Human engagement is required for many aspects of research and can be augmented by online platforms (Kupe, 2020). Thus, the academic research space can benefit from a stronger hybrid future. Traditionally universities have been slow to change, but the pandemic revealed that rapid change is possible when these knowledge organizations sense urgency and no room for inaction (Guzman, 2020).

4. Conclusions

The COVID-19 pandemic has affected research institutions in many countries. Notably, the degree of its disruption and the ability of those institutions to mitigate the pandemic's impact have varied considerably across settings. More established research institutions generally have the resources and infrastructure to weather the pandemic, while less developed research institutions have more limited capacity, and COVID-19 actually heightened their challenges. In any case, the pandemic not only posed substantial challenges for practically all research institutions, but has also resulted in unique opportunities that we could seize for resetting the research world.

While COVID-19 has become the top priority, researchers and research institutions should draw more attention to opportunities and shift to a more positive narrative to mobilise for change. (Basnyat et al., 2020).

We must seize this window of opportunity to engage the public on the importance of health research and the need for increased, longer-term investment into health research to benefit society at large (Levine and Rathmell, 2020). We also need a long-term strategy and vision for research (Egger, 2020). Crisis driven short term thinking is neither sustainable nor strategic (Pai, 2020b). Hence, visionary research models and paradigms must emerge from this pandemic (Weiner et al 2020). Now is the time to reconstruct research models and paradigms to fit a world where crisis is the new normal. As Winston Churchill has said: “Never let a good crisis go to waste.”

References

Basnyat, B., Salami, O., Karkey, A., Moore, C., Giri, A., and Olliaro, P. (2020, December 6). The impact of covid-19 on health delivery and research in South Asia. British Medical Journal. https://blogs.bmj.com/bmj/2020/09/23/the-impact-of-covid-19-on-health-delivery-and-research-in-south-asia/

Du, Z., Javan, E., and Nugent, C. (2020). Using the COVID-19 to influenza ratio to estimate early pandemic spread in Wuhan, China and Seattle, US. EClinicalMedicine, 100479.

Egger, M. (2020, December 7). We are here to solve problems, not to COVIDise. Horizons. https://www.horizons-mag.ch/2020/06/04/we-are-here-to-solve-problems-not-to-covidise/

Gill, D., and Ponsford, M.J. (2020). Testing for antibodies to SARS-CoV-2. British Medical Journal, 371. https://doi.org/10.1136/bmj.m4288

Gnanavel, S., Orri, M., Mohammed, M., Dray, J., Baroud, E., Kato, H., Jui, G.T., Rajalakshmi, A.K., Hansen, A.S., Seker, A., Ori, D., Munjiza, A., and Martsenkovskyi, D. (2020). Child and adolescent psychiatry research during the COVID-19 pandemic. Lancet Psychiatry,7(9), 735. doi: 10.1016/S2215-0366(20)30314-X. PMID: 32828155

Gostin, L.O. (2020, December 8). Science, Leadership, and Public Trust in the COVID-19 Pandemic. Milbank Quarterly Opinion. https://doi.org/10.1599/mqop.2020.0715.

Guglielmi, G. (2020). Fast coronavirus tests: what they can and can’t do. Nature, 585, 498-498.

Guzman, D. (2020, December 7). 3 Challenges and 3 Opportunities for Researchers during COVID-19. ExLibris. https://exlibrisgroup.com/blog/researchers-covid19-3-challenges-3-opportunities/

Harper, L., Kalfa, N., Beckers, G.M.A., Kaefer, M., Nieuwhof-Leppink, A.J., Fossum, M., Herbst, K.W., Bagli, D., and ESPU Research Committee (2020). The impact of COVID-19 on research. Journal of Pediatric Urology, 16(5),715-716. doi: 10.1016/j.jpurol.2020.07.002. Epub 2020 Jul 9. PMID: 32713792

Kupe, T. (2020, December 8). COVID-19: A time to reimagine and reposition universities. University World News. https://www.universityworldnews.com/post.php?story=20201102155159763

Lancet (2020). Research and higher education in the time of COVID-19. Lancet, 396(10251), 583. doi: 10.1016/S0140-6736(20)31818-3.

Levine, R.L., and Rathmell, W.K. (2020). COVID-19 impact on early career investigators: a call for action. Nature Reviews Cancer, 20, 357–358. https://doi.org/10.1038/s41568-020-0279-5

Lovett, S. (2020, December 8). Pfizer vaccine: Over 80% of doses already sold to world’s richest countries. The Independent. https://www.independent.co.uk/news/health/covid-pfizer-vaccine-doses-latest-uk-supplies-b1721162.html

Maslog, C. (2020, December 6). The science and economics of COVID-19 vaccines. SciDev.Net. https://www.scidev.net/asia-pacific/medicine/column/the-science-and-economics-of-covid-19-vaccines/

McDermott, M.M., and Newman, A.B. (2020). Preserving Clinical Trial Integrity During the Coronavirus Pandemic. Journal of American Medical Association, 323(21), 2135-2136. doi:10.1001/jama.2020.4689.

Pai, M. (2020a, December 6). 'Covidisation' of academic research: opportunities and risks. Nature Research Communities: Microbiology. https://naturemicrobiologycommunity.nature.com/posts/65638-covidisation-of-academic-research-opportunities-and-risks

Pai, M. (2020b). Covidization of research: what are the risks? Nature Medicine, 26, 1159

Peters, M.A., Rizvi, F., McCulloch, G., Gibbs, P., Gorur, R., Hong, M., et al. (2020) Reimagining the new pedagogical possibilities for universities post-Covid-19. Educational Philosophy and Theory. DOI: 10.1080/00131857.2020.1777655

Rosales-Mendoza, S., Comas-García, M., and Korban, S.S. (2020). Challenges and Opportunities for the Biotechnology Research Community during the Coronavirus Pandemic. Trends in Biotechnology, 38(8), 823-824. doi: 10.1016/j.tibtech.2020.04.016. PMID: 32423724

Reidpath, D., Allotey, P., 166 signatories (2020). Preserve Global South's research capacity. Science, 368(6492), 725. DOI: 10.1126/science.abc2677

Roush, K. (2020). The Race to Develop a COVID-19 Vaccine. American Journal of Nursing, 120 (10), 14-15. doi: 10.1097/01.NAJ.0000718556.85319.00

Sayson, I.C. (2020, December 6). Philippines Likely to Join Russia Vaccine Trials Later This Year. Bloomberg. https://www.bloomberg.com/news/articles/2020-11-11/philippines-likely-to-join-russia-vaccine-trials-later-this-year

Shwarz, J.L. (2020). Evaluating and Deploying Covid-19 Vaccines — The Importance of Transparency, Scientific Integrity, and Public Trust. New England Journal of Medicine, 383, 1703-1705. DOI: 10.1056/NEJMp2026393

Termini, C.M., and Traver, D. (2020). Impact of COVID-19 on early career scientists: an optimistic guide for the future. BMC Biology, 18(1), 95. doi: 10.1186/s12915-020-00821-4. PMID: 32731867

Venkatesan, P. (2020). COVID-19 diagnostics—not at the expense of other diseases. Lancet Microbe, 1(2), e64. doi: 10.1016/S2666-5247(20)30041-0

Weiner, D.L., Balasubramaniam, V., Shah, S.I., and Javier, J.R., & Pediatric Policy Council (2020). COVID-19 impact on research, lessons learned from COVID-19 research, implications for pediatric research. Pediatric Research, 88(2), 148-150. doi: 10.1038/s41390-020-1006-3. Epub 2020 Jun 16. PMID: 32544922

Widianto, Y., & Liu, R. (2020, December 6). Sinovac launches Phase 3 trial for COVID-19 vaccine in Indonesia, reports Phase 2 details. Reuters. https://uk.reuters.com/article/us-health-coronavirus-indonesia-vaccine/sinovac-launches-phase-3-trial-for-covid-19-vaccine-in-indonesia-reports-phase-2-details-idUSKCN2570E9

World Bank (2020, December). From Containment to Recovery. World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/34497/9781464816413.pdf

WHO (2020a, December). WHO Coronavirus Disease (COVID-19) Dashboard. World Health Organization. https://covid19.who.int/

WHO (2020b, December). Draft landscape of COVID-19 candidate vaccines. World Health Organization. https://www.who.int/publications/m/item/draft-landscape-of-covid-19-candidate-vaccines

Xu, X. (2020, December 8). How can we reimagine future global research post COVID-19? University World News. https://www.universityworldnews.com/post.php?story=20201021034340242

Indonesia's Potential for Elucidating New Therapeutic Treatments for COVID-19

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Abstract

Many therapeutic strategies have been devised to combat the COVID-19 pandemic, including the development of new vaccines, the administration of antivirals, and the use of plant-derived medicines. Unfortunately, the current strategies are either not yet available, or have not convincingly and unequivocally shown the desired efficacy needed to combat the pandemic. The identification of active compounds in plant-derived medicines can lead to new antivirals in the future, which makes plant biodiversity an indispensable resource. Countries that have high biodiversity such as Indonesia can play an important role in the elucidation and development of new plant-derived medicines and antivirals. In this article, we highlight the potential of Indonesia's assets such as its plant diversity and a strong history of utilizing traditional medicines to fight the current pandemic. We also introduce possible roadmaps for the development of new treatments from the assets and policy interventions that can be implemented.

1. Introduction

The COVID-19 pandemic has wreaked havoc on many aspects of life. So much so to the point where national and global agendas have been halted and reconsidered (van Staden, 2020). The pandemic has caused the slowing down of the global economy (Gopalan & Misra, 2020; Nicola et al., 2020), reorientation of education systems (Teräs et al., 2020), revamping of healthcare systems (Miller et al., 2020; Ming et al., 2020), mass environmental changes (Lal et al., 2020; Shakil et al., 2020; Somani et al., 2020), to even the halt and reorganization of professional sports (Corsini et al., 2020; Difiori et al., 2020).

Indonesia is one of the countries that has been hit hard by the current pandemic in many aspects (Setiati & Azwar, 2020). The Indonesian Government has implemented many strategies to balance the welfare and the wellbeing of its citizens, including the implementation of large scale social restrictions, which have proven to be not as effective as desired (Purnama & Susanna, 2020; Suraya et al., 2020).

The large scale social restrictions were meant to keep the economy running, while protecting citizens from new infections, because if left uncontained, there is a large possibility of the occurrence of a large scale outbreak (Aldila et al., 2020). In fact, at the time of this writing, the infection rate in Indonesia has gone up to approximately 5,000 infections per day, with a rising trajectory (Komite Penanganan COVID-19 dan Pemulihan Ekonomi Nasional, 2020). The increasing number of infections will inevitably have negative implications on the economy, which is exactly what the Indonesian Government is trying to avoid.

A lot of hope is being put on new vaccines to turn the tide and reduce the number of infections and return to pre-pandemic normalcy. However, successful implementation of vaccinations to slow down the pandemic depends on several factors, including the effectiveness the vaccines, the prices in which they are available, and how widespread the vaccinations can be implemented at a certain time period (Harapan et al., 2020). In addition, for the time being, there are still some *caveats* or risks that are related to the implementation of vaccines, which we will further elaborate (W. H. Chen et al., 2020).

Another option, which also has potential in fighting the pandemic and other novel diseases, is by using plant-derived medicines (Ghildiyal et al., 2020; Weng, 2020; Wink, 2020). Indonesia can play a significant role in the effort of elucidating novel treatments from plants. Mainly due to its immense biodiversity (Ragamustari & Sukara, 2019) and its strong and long tradition in using plant-based medicines (Elfahmi et al., 2014; Hartono Wijaya et al., 2016; Stevensen, 1999).

Unfortunately, there are also bottlenecks and challenges in the development of new plant-based medicines in Indonesia that need to be managed, from the low science and technology capacity, underdeveloped national innovation system (Ragamustari et al., 2020), to the mismanagement of natural resources (Ragamustari & Sukara, 2019). The roadmap to develop new plant-based medicines, especially to fight the current pandemic (from an Indonesian perspective) is the main topic of the current article.

2. The challenges for developing a new vaccine for COVID-19

There are important considerations for mass application of a vaccine for COVID-19, namely its effectiveness and safety. The vaccine needs to show high efficacy, while at the same time be safe for the vaccinees. Finding a silver bullet will be problematic because people who are infected might show different physiological reactions toward a certain vaccine. Thus, some safety measures related to the choice of vaccine platform, choice of adjuvant, mode/route of vaccine administration, age of vaccinees, and pre-existing immunity need to be meticulously considered (Jeyanathan et al., 2020).

The attempt in developing a new vaccine for COVID-19 immediately began after the outbreak in its origin place at Wuhan, China at the end of 2019. By January 2020, the genetic sequence of the SARS-CoV-2 virus, which causes the COVID-19 disease was published (Thanh Le et al., 2020). The genetic sequence became a basis for laboratories and vaccine manufacturers to produce a vaccine for COVID-19. As of July 2020, there are already more than 160 vaccine candidates that have been developed by various laboratories and companies. However only a small amount have entered into I, II, and III clinical trials (Jeyanathan et al., 2020).

Generally, there are six categories of technologies or approaches that are used to develop a vaccine for COVID-19, which include: 1) live attenuated virus, 2) recombinant viral-vectored vaccines, 3) inactivated or killed viruses, 4) protein subunit vaccines, 5) virus-like particles, and 6) nucleic acid based (mRNA and DNA) vaccines. Each of the technologies have pluses and minuses. Out of the six categories, the total number of vaccines per July 2020 that have gone into pre-clinical trial is 139, while the number of vaccines that have gone into clinical trial is 27. None from the live attenuated virus category have gone into clinical trials, while at least one of vaccine from the other categories have gone into clinical trial. The three best COVID-19 candidates are viral vectored and mRNA-based vaccines (W. H. Chen et al., 2020; Jeyanathan et al., 2020).

There several underlying reasons for the slow progress of the development of a working and effective vaccine for COVID-19. One of them is the highly mutative nature of the SARS-CoV-2 virus (Lal et al., 2020). In addition, the mechanisms of COVID-19 infection and immune responses are not yet well understood (Jeyanathan et al., 2020). In fact, there are cases in which the SARS coronavirus vaccines may actually result in increased infectivity, which is dangerous for the person who is infected (W. H. Chen et al., 2020).

Another factor that will affect the timeline of mass application of a vaccine (if a working and effective one is developed) is a strategy for mass vaccination, which is related to production capacity of the vaccines. Ideally, the scenario will consist of three stages. The first stage is when there is limited supply of the vaccine. The vaccinees to be prioritized will be those who have the highest risk of mortality, such as people who have co-morbidities, health workers, the elderly, and ethnic minorities who have been hit the hardest by the pandemic. The second stage will be focused on individuals who were already infected but have recovered, were vaccinated during the medical trials (with candidate vaccines), or people who have been vaccinated in the first stage but have not developed adequate immunity to the virus. All of these groups have similarity in that all have waning immunity and are susceptible to future infections. The last stage is the period when there is enough vaccine supplies to conduct mass vaccinations, where vaccinations will be carried out and coordinated at the national level for the masses (Jeyanathan et al., 2020). In normal conditions, rationally, the mentioned scenario might take 10-15 years. But due to the urgency of combating the pandemic, it is compressed into 1-2 years.

Despite the laborious efforts to develop a vaccine for COVID-19, there is no guarantee that a working vaccine will be available anytime soon. Thus, it is imperative that alternative strategies to complement the effort to develop new vaccines for combating COVID-19 be done simultaneously. One strategy that has a potentially positive outcome is the use and development of antivirals.

3. The utilization of antivirals for COVID-19 treatment

Because of the unavailability of any working vaccines for the SARS-CoV-2 virus, the fight against the pandemic is still dependent on antiviral drugs and other methods. The antivirals being used for treatment of COVID-19 are ones that are used to treat other diseases caused by other viruses/organisms such as HIV, malaria, SARS-CoV, MERS, and influenza viruses (Jomah et al., 2020; Şimşek Yavuz & Ünal, 2020). Unfortunately, the efficacy of such antivirals toward COVID-19 showed mixed results and are correlated with many factors that are yet to be elucidated (Jomah et al., 2020).

Understanding the types of antivirals available will help in devising a strategy that is best suited for combating COVID-19. Antivirals are generally divided into six categories, which include protease inhibitors, broad spectrum antivirals, RNA-dependent RNA polymerase inhibitors, nucleoside inhibitors, neuroamidase inhibitors, and polymerase acidic endonuclease inhibitors (Teoh et al., 2020).

One of the most popular antivirals that is used to treat COVID-19 patients is hydroxychloroquine (Vinetz, 2020). It originally wasn't an antiviral at all and was used for the treatment of malaria and autoimmune diseases. The drug inhibits certain cellular functions and molecular pathways (Şimşek Yavuz & Ünal, 2020), which in turn interferes with the entry of the SARS-CoV-2 into the host cell (Frediansyah et al., 2020).

Early studies on efficacy of hydroxychloroquine toward COVID-19 reported that the drug showed antiviral activity toward SARS-CoV-2 and can be used for treatment of COVID-19 patients (Z. Chen et al., 2020; Gautret et al., 2020). These results have been the base for the authorization of the drug in national healthcare systems for treating COVID-19 patients. In fact, in Indonesia, the formal protocol for treating COVID-19 patients in the early stage of infection involve the administration of hydroxychloroquine along with azithromycin, vitamin C, and symptomatic treatments (Siswanto et al., 2020).

In reality, the administration of hydroxychloroquine for COVID-19 patients has shown mixed results. The very same report that showed hydroxychloroquine sped up the recovery time for some COVID-19 patients, also showed that the drug showed negative or no significant effect toward other patients. In addition, the report was also based on an imperfect research design that used a very small sample size and lacked important data such as the patients' cardiogram, total virus count and no placebo control (Z. Chen et al., 2020; Vinetz, 2020). However, it should be noted that placebo control is deemed unethical in the current pandemic situation. A more recent report on the administration of hydroxychloroquine have actually showed a range of different effects from no significant efficacy to the worsening of the condition of patients. In fact, it is not recommended for patients who experience pneumonia and require oxygen (Mahévas et al., 2020).

As mentioned earlier, Indonesia has been a strong advocator of the use of hydroxychloroquine and is still continuing to use it despite the antiviral being banned by WHO (Lamb & Allard, 2020). The reasons of the Indonesian Government's stance are due to the inconclusive results of clinical trials (on the efficacy or danger of hydroxychloroquine and other antivirals), the possible differences of Indonesian SARS-CoV-2 line with the one in other places (where there is still an open possibility that the antiviral have efficacy toward the Indonesian SARS-CoV-2 line), the differences in genetics of Indonesians with other populations (where there is a possibility that the physiology of Indonesians are suitable for the administration of hydroxychloroquine), and mainly, because of the lack of other options (Surbakti, 2020).

Besides hydroxychloroquine, there are other antivirals that have been authorized for COVID-19 treatment with varying degrees of success. For example, antivirals such as umifenovir, lopanovir, darunavir, atazanavir, saquinavir, emtricitabine, azvudine, remdisivir, favipiravir (Avigan), ribavirin, sofosbuvir, oseltamivit (Tamiflu) have all been authorized for use in one country or another for emergency COVID-19 cases (Frediansyah et al., 2020). Remdesivir and lopinavir have specifically been authorized by the United States Food and Drug administration for treatment of COVID-19 in emergency cases that involve severe infections of adults and children in the US (Jomah et al., 2020).

It should also be noted that the administration of antivirals that were mentioned have risks such as adverse side effects and contraindications. Adverse side effects include a combination of one or more of the following: gastrointestinal effects, allergic reactions, hyperuricemia, diarrhea, decreased appetite, kidney injury, hyperglycemia, fever, fatigue, nausea, cardiac conduct abnormalities, pancreatitis, bronchitis, sinusitis, or other adverse effects depending on the antiviral drug being administered. Some of the drugs should also not to be used by certain groups of people, such as people with hypersensitivity, children under a certain age, and people who are pregnant (Teoh et al., 2020).

Although the administration of antivirals for COVID-19 patients, including the ones authorized for use by certain countries during emergencies have been a hit and miss, and there is not enough information to devise a clinical practice (Teoh et al., 2020), research on antivirals need to be continued. As it opens up the possibility of new therapeutic strategies by targeting specific stages of the SARS-CoV-2 life cycle (Frediansyah et al., 2020). Nevertheless, we are still in dire need for other therapeutic strategies for effectively combating COVID-19.

4. Plant-derived traditional medicines and treatment

The non-existence of a working vaccine and the erratic results of available antivirals have forced medical practitioners to look for alternative strategies to treat COVID-19 patients. One strategy that has been used and achieved a certain degree of success is the use of plant-derived traditional medicines (Yang et al., 2020).

Plant-derived medicines have been an integral part of human civilization since its beginnings (Weng, 2020). They are widely used all around the world and are intertwined with many traditional cultures, including China (traditional Chinese medicine), Japan (kampo), Indonesia (jamu), and India (ayurvedic medicine). In Europe and the United States, plant-derived traditional medicines have found their way through homeopathy and phytotherapy (Itokawa et al., 2008). Plant-derived medicines also still play an important role modern medicine, where approximately 25% of all the modern medicines are directly or indirectly derived from plants (Calixto, 2000). In addition, the majority of population in some countries, especially developing countries, still depend on plant-derived traditional medicines as their primary source of healthcare, mainly due to the limited access toward conventional health services (World Health Organization (WHO), 2013).

Two major characteristics of plant-derived traditional medicines and other phytoterapeutic medicines are as follows: 1) that the active principles and mechanisms that lead to their efficacy are generally unknown; and 2) the pharmacological action is usually not as strong as conventional medicines and does not show immediate effect (Calixto, 2000).

In comparison with the administration of vaccines or antivirals, plant-derived traditional medicines have several advantages. Among them is their availability and price. Especially if the ingredients for the medicine mixture is embedded in the population's culture and history. In addition, plant-derived traditional medicines are generally regarded as relatively safe and shows less frequent adverse side effects if consumed within reasonable amounts (Calixto, 2000; Zeng & Jiang, 2010). However, it is worth noting that irresponsible administration of plant-derived traditional medicines has the potential to cause adverse side effects, especially for people who are simultaneously taking different medications, where it can trigger adverse drug reactions (Zeng & Jiang, 2010). Other risks that are related to the administration of plant-derived traditional medicines include poor quality products used in medication, unqualified practitioners, improper diagnosis, and misleading information from practitioners (World Health Organization (WHO), 2013).

In relation to the COVID-19 pandemic, several cases in China where plant-derived traditional medicines were used to treat COVID-19 patients have shown positive results (Weng, 2020; Yang et al., 2020). China is known to have a long history spanning over millennia of using plants in the form of Traditional Chinese Medicines (TCM) (Weng, 2020). TCM is also integrated into the Chinese healthcare system, which is coordinated by the National Administration of Traditional Chinese Medicine (NATCM), so administration of TCM is officially authorized for treating COVID-19 patients (Yang et al., 2020).

An example of a TCM showing efficacy that is being administered to COVID-19 patients in China is the lung cleansing and detoxifying decoction (LCDD) (Weng, 2020). LCDD was made based on a classical literature wrote by Zhang Zhonjing (AD 150~219), titled *Treatise on Cold Pathogenic and Miscellaneous Diseases*. Four classical formulas were used as the basis to make LCDD, which contains 21 different plant species. After the authorization of its use, LCDD has been widely used in China by 28 provinces and municipalities (Weng, 2020).

Thus, it is indeed possible to develop new plant-derived medicines based on traditional knowledge. However, the process might not be as straightforward as it is in China. There are many bottlenecks in the adaptation of traditional medicines such as LCDD outside of China. These bottlenecks include 1) the lack of societal and cultural acceptance and trust toward traditional medicines, 2) the lack of institutional structure to support the transition of traditional medicines for use in conventional healthcare system, and 3) the lack of understanding of the science behind traditional medicines result in low acceptance by patients and physicians (Weng, 2020).

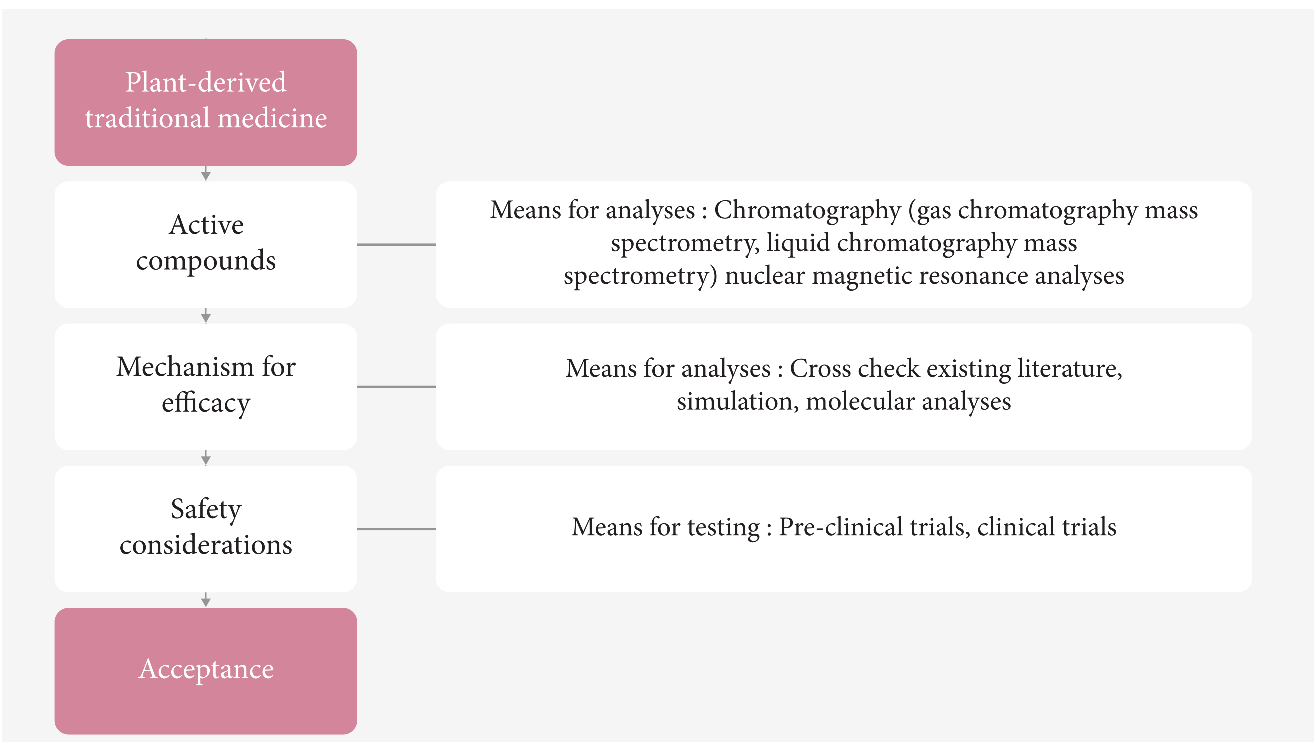
The first bottleneck can be managed by education and propaganda by the government of a nation. This bottleneck will differ depending on a country's social and cultural makeup. Indonesia for example, has a long and strong history in using traditional medicines, which make this bottleneck less significant. The second bottleneck can be managed by designing new institutions and policies that support the transition of traditional medicines into the conventional healthcare system, akin to China's NATCM and TCM adaption roadmap. Indonesia actually has a national commission for the scientification of jamu, which was formed in 2013 through the decree of the Indonesian Ministry of Health Number 296/MENKES/SK/VIII/2013. Unfortunately, there is very little information on what the commission has been doing since its inception. The last bottleneck can be managed by providing better scientific evidence on the mechanisms of the efficacy of plant-derived traditional medicines. There are already many researches that have been done on the subject (Kartini et al., 2019; Sumarni et al., 2019), but need to be compiled into a structured database.

5. The science behind plant-derived traditional medicines

As has been mentioned, understanding the science behind plant-derived traditional medicines is an important step for acceptance by patients and physicians so that their transition into conventional healthcare systems can take place.

Generally, plants exhibit therapeutic attributes because of secondary metabolites they produce. In relation to the current pandemic, secondary metabolite groups that exhibit antiviral activity that have the potential to be used against SARS-CoV-2 include phenolics, terpenoids, and alkaloids. The largest group of plant secondary metabolites that show antiviral activity is phenolics, which consists of phenolic acids, flavonoids, stilbenes, coumarins, and tannins (Itokawa et al., 2008; Jahan & Onay, 2020). Thus, the first step to establish the scientific foundation of plant-derived traditional medicines is by elucidating the bioactive compounds they produce as secondary metabolites.

Once secondary metabolites from the plant-derived medicine have been purified and identified, the mechanisms of their therapeutical attributes need to be elucidated. There are two ways to do this. First, we can refer to past researches that have elucidated the therapeutical mechanisms of the identified compounds, which are generally elucidated through molecular analysis (Dao et al., 2012; Lin et al., 2005). If there is not yet any information on the compound's therapeutic mechanisms, molecular analyses needs to be conducted. After establishing the types of compounds and the mechanisms of their



[Figure 1] *Scientificiation* process of plant-derived traditional medicine

therapeutical attributes, the scientific groundings can be further strengthened by conducting pre-clinical and clinical trials of the plant-derived medicine. A graphical representation of the whole scientification process can be seen in Figure 1.

It is important to note that each of these steps require a lot of investments in the form of infrastructures, especially those that are related to tools for analyses, such as PCR thermocycles, chromatography equipment, nuclear magnetic resonance equipment, etc. (Figure 1). Ideally the funding for equipment should be burdened on the government because it is related to the national interest.

6. Indonesia's plant-derived traditional medicine and plant diversity

The scheme that was provided for the *scientification* process of plant-derived traditional medicines can be used by Indonesia to optimize two of its main assets for fighting the pandemic. The assets include immense traditional knowledge on plant-derived medicines and immense plant diversity to support it.

Indonesian plant-derived traditional medicine or *jamu*, is in many ways similar to that of TCM in China. Both are embedded in the culture of the societies and are still used for the treatment of many kinds of sickness (Elfahmi et al., 2014; Weng, 2020). However, the way the Indonesian Government treat *jamu* is different from how the Chinese Government is treating TCM, at least in the way both heritages are positioned in their respective healthcare systems. Whilst TCM is being incorporated in the Chinese healthcare system and is being used officially for the treatment of COVID-19, *jamu* is still in a different category from conventional medicines. Plant-derived traditional medicines are further divided into three categories that include herbal medicines, scientific-based herbal medicines, and clinical-based herbal medicines, with the majority of *jamu* being in the first (lowest) category with no scientific grounding whatsoever (Tripoli & Wahyono, 2015). Ideally, all *jamu* should be moved to the third category (clinical-based herbal medicines), which has the highest legitimacy to be used for treatment of sickness.

In the context of the current pandemic, more focus should be put on *jamu* mixtures that have highest probability as treatment for COVID-19. The measurement of the probability can be done by rationalization and comparing certain *jamu* with TCM that have successfully been used for treating COVID-19 (Hartanti et al., 2020). The *jamu* that have been screened can then be put into the pipeline for *scientification* that was previously mentioned. However, in addition to pushing *jamu* as an alternative treatment there also needs to be adequate information to the public of the danger of unauthorized traditional medicine (*jamu*) for COVID-19 treatment (Lim & Pranata, 2020).

In addition to the immense knowledge on *jamu* that can be a starting point for the elucidation of novel COVID-19 treatments, Indonesia also has immense potential in the form of its biodiversity (Mittermeier et al., 1997), specifically its plant diversity. Indonesia is the home of 80% of all medicinal plants in the world and has 1,845 forest plant species that can readily be used for medicines (Elfahmi et al., 2014).

There have been other researches and projects dedicated to discover and identify Indonesian plant diversity. One of the most notable is the project done by Plant Resources of South East Asia (PROSEA), which was done from 1985 to 2016 by the PROSEA Foundation (*PROSEA Plant Resources of South East*

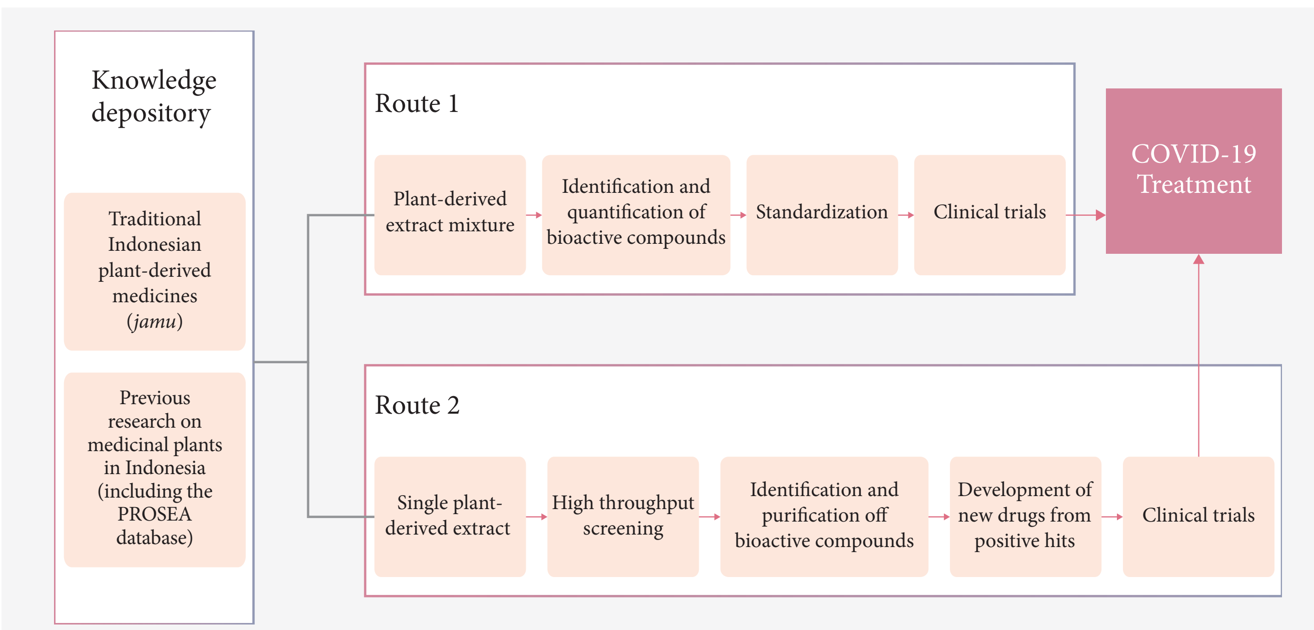
Asia Website, 2020). The project was an international collaboration and produced 19 book volumes containing a database of plants in different categories. Three volumes were dedicated to medicinal and poisonous plants, where 1,141 species were identified and characterized (de Padua et al., 1999; Lemmens & Bunyapraphatsara, 2003; van Valkenburg & Bunyapraphatsara, 2002). In addition to the PROSEA project, there have been research that follow it up and discovered there were actually more species, which weren't covered by the PROSEA books (Roosita et al., 2008; Van Sam et al., 2008), opening up even more possibilities.

The information from such researches and projects can be a starting point for the screening of plants that have antiviral attributes. A high throughput screening method such as the ones done in previous researches (Min et al., 2018; N. Powers & N. Setzer, 2016) could quickly help determine preliminary candidates that can be further be assessed for their antiviral activities, especially toward COVID-19.

7. A putative roadmap for the development of new treatment strategies for COVID-19 in Indonesia

From the above, we can design a putative roadmap for the development of novel treatment strategies for COVID-19 (Figure 2). In the roadmap we have made, there are two pathways in developing novel treatment strategies, which are by 1) using whole extracts of medicinal plant mixtures based on rationalization of *jamu* or 2) using high-throughput screening of plants that potentially have antiviral secondary metabolites.

The first pathway is similar to what has been done in China with TCM-based treatment for COVID-19, which might offer synergistic effects of many different plant metabolites against SARS-CoV-2.



[**Figure 2**] A putative roadmap for the development of novel treatment strategies for COVID-19

The most important aspect is the standardization of the amounts of each ingredient in the medicine mixture to avoid adverse effects. The second pathway is the bioprospecting the exact compounds that are responsible for the efficacy toward the virus.

In both pathways, knowing the metabolite contents of the mixtures or plants is essential. This process will need analyses tools such as chromatography apparatuses to detect, identify, and purify the metabolites. To take it even further, metabolite pathways and gene networks can be established to set up systems for producing target metabolites with the help of synthetic biology. Chromatography apparatuses such as High-Performance Liquid Chromatography, Gas Chromatography Mass Spectrometry, and Liquid Chromatography Mass Spectrometry will be essential for this step. Other analysis apparatus for detailed identification of the metabolites such as Nuclear Magnetic Resonance spectroscopy will also be indispensable. In addition, kits and apparatuses that are important for molecular analysis will also be indispensable.

It is worth noting that the price of such apparatuses can be quite expensive, reaching up to 200,000 USD per apparatus. Not to mention the day-to-day operation and analyses costs that need to be continuously be provided. Thus, in the context of Indonesia, where such apparatuses are either not available or not readily accessible, their procurement or re-inventory needs to be done, preferably by the Indonesian Government.

The Indonesian Government has made a committee for combating COVID-19 and restoration of the national economy (*Committee for COVID-19 and National Economy Restoration Website (Komite Penanganan COVID-19 Dan Pemulihan Ekonomi Nasional*), 2020). However, there is no clear definition or information on what the committee is responsible for and its job description. For the realization of the roadmap that we have shown, there needs to be an *ad hoc* committee in charge of it, and is preferably directly under the highest authority, which in the case of Indonesia, is the President. The committee also needs to be given the freedom to connect important stakeholders and conduct activities that can support the realization of the roadmap.

8. Science and technology capacity are key to unlocking the potentials of biodiversity

The mastery of science and technology (S&T) is one of the key aspects in being able to unlock the potentials of natural resources and convert them into products with higher value (Ragamustari & Sukara, 2019). The success of the roadmap that we introduced is also very much connected, if not dependent on Indonesia's S&T capacity.

One concept that is often used to understand the state of a country's S&T capacity is the National Innovation System (NIS) (Lundvall, 2007; Lundvall et al., 2002). This concept is then interpreted in many ways to analyze S&T and innovation capacity of a country using multidisciplinary approaches. For example, a previous research introduced the National Innovation Capacity concept that was derived from NIS, and was used to rank the innovation capacities of different countries (Rongping et al., 2019). In another research, the NIS was used to identify the evolutionary dynamics of S&T capacity of different countries (Ragamustari et al., 2020).

The similarities between researches based on NIS is the agreement that one of the most important aspects of a nation's S&T and innovation capacity is the commitment toward S&T, which is indicated first and foremost by the amount of expenditure for research and development of new technology. In this aspect, Indonesia needs much improvement, as its gross expenditure on R&D is only 0.2% of its GDP (latest available data, 2018), which is low even in comparison to its regional neighbors such as Malaysia (1.44%, 2016), Thailand (1%, 2017), or even Vietnam (0.53%, 2017), let alone developed countries (UNESCO, 2020). This needs to change, because research is not cheap, and as mentioned earlier, the procurement and maintenance of the tools needed for continuous research related to the roadmap for the COVID-19 treatment development can be very costly.

Besides the amount of expenditure being put into the research and development pipeline, other basic indicators for science and technology capacity include number of researchers, institutions for S&T capacity development, number of patent applications, number of scientific articles produced, and revenue from high-tech products, all in which Indonesia is lacking except for the number of institutions for S&T development. In addition, Indonesia also still suffers from a lack of identity on how its S&T is developing (Ragamustari et al., 2020).

There are several things that can be done to improve Indonesia's current S&T capacity, which include: 1) the reformation of institutions involved in S&T capacity development (including how they interact among each other and with other important stakeholders), 2) Increase GERD as percentage of GDP to a certain target, 3) incorporate industry in the development of S&T capacity, and 4) make a large scale propaganda on the importance of S&T capacity (Ragamustari et al., 2020).

The process of increasing Indonesia's S&T capacity is long-term, and for combating the current pandemic, the country needs to more pragmatic and work with what it currently has. Nevertheless, if Indonesia can reach a certain threshold of S&T capacity, and a clear direction to it (preferably one that is geared toward utilization of its biodiversity), Indonesia can no doubt produce many important products that are needed globally. In relation with COVID-19, an adequate level of S&T capacity will help Indonesia realize the roadmap that was introduced efficiently and optimally.

With the era of synthetic biology dawning upon us (Awan et al., 2016; Guzmán-Trampe et al., 2017; Lee et al., 2012), Indonesia's biodiversity is of immense potential. Perhaps in the future, as mentioned earlier, novel antivirals can be produced through synthetic biology, based on plant metabolites that are found from Indonesian biodiversity.

9. Conclusion

Without a working vaccine, erratic results of administration of available antivirals, and the difficulties of introducing plant-derived traditional medicines to conventional healthcare systems, all possible strategies to combat the COVID-19 pandemic need to be done.

For Indonesia, a country with immense biodiversity and strong history in the use of plant-derived traditional medicines, devising strategies to combat the pandemic based on those two assets make a lot of sense. From those assets, new treatments and products to combat COVID-19 can be developed, granted that there is a clear roadmap for development, adequate supporting system/bureaucracy, and S&T capacity. Indonesia's success in developing new treatments and products will also benefit the global community.

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References

Aldila, D., Khoshnaw, S. H. A., Safitri, E., Anwar, Y. R., Bakry, A. R. Q., Samiadji, B. M., Anugerah, D. A., GH, M. F. A., Ayulani,I. D., & Salim, S. N. (2020). A mathematical study on the spread of COVID-19 considering social distancing and rapid assessment: The case of Jakarta, Indonesia. *Chaos, Solitons & Fractals, 139*(January), 110042. https://doi.org/10.1016/j.chaos.2020.110042

Awan, A. R., Shaw, W. M., & Ellis, T. (2016). Biosynthesis of therapeutic natural products using synthetic biology. *Advanced Drug Delivery Reviews, 105*, 96–106. https://doi.org/10.1016/J.ADDR.2016.04.010

Calixto, J. B. (2000). Efficacy, safety, quality control, marketing and regulatory guidelines for herbal medicines (phytotherapeutic agents). *Brazilian Journal of Medical and Biological Research*, 33(2), 179–189. http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=emed5&NEWS=N&AN=2000095062

Chen, W. H., Strych, U., Hotez, P. J., & Bottazzi, M. E. (2020). The SARS-CoV-2 Vaccine Pipeline: an Overview. *Current Tropical Medicine Reports*, 7(2), 61–64. https://doi.org/10.1007/s40475-020-00201-6

Chen, Z., Hu, J., Zhang, Z., Jiang, S., Han, S., Yan, D., Zhuang, R., Hu, B., & Zhang, Z. (2020). *Efficacy of hydroxychloroquine in patients with COVID-19: results of a randomized clinical trial*. 7. https://doi.org/10.1101/2020.03.22.20040758

Committee for Covid-19 and National Economy Restoration Website (Komite Penanganan Covid-19 dan Pemulihan Ekonomi Nasional). (2020). https://covid19.go.id/

Corsini, A., Bisciotti, G. N., Eirale, C., & Volpi, P. (2020). Football cannot restart soon during the COVID-19 emergency! A critical perspective from the Italian experience and a call for action. *British Journal of Sports Medicine*, 54(20), 1186–1187. https://doi.org/10.1136/bjsports-2020-102306

Dao, T. T., Dang, T. T., Nguyen, P. H., Kim, E., Thuong, P. T., & Oh, W. K. (2012). Xanthones from Polygala karensium inhibit neuraminidases from influenza A viruses. *Bioorganic & Medicinal Chemistry Letters*, 22(11), 3688–3692. https://doi.org/10.1016/j.bmcl.2012.04.028

de Padua, L., Bunyapraphatsara, N., & Lemmens, R. (Eds.). (1999). PROSEA Plant *Resources of South East Asia 12 (1) Medicinal and Poisonous Plants 1*. Backhuys Publishers.

Difiori, J. P., Green, G., Meeuwisse, W., Putukian, M., Solomon, G. S., & Sills, A. (2020). Return to sport for North American professional sport leagues in the context of COVID-19. *British Journal of Sports Medicine*, 1–6. https://doi.org/10.1136/bjsports-2020-103227

Elfahmi, Woerdenbag, H. J., & Kayser, O. (2014). Jamu: Indonesian traditional herbal medicine towards rational phytopharmacological use. Journal of Herbal Medicine, 4(2), 51–73. https://doi.org/10.1016/J.HERMED.2014.01.002

Frediansyah, A., Tiwari, R., Sharun, K., Dhama, K., & Harapan, H. (2020). Antivirals for COVID-19: A critical review. *Clinical Epidemiology and Global Health, June*, 0–1. https://doi.org/10.1016/j.cegh.2020.07.006

Gautret, P., Lagier, J., Parola, P., Hoang, V. T., Meddeb, L., Sevestre, J., Mailhe, M., Doudier, B., Aubry, C., Amrane, S., Seng, P., Hocquart, M., Eldin, C., Finance, J., Vieira, V. E., Tissot-Dupont, H. T., Honoré, S., Stein, A., Million, M., … Raoult, D. (2020). Clinical and microbiological effect of a combination of hydroxychloroquine and azithromycin in 80 COVID-19 patients with at least a six-day follow up: A pilot observational study. *Travel Medicine and Infectious Disease, 34*(January), 101663. https://doi.org/10.1016/j.tmaid.2020.101663

Ghildiyal, R., Prakash, V., Chaudhary, V. K., Gupta, V., & Gabrani, R. (2020). Phytochemicals as Antiviral Agents: Recent Updates. In Plant-derived Bioactives (pp. 279–295). Springer Singapore. https://doi.org/10.1007/978-981-15-1761-7_12

Gopalan, H. S., & Misra, A. (2020). COVID-19 pandemic and challenges for socio-economic issues, healthcare and National Health Programs in India. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews, 14*(5), 757–759. https://doi.org/10.1016/j.dsx.2020.05.041

Guzmán-Trampe, S., Ceapa, C. D., & Manzo-Ruiz, M. (2017). Synthetic biology era: Improving antibiotic's world. *Biochemical Pharmacology, 134*, 99–113. https://doi.org/10.1016/J.BCP.2017.01.015

Harapan, H., Wagner, A. L., Yufika, A., Winardi, W., Anwar, S., Gan, A. K., Setiawan, A. M., Rajamoorthy, Y., Sofyan, H., & Mudatsir, M. (2020). Acceptance of a COVID-19 Vaccine in Southeast Asia: A Cross-Sectional Study in Indonesia. *Frontiers in Public Health, 8*(July), 1–8. https://doi.org/10.3389/fpubh.2020.00381

Hartanti, D., Dhiani, B. A., Charisma, S. L., & Wahyuningrum, R. (2020). The Potential Roles of Jamu for COVID-19: A Learn from the Traditional Chinese Medicine. *Pharmaceutical Sciences and Research, 7*(4), 12–22. https://doi.org/10.7454/psr.v7i4.1083

Hartono Wijaya, S., Tanaka, Y., Altaf-Ul-Amin, M., Hirai Morita, A., Mochamad Afendi, F., Batubara, I., Ono, N., K. Darusman, L., & Kanaya, S. (2016). Utilization of KNApSAcK Family Databases for Developing Herbal Medicine Systems. *Journal of Computer Aided Chemistry*, 17(0), 1–7. https://doi.org/10.2751/jcac.17.1

Itokawa, H., Morris-Natschke, S. L., Akiyama, T., & Lee, K. H. (2008). Plant-derived natural product research aimed at new drug discovery. *Journal of Natural Medicines*, 62(3), 263–280. https://doi.org/10.1007/s11418-008-0246-z

Jahan, I., & Onay, A. (2020). Potentials of plant-based substance to inhabit and probable cure for the covid-19. *Turkish Journal of Biology, 44*(Special issue 1), 228–241. https://doi.org/10.3906/biy-2005-114

Jeyanathan, M., Afkhami, S., Smaill, F., Miller, M. S., Lichty, B. D., & Xing, Z. (2020). Immunological considerations for COVID-19 vaccine strategies. *Nature Reviews Immunology*, 20(October), 615–632. https://doi.org/10.1038/s41577-020-00434-6

Jomah, S., Asdaq, S. M. B., & Al-Yamani, M. J. (2020). Clinical efficacy of antivirals against novel coronavirus (COVID-19): A review. *Journal of Infection and Public Health, 13*(9), 1187–1195. https://doi.org/10.1016/j.jiph.2020.07.013

Kartini, K., Jayani, N. I. E., Octaviyanti, N. D., Krisnawan, A. H., & Avanti, C. (2019). Standardization of Some Indonesian Medicinal Plants Used in "Scientific Jamu." *IOP Conference Series: Earth and Environmental Science, 391*(1). https://doi.org/10.1088/1755-1315/391/1/012042

Komite Penanganan Covid-19 dan Pemulihan Ekonomi Nasional. (2020). *Peta Sebaran Covid-19 di Indonesia.* https://covid19.go.id/peta-sebaran

Lal, P., Kumar, A., Kumar, S., Kumari, S., Saikia, P., Dayanandan, A., Adhikari, D., & Khan, M. L. (2020). The dark cloud with a silver lining: Assessing the impact of the SARS COVID-19 pandemic on the global environment. *Science of The Total Environment, 732*(January). https://doi.org/10.1016/j.scitotenv.2020.139297

Lamb, K., & Allard, T. (2020, May 27). Indonesia, major advocate of hydroxychloroquine, told by WHO to stop using it. *The Jakarta Post*. https://www.thejakartapost.com/news/2020/05/27/indonesia-major-advocate-of-hydroxychloroquine-told-by-who-to-stop-using-it.html

Lee, J. W., Na, D., Park, J. M., Lee, J., Choi, S., & Lee, S. Y. (2012). Systems metabolic engineering of microorganisms for natural and non-natural chemicals. *In Nature Chemical Biology* (Vol. 8, Issue 6, pp. 536–546). https://doi.org/10.1038/nchembio.970

Lemmens, R., & Bunyapraphatsara, N. (Eds.). (2003). *PROSEA Plant Resources of South East Asia 12 (3) Medicinal and Poisonous Plants 3*. Backhuys Publishers.

Lim, M. A., & Pranata, R. (2020). The insidious threat of jamu and unregulated traditional medicines in the COVID-19 era. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews, 14*(5), 895–896. https://doi.org/10.1016/j.dsx.2020.06.022

Lin, C.-W., Tsai, F.-J., Tsai, C.-H., Lai, C.-C., Wan, L., Ho, T.-Y., Hsieh, C.-C., & Chao, P.-D. L. (2005). Anti-SARS coronavirus 3C-like protease effects of Isatis indigotica root and plant-derived phenolic compounds. *Antiviral Research, 68*(1), 36–42. https://doi.org/10.1016/j.antiviral.2005.07.002

Lundvall, B. Å. (2007). National innovation systems - Analytical concept and development tool. *Industry and Innovation*, 14(1), 95–119. https://doi.org/10.1080/13662710601130863

Lundvall, B. Å., Johnson, B., Andersen, E. S., & Dalum, B. (2002). National systems of production, innovation and competence building. *Research Policy, 31*, 213–231. https://doi.org/10.4134/CKMS.2012.27.1.037

Mahévas, M., Tran, V. T., Roumier, M., Chabrol, A., Paule, R., Guillaud, C., Fois, E., Lepeule, R., Szwebel, T. A., Lescure, F. X., Schlemmer, F., Matignon, M., Khellaf, M., Crickx, E., Terrier, B., Morbieu, C., Legendre, P., Dang, J., Schoindre, Y., … Costedoat-Chalumeau, N. (2020). Clinical efficacy of hydroxychloroquine in patients with covid-19 pneumonia who require oxygen: Observational comparative study using routine care data. *The BMJ, 369*, 1–8. https://doi.org/10.1136/bmj.m1844

Miller, I. F., Becker, A. D., Grenfell, B. T., & Metcalf, C. J. E. (2020). Disease and healthcare burden of COVID-19 in the United States. *Nature Medicine*, 26(8), 1212–1217. https://doi.org/10.1038/s41591-020-0952-y

Min, N., Leong, P. T., Lee, R. C. H., Khuan, J. S. E., & Chu, J. J. H. (2018). A flavonoid compound library screen revealed potent antiviral activity of plant-derived flavonoids on human enterovirus A71 replication. *Antiviral Research, 150*, 60–68. https://doi.org/10.1016/j.antiviral.2017.12.003

Ming, W.-K., Huang, J., & Zhang, C. (2020). *Breaking down of the healthcare system: Mathematical modelling for controlling the novel coronavirus (2019-nCoV) outbreak in Wuhan, China*. https://doi.org/10.1101/2020.01.27.922443

Mittermeier, R. A., Goettsch Mittermeier, C., & Robles Gil, P. (1997). *Megadiversity : earth's biologically wealthiest nations*. CEMEX.

N. Powers, C., & N. Setzer, W. (2016). An In-Silico Investigation of Phytochemicals as Antiviral Agents Against Dengue Fever. *Combinatorial Chemistry & High Throughput Screening, 19*(7), 516–536. https://doi.org/10.2174/1386207319666160506123715

Nicola, M., Alsafi, Z., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, M., & Agha, R. (2020). The socio-economic implications of the coronavirus pandemic (COVID-19): A review. *International Journal of Surgery*, 78(January), 185–193. https://doi.org/10.1016/j.ijsu.2020.04.018

PROSEA Plant Resources of South East Asia Website. (2020). http://proseanet.org/prosea/implementation.php

Purnama, S. G., & Susanna, D. (2020). Attitude to COVID-19 Prevention With Large-Scale Social Restrictions (PSBB) in Indonesia: Partial Least Squares Structural Equation Modeling. *Frontiers in Public Health, 8*(October), 1–10. https://doi.org/10.3389/fpubh.2020.570394

Ragamustari, S. K., Parwanto, N. B., Nawir, A. A., & Sukara, E. (2020). *Indonesia's Science and Technology Capacity Evolution Dynamics from 1970 to 2018 in Respect to the Republic of Korea's.*

Ragamustari, S. K., & Sukara, E. (2019). Strengthening the genetic diversity conservation narrative in Indonesia: challenges and prospects. *Biodiversity and Conservation*. https://doi.org/10.1007/s10531-019-01749-0

Rongping, M., Kangwei, C., & Kaihua, C. (2019). National Innovation Capacity Index: A Cross-Country Comparative Analysis. Advances in Psychological Science, 1(2), 132. https://doi.org/10.3724/sp.j.2096-5141.2019.0009

Roosita, K., Kusharto, C. M., Sekiyama, M., Fachrurozi, Y., & Ohtsuka, R. (2008). Medicinal plants used by the villagers of a Sundanese community in West Java, Indonesia. *Journal of Ethnopharmacology,* 115(1), 72–81. https://doi.org/10.1016/j.jep.2007.09.010

Setiati, S., & Azwar, M. K. (2020). COVID-19 and Indonesia. *Acta Med Indones - Indones J Intern Med, 52*(1), 84–89. https://www.researchgate.net/profile/Muhammad_Azwar3/publication/340645813_COVID-19_and_Indonesia/links/5e96ba6a92851c2f52a2ef2e/COVID-19-and-Indonesia.pdf

Shakil, M. H., Munim, Z. H., Tasnia, M., & Sarowar, S. (2020). COVID-19 and the environment: A critical review and research agenda. *Science of the Total Environment, 745*, 141022. https://doi.org/10.1016/j.scitotenv.2020.141022

Şimşek Yavuz, S., & Ünal, S. (2020). Antiviral treatment of covid-19. *Turkish Journal of Medical Sciences, 50*(SI-1), 611–619. https://doi.org/10.3906/sag-2004-145

Siswanto, S., S. Utama, O., S. Adisetiadi, A., E. Pranasakti, M., & S. Hakim, M. (2020). Early hydroxychloroquine and azithromycin as combined therapy for COVID-19: a case series. *Journal of Thee Medical Sciences (Berkala Ilmu Kedokteran), 52*(03), 173–180. https://doi.org/10.19106/jmedscisi005203202016

Somani, M., Srivastava, A. N., Gummadivalli, S. K., & Sharma, A. (2020). Indirect implications of COVID-19 towards sustainable environment: An investigation in Indian context. *Bioresource Technology Reports, 11*(June), 100491. https://doi.org/10.1016/j.biteb.2020.100491

Stevensen, C. (1999). JAMU: an Indonesian herbal tradition with a long past, a little known present and an uncertain future. *Complementary Therapies in Nursing and Midwifery, 5*(1), 1–3. https://doi.org/10.1016/S1353-6117(99)80062-6

Sumarni, W., Sudarmin, S., & Sumarti, S. S. (2019). The scientification of jamu: A study of Indonesian's traditional medicine. *Journal of Physics: Conference Series, 1321*(3). https://doi.org/10.1088/1742-6596/1321/3/032057

Suraya, I., Nurmansyah, M. I., Rachmawati, E., Al Aufa, B., & Koire, I. I. (2020). The impact of large-scale social restrictions on the incidence of covid-19 : A case study of four provinces in Indonesia. *Kesmas, 15*(2), 49–53. https://doi.org/10.21109/KESMAS.V15I2.3990

Surbakti, H. A. (2020, June 23). Alasan RI Masih Pakai Hydroxychloroquine Meski Disetop WHO. *CNBC Indonesia.* https://www.cnbcindonesia.com/tech/20200623170847-37-167464/alasan-ri-masih-pakai-hydroxychloroquine-meski-disetop-who

Teoh, S. L., Lim, Y. H., Lai, N. M., & Lee, S. W. H. (2020). Directly Acting Antivirals for COVID-19: Where Do We Stand? *Frontiers in Microbiology, 11*(June). https://doi.org/10.3389/fmicb.2020.01857

Teräs, M., Suoranta, J., Teräs, H., & Curcher, M. (2020). Post-Covid-19 Education and Education Technology 'Solutionism': a Seller's Market. *Postdigital Science and Education, 2*(3), 863–878. https://doi.org/10.1007/s42438-020-00164-x

Thanh Le, T., Andreadakis, Z., Kumar, A., Gómez Román, R., Tollefsen, S., Saville, M., & Mayhew, S. (2020). The COVID-19 vaccine development landscape. *Nature Reviews. Drug Discovery, 19*(5), 305–306. https://doi.org/10.1038/d41573-020-00073-5

Tripoli, F., & Wahyono, B. (2015). TRADITIONAL MEDICINE (JAMU) IN MODERN MEDICAL DISCOURSE. *The International Journal of Social Science, 25*(1), 55–65. http://repository.petra.ac.id/17074/1/Publikasi1_00051_2112.pdf

UNESCO. (2020). *Data for the Sustainable Development Goals*. http://uis.unesco.org/en/home

Van Sam, H., Baas, P., & Keßler, P. J. A. (2008). Traditional medicinal plants in Ben En National Park, Vietnam. *Blumea - Biodiversity, Evolution and Biogeography of Plants, 53*(3), 569–601. https://doi.org/10.3767/000651908X607521

van Staden, C. (2020). COVID-19 and the crisis of national development. *Nature Human Behaviour, 4*(5), 443–444. https://doi.org/10.1038/s41562-020-0852-7

van Valkenburg, J. L., & Bunyapraphatsara, N. (Eds.). (2002). *PROSEA Plant Resources of South East Asia 12 (2) Medicinal and Poisonous Plants 2*. Backhuys Publishers.

Vinetz, J. M. (2020). Lack of efficacy of hydroxychloroquine in covid-19. *The BMJ, 369*(May), 1–2. https://doi.org/10.1136/bmj.m2018

Weng, J. K. (2020). Plant Solutions for the COVID-19 Pandemic and Beyond: Historical Reflections and Future Perspectives. *Molecular Plant, 13*(6), 803–807. https://doi.org/10.1016/j.molp.2020.05.014

Wink, M. (2020). Potential of DNA intercalating alkaloids and other plant secondary metabolites against SARS-CoV-2 causing COVID-19. *Diversity, 12*(5), 1–10. https://doi.org/10.3390/D12050175

World Health Organization (WHO). (2013). WHO Traditional Medicine Strategy 2014-2023. *World Health Organization (WHO)*, 1–76. http://apps.who.int/iris/bitstream/10665/92455/1/9789241506090_eng.pdf?ua=1 (Accessed 09.09.2016)

Yang, Y., Islam, M. S., Wang, J., Li, Y., & Chen, X. (2020). Traditional Chinese medicine in the treatment of patients infected with 2019-new coronavirus (SARS-CoV-2): A review and perspective. *International Journal of Biological Sciences, 16*(10), 1708–1717. https://doi.org/10.7150/ijbs.45538

Zeng, Z. P., & Jiang, J. G. (2010). Analysis of the adverse reactions induced by natural product-derived drugs. *British Journal of Pharmacology, 159*(7), 1374–1391. https://doi.org/10.1111/j.1476-5381.2010.00645.x

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