Annual Report of Center for Sustainability Science

Contents

Foreword

The year of 2020 was a difficult year for the world due to the COVID-19 pandemic. In addition to the threat to human health, world economy encountered unprecedented challenges. The world may be able to recover soon; however, it is critical to take the right pathway heading toward sustainability of human society. Focusing on sustainability aligns with the strategic goals of the Academia Sinica, based on which the Center for Sustainability Science's (CSS) was established in 2012.

In addressing global and national interests, CSS issued proposal calls on five topics in 2020. After careful reviews, 7 out of the 14 group proposals were approved to receive funding for three years. We believe that excellent scientific results will come out of these projects.

Despite tremendous challenges for the operation of CSS international programs and the cancellation of several international events due to travel restrictions, the CSS was able to continue international communications through virtual means. Consequently, all three international CSS programs have witnessed substantial development.

Partnering with the Ministry of Science and Technology (MOST), Academia Sinica was accepted as a member of the Belmont Forum in the 2020 Plenary Meeting. The Belmont Forum Program Office in Taipei was relocated to our campus and is now being hosted by the CSS. The CSS has become the contact point and information center for all international and domestic activities of the Belmont Forum in Taiwan. In addition, the IRDR ICoE-Taipei hosted a virtual Advanced Institute in the second half of 2020. With the agreement of the International Science Council, the CSS successfully extended the IRDR ICoE contract to the end of 2021. Finally, Future Earth Taipei strongly endorsed and participated in the Future Earth reorganization and transition process and, in compliance with international initiatives, added three domestic working groups: Sustainability in the Digital Age, Early Career Researcher Network, and Non-Governmental Organizations (NGOs). Such an innovative expansion will significantly aid collaboration with international communities on sustainability sciences.

Thank you for all of the contributions on and out of the Academia Sinica campus. We are committed at Academia Sinica to becoming an active member of the international family. Such a cohort is vital to help build a sustainable and better future. The CSS will keep pursuing its missions and continue to work on transdisciplinary projects that provide useful solutions to sustainability problems. Your opinions and comments are always welcomed.

Mei-Yin Chou

Mei-Yin Chou
Chairperson, Center for Sustainability Science
Academia Sinica

Introduction

The Earth system has changed unprecedentedly at a global scale due to human activities. Therefore, scientists believe that Earth has entered the Anthropocene epoch since the mid-20th century. While humans attempt to respond to impacts of climate and environmental change, they also need to face rising network risks, as human and technological networks grow. The intertwining relationships between human societies and biosphere have increased the complexity of the problems and the difficulty to resolve the problems. Therefore, the grand challenge is to enhance sustainability and resilience of the human society, and call for collective efforts from scientists of various disciplines and stakeholders of multiple sectors in societies.

Academia Sinica, the most preeminent academic institution of Taiwan, was founded to promote and undertake scholarly research in the sciences and humanities. In addition to academic exploration, scientists in Academia Sinica are aware of their social responsibility to provide sound scientific evidence and information to solve key global sustainability problems that threaten the human society survival. Therefore, the Center for Sustainability Science (CSS) was established in 2012 to promote researches and activities that strive for the sustainability of the Earth system and human society. Our core missions include:

(1) To plan, organize, and promote Sustainability Science Research Program (SSRP), that is, "problem-solving-oriented, trans-disciplinary, and stakeholder-inclusive.

(2) To host the project offices for three sustainability science-related international cooperation programs (i.e., IRDR-ICoE, Future Earth, Belmont Forum) and connect Taiwan's researchers with the global sustainability research community.

(3) To provide evidence-based policy recommendations on significant sustainability issues.

Organization and Task

- Academia Sinica
  - Center for Sustainability Science (CSS)
    - Program Panel Committee
    - Executive Office
    - Advisory Board

Policy Recommendations
- Task Force on Key Sustainability Issues (e.g., Decarbonization/Net Zero)
- Sustainability Forum

Sustainability Science Research Program
- Research Project
- Regular Seminar
- Open Symposium
- Outcome Workshop

International Program
- Integrated Research on Disaster Risk (IRDR), International Centre of Excellence (ICoE)-Taipei
- Future Earth Taipei
- Belmont Forum

Program Panel Committee

- Dr. Faa-Jeng Lin
- Dr. Fuh-Jyh Jan
- Dr. Hsun-Ling Bai
- Dr. Jin-Li Hu
- Dr. Kuei-Tien Chou
- Dr. Lee-Yaw Lin
- Dr. Mei-Lien Chen
- Dr. Shin-Cheng Yeh
- Dr. Teng-Chiu Lin
- Dr. Yu-Pin Lin

Advisory Board

- Dr. Yuan-Tseh Lee (Chairperson)
- Dr. Gordon McBean
- Dr. Hiroshi Matsumoto
- Dr. Johan Rockström
- Dr. Leland H. Hartwell
- Dr. Mark Stafford Smith
- Dr. Michael Crow
- Dr. Mohd Nordin Hasan
- Dr. Olive Shisana
- Dr. Shaw Chen Liu

Members of Executive Office

Chairperson: Vice President Dr. Mei-Yin Chou
Executive Secretary: Dr. Yue-Gau Chen
Deputy Executive Secretary/Director of International Programs Dr. Shih-Chun Candice Lung, Dr. Jian-Cheng Lee
Distinguished Visiting Chair: Dr. Yu Wang
Visiting Specialist: Dr. Liang-Yung Wei
Administration Chief of CSS Office: Dr. Shih-Yun Kuo
Officers of International programs: Dr. Chia-Hsing Lee, Dr. Ying-Hsuan Lin, Dr. Yi-Chun Lin, Dr. Yu-Chun Chung, Dr. Han-Yu Chiu
Program managers: Yun-Han Chin, Chia-Hui Yen, Chia-Lun Kuo
Administrative Secretary of International Programs: Bo-Hong Tsai, Tzu-Hsun Chang, Ming-Shan Chiang, Yen-Yu Chou

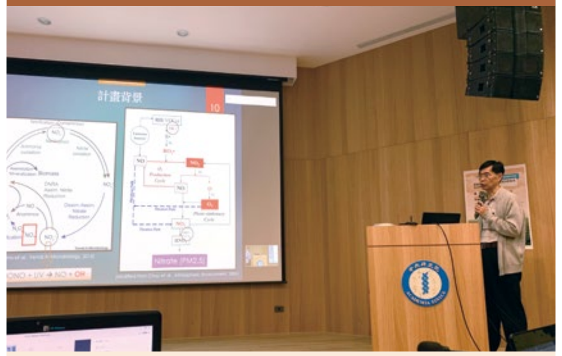
Activities in 2020

January 16

Open Symposium: Energy

The symposium reviewed key energy issues in Taiwan, such as scientific assessment, energy policy, institution, governance, etc.

April 21



SSRP Seminar

Emissions of Reactive Nitrogen Species due to Fertilization and its Impacts to Air Quality (PI: Charles C.-K. Chou)

July 31

SSRP Outcome Workshop

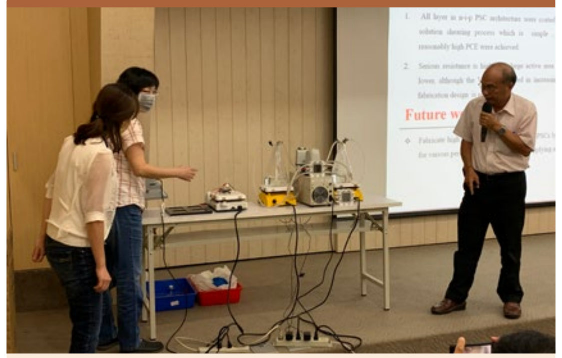
Effects of Environmental Changes on Rice Growth and Production in Taiwan (PI: Ming-Che Shih)

August 19

Open Symposium: Sustainability Forum on Taiwan's Transition toward Sustainability in a Post-COVID-19 World

The symposium invited two keynote speakers to share their valuable perspectives on "The Sustainability Transition of Taiwan Society" and "The Development of Sustainability Science" in a post-COVID-19 world. Panelists and participants were lively discussing over Taiwan's transition toward sustainability from various perspectives.

September 9



SSRP Outcome Workshop

High Efficiency Solar Fuels: From Materials Development to Device Integration (PI: Yu-Tai Tao)

October 31

Academia Sinica Open Campus CSS Lecture: COVID-19: An Opportunity to Pause and Reset for Sustainable Human Development

November 3

SSRP Outcome Workshop

Biological Impacts of Climate Change on Mountain Regions: An Integrative Study (PI: Mao-Ning Tuanmu)

IRDR ICoE-Taipei

Facebook

Twitter

Introduction

Integrated Research on Disaster Risk (IRDR) is an international research program co-created by the International Science Council (ISC) and the United Nations Office for Disaster Risk Reduction (UNDRR). It aims to promote transdisciplinary integrated research that addresses the challenges brought about by natural disasters. The program's research objectives include understanding the characterization of hazard, vulnerability, and risk, exploring effective decision making in complex and changing risk contexts, and reducing risk and curbing losses through knowledge-based actions. Since the work requires expertise from a variety of disciplines, such as the natural and socioeconomic sciences, it is critical to develop researchers with multidisciplinary skills. Hence, the Academia Sinica established the International Centre of Excellence in Taipei of IRDR (IRDR ICoE-Taipei) in 2010, and the Center for Sustainability Science hosts this program's office.

IRDR ICoE-Taipei is a region-wide initiative serving as an international platform of disaster risk reduction for building capacity and facilitating collaborative research. The primary tasks include building capacity in the Asia-Pacific region by organizing regional training courses; facilitating collaborative research of young scientists; and creating a network to connect scientists, engineers, government officers, practitioners, and stakeholders. These tasks also match the action priorities of the Sendai Framework for Disaster Risk Reduction (SFDRR), which means that IRDR ICoE-Taipei commits to keeping up with the global agenda (Figure 1).

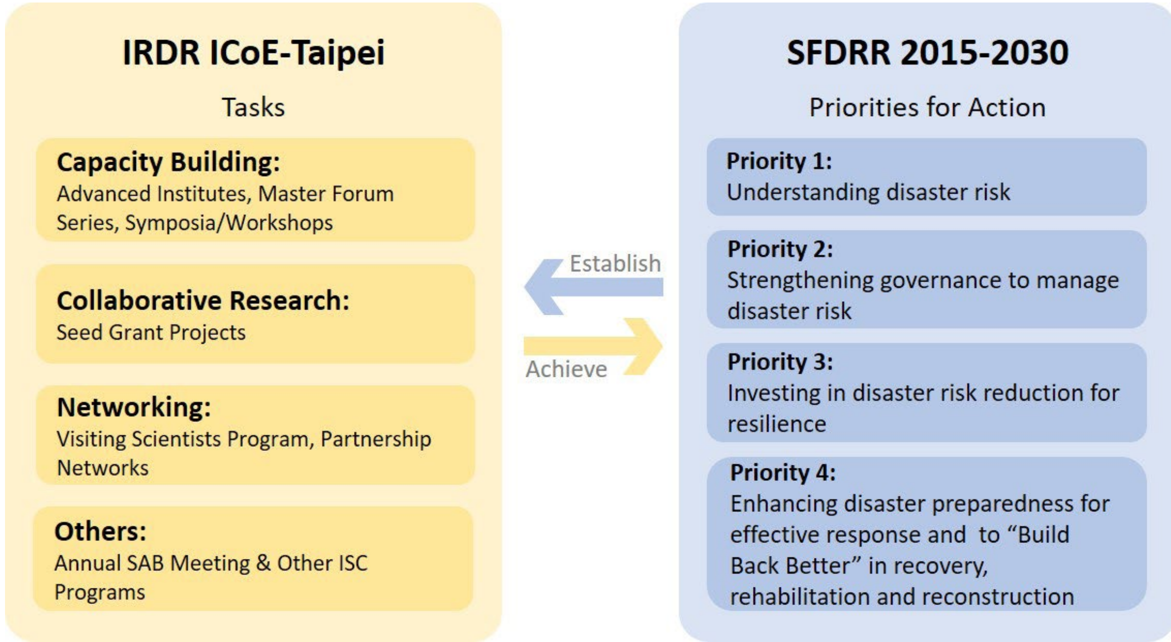


Figure 1. The tasks of IRDR ICoE-Taipei to match the priorities of SFDRR

Highlights in 2020

2020 was a year of surprises and challenges. Due to the COVID-19 pandemic, the IRDR ICoE-Taipei had to cancel many international activities and two scheduled training courses, namely the Advanced Institute on Knowledge-Based Action (AI-KBA) and the Advanced Institute on Natural Disaster Risk Reduction of Nepal. However, at the same time, we took the opportunity to enhance our capability of conducting online virtual activities. Below are the highlights of 2020.

1. Strengthening the link with the international community

To synchronize with the international research agenda of disaster risk reduction (DRR), IRDR ICoE-Taipei cooperated closely with IRDR, ISC, and the Regional Office for Asia and the Pacific of ISC (ISC ROAP). This year, IRDR ICoE-Taipei participated in two scientific committee (SC) virtual meetings of IRDR—namely the 23rd IRDR SC Meeting and the 24th IRDR SC Meeting—and provided regional viewpoints (Figure 2). We also actively participated in seminars on disaster prevention, mitigation, adaptation, and related online events organized by the IRDR family, ISC, and Risk KAN of Future Earth, such as the 2020 Asia-Pacific Science and Technology Conference for Disaster Risk Reduction (eAPSTCDRR), the Asia Pacific Webinar on Rethinking Human Development, and Risk KAN webinars, among others.

In addition, we reviewed our past work and matched the development focus with the action priorities of SFDRR. The result showed that the primary contribution of the IRDR ICoE-Taipei lies in Priority 4 "Enhancing disaster preparedness for effective response and to build back better in recovery, rehabilitation and reconstruction." Such experiences were also provided to the international community for demonstrating regional work.

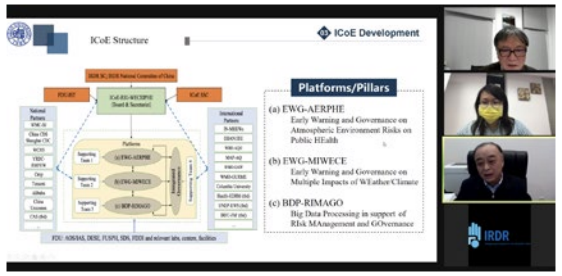


Figure 2. Report of the development of a new ICoE from the IRDR IPO in IRDR SC Meeting

2. Building the DRR Capability of the AP region

Even though the original 2020 plan was disrupted by COVID-19, IRDR ICoE-Taipei managed to organize a virtual training workshop, the 2020 Advanced Institute on Health Investigation and Air Sensing for Asian Pollution (AI on Hi-ASAP). This AI was the second year of a three-year training course to develop health–air pollution transdisciplinary researchers in the Asia Region. The focus of this AI was on the study design and data analysis of sensor evaluation, exposure assessment, and exposure-health evaluation (Figure 3). Research groups comprising public health and atmospheric chemistry researchers from 12 different areas in Asia participated in Hi-ASAP. These participants planned to adopt the same research methodology in air pollution sensing and health studies in their own country in order to conduct international comparisons. This online training workshop, held on October 5–6, 8, and 15, 2020, was also our first attempt at organizing virtual international training courses (Figure 4). It showed the flexibility and resilience of IRDR ICoE-Taipei despite the pandemic circumstances.

From 2015 to 2020, the DRR training courses offered by IRDR ICoE-Taipei have cumulatively trained 276 people in the Asia and the Pacific region. (Figure 5)

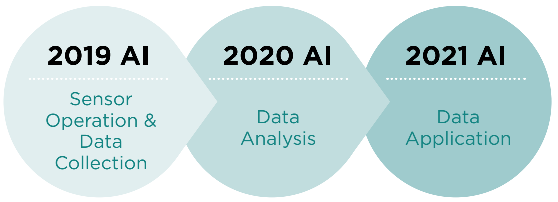


Figure 3. The focus of AI on Hi-ASAP (2019–2021)

Table 1. Past work compilation based on the SFDRR roadmap

SFDRR / IRDR ICoE-Taipei	Priority 1: Understanding disaster risk	Priority 2: Strengthening disaster risk governance to manage disaster risk	Priority 3: Investing in DRR for resilience	Priority 4: Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction
Capacity Building	· TW-NDRMA 2016 · AI-SOCD 2017 · AI-LRR&TS 2018 · TC-EHRA 2018 · AI-Hi-ASAP 2019 · AI-Hi-ASAP 2020	· TW-SAMD 2015 · Master Talk 2020: Rebuilding from COVID-19 to Achieve Global Agenda 2030 · Master Talk 2020: Taiwan Model for Mitigation of Pandemic Disaster	· TW-MFSWRST 2016	· AI-DATA 2012 · AI-FORIN 2012 · AI-DRRLM 2015 · AI-KBA 2017 · AI-SOCD heat 2018 · TC-EEW 2019 · TC-LIHM 2019 · AI-ACV 2019
Collaborative Research	· Seed Grant: AI-LRR&TS · Seed Grant: TC-EHRA · Seed Grant: AI-SOCD 2017 · Seed Grant: AI-Hi-ASAP 2019	· Seed Grant: AI-Hi-ASAP 2020		· Seed Grant: AI-DRRLM · Seed Grant: AI-SOCD heat · Seed Grant: AI-KBA 2017 · Flagship Project
Networking	· Young Scientists Conference · Workshop on Exposure Assessment	· PARR Fellowship · Workshop to Strengthen Scientific Advisory Capacities · Relevant Meetings	· CAR II 2011 · Flagship Project · Relevant Meetings · PIAD	· WSS-ISSC Seminar · PIAD · Relevant Meetings
Others	· Visiting Scholar	· SAB meeting · Visiting Scholar	· WSS-ISSC Seminar	· Report: FORIN case study · Article: Improved Evacuation Procedures

Figure 4. The virtual training workshop "AI on Hi-ASAP"

Figure 5. Total trainees in 2015-2020

3. Expanding disaster topics to an emerging risk: Epidemics

Most of the issues that IRDR tackles are related to natural hazards, such as earthquakes and weather- and climate-related hazards. Due to COVID-19, this year, we expanded disaster topics to one that we rarely explore—epidemics. Two distinguished scholars were invited to the Master Forums to provide some valuable insights into societal responses and transformation during the pandemic. Dr. Gordon McBean, a well-known climate scientist and the former president of ISC, addressed how the global community can seize opportunities to accelerate social transformation with "Rebuilding from COVID-19 to Achieve Global Agenda 2030." In addition, Dr. Chen Chien-Jen, a well-known epidemiologist and also the former vice-president of Taiwan, delivered the discussion "COVID-19 Containment and Economic Revitalization: Taiwan Model for Mitigation of Pandemic Disaster" and shared how Taiwan managed to contain COVID-19 and reduce the economic impact that the pandemic would have caused.

4. Enhancing Regional Collaborative Research

To enhance regional collaborative research and to grant funding opportunities to junior researchers, the IRDR ICoE-Taipei provides the Seed Grant for the AI participants who have just completed AI training. In 2020, seven awarded projects, three AI- KBA follow-up projects, and four AI-SOCD follow-up projects had been completed and had submitted their final reports (Table 2). The three AI-KBA projects fully emphasized the transdisciplinary and systematic research design and data analysis covering the areas of natural disasters and community disaster relief. The four AI-SOCD projects dealt with the relationships between environmental air quality and health issues through systematic thinking and emphasized the effect of policy intervention. These research groups not only conducted real field work on real problems but also published articles outlining the results, meaning that the combination of the AI-Seed Grant model can achieve both academic contribution and practical solution. In addition, the implementation of these seed projects have proved that the IRDR ICoE-Taipei has made a clear and positive influence on young researchers, and it can be expected that such an influence will continue to spread outward.

Table 2. Closed Seed Grant Projects in 2020

Project Number and Principal Investigator	Project Title
AI-KBA-01 PI: Indrajit Pal	Evidenced Based analysis of Flood Risk Management and Social Vulnerability – A System Approach in Sakon Nakhon Province, Thailand
AI-KBA-02 PI: Khamarrul Azahari Razak	Earthquake Resilient Communities in ASEAN Region: A Transdisciplinary Approach
AI-KBA-06 PI: Mohamad Syazli Fathi	Developing Humanitarian Aid Distribution Process Information System Framework for ASEAN Countries
AI-SOCD-03 PI: Melliza Cruz	Building Urban Resilience: A Systems Approach to Analyzing Social and Personal Health Risks of Jeepney Commuters and Drivers to $PM_{2.5}$ in Metro Manila, Philippines
AI-SOCD-04 PI: Ohnmarmay Tin Hlaing	Interface Between Science Based Data and Policy Action to Improve the Existing Mandalay City Waste Management: Ambient Air Monitoring, Air Impact Assessment, Personal $PM_{2.5}$ Exposure, Health Risk Assessment, Awareness and Mitigation Measures
AI-SOCD-05 PI: Mohd Talib Latif	The Influence of Biomass Burning on High Concentration of $PM_{2.5}$ in Selected Areas in Southeast Asia
AI-SOCD-07 PI: Wiwiek Setyawati	Urban Transportation-related Air Quality and their Impact on Human Health

5. Growing attention on social media

While the pandemic shut down face-to-face or physical activities, the IRDR ICoE-Taipei emphasized its focus on online social media platforms and engagement. In 2020, we made 50 posts on Facebook and 61 tweets on Twitter, sharing DRR-related knowledge and news. These posts covered a variety of news, such as the events held by the IRDR ICoE-Taipei, activities and information of related organizations, and DRR-related science and policy new knowledge. By regularly posting information, the IRDR ICoE-Taipei has drawn more attention from international followers on social media (Figure 6).

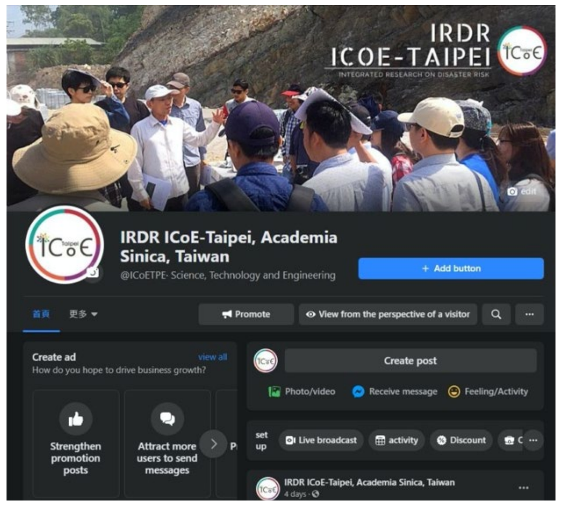


Figure 6. IRDR ICoE-Taipei put effort into activity promotion on Facebook and Twitter in 2020

Activities in 2020

September 29

Online Master Forum Series - Rebuilding from COVID-19 to Achieve Global Agenda 2030

Our planet Earth is being impacted by the global COVID-19 pandemic, and governments are addressing the issue in many ways. There is an opportunity now to build upon global scientific expertise crossing the span of Global Agenda 2030—Climate Agreement, Sendai Framework, Sustainable Development and related issues—to create integrated, transdisciplinary scientific partnerships and international research programs to respond and recover from COVID-19 through strategic approaches that also address the Global Agenda. In order to address this issue and share insights, IRDR ICoE-Taipei started a Master Forum Series. It was our great honor to have had Dr. Gordon McBean as our first keynote speaker.

October 5-6, 8, 15

AI on Hi-ASAP held online in 2020

2020 Advanced Institute on Health Investigation and Air Sensing for Asian Pollution (AI on Hi-ASAP)

This online training workshop was dedicated to health and atmospheric chemistry researchers. Currently, research groups from 12 different areas in Asia are participating in Hi-ASAP and planning to adopt the same research methodology in air pollution sensing and health studies to conduct international comparisons. The workshop focused on the study design and data analysis of sensor evaluation, exposure assessment, and exposure-health evaluation.

November 12

2020 SAB meeting was held both in person and virtually

2020 Scientific Advisory Board (SAB) meeting (virtual)

Because of COVID-19, the ICoE-Taipei held the SAB meeting online this year. It is its most important core strategic meeting, in which members review and comment on the operation of ICoE-Taipei. In addition to the SAB members, Dr. John Handmer, Chairman of the Scientific Committee of IRDR, Qunli Han, the Director of IRDR IPO, Dr. Mazlan Othman, the Director of ISC ROAP, and Charles Erkelens, Operations Director of ISC, also actively participated, providing valuable insights.

December 1

Master Talk with Dr. Chen Chien-Jen on Taiwan Model for Mitigation of Pandemic Disaster

Ex-VP talked about the COVID-19 Containment and Economic Revitalization: Taiwan Model for Mitigation of Pandemic Disaster (Virtually and in Person)

The former vice-president Chen Chien-Jen shared how Taiwan managed to contain COVID-19 and reduce the economic impact that the pandemic would have caused, highlighting how the very careful contact tracing and stringent quarantine of close contacts performed by the government proved to be the best ways to contain COVID-19.

Future Earth Taipei

Introduction

Future Earth is a global scientific network that promotes sustainability science and drives transformations toward sustainability. Based on previously established programs such as the International Geosphere-Biosphere Programme (IGBP) and DIVERSITAS, the Future Earth network was officially announced in 2012 and finally established in 2015. Future Earth, based on the culmination of three decades worth of effort, aims to understand connections among environmental, social, and economic systems and utilize this knowledge to develop evidence-based policies and actions. A three-pronged approach is currently being followed: 1) facilitating research and innovation through global research projects (GRPs); 2) building and mobilizing networks, such as Knowledge-Action Networks (KANs); and 3) shaping the global narrative by facilitating conversations between scientists and decision-makers. As a member of the International Science Council (a key player of the Governing Council of Future Earth), Academia Sinica has actively participated in developing Future Earth and its vision.

In 2015, Future Earth Taipei was officially established, and the Center for Sustainability Science at Academia

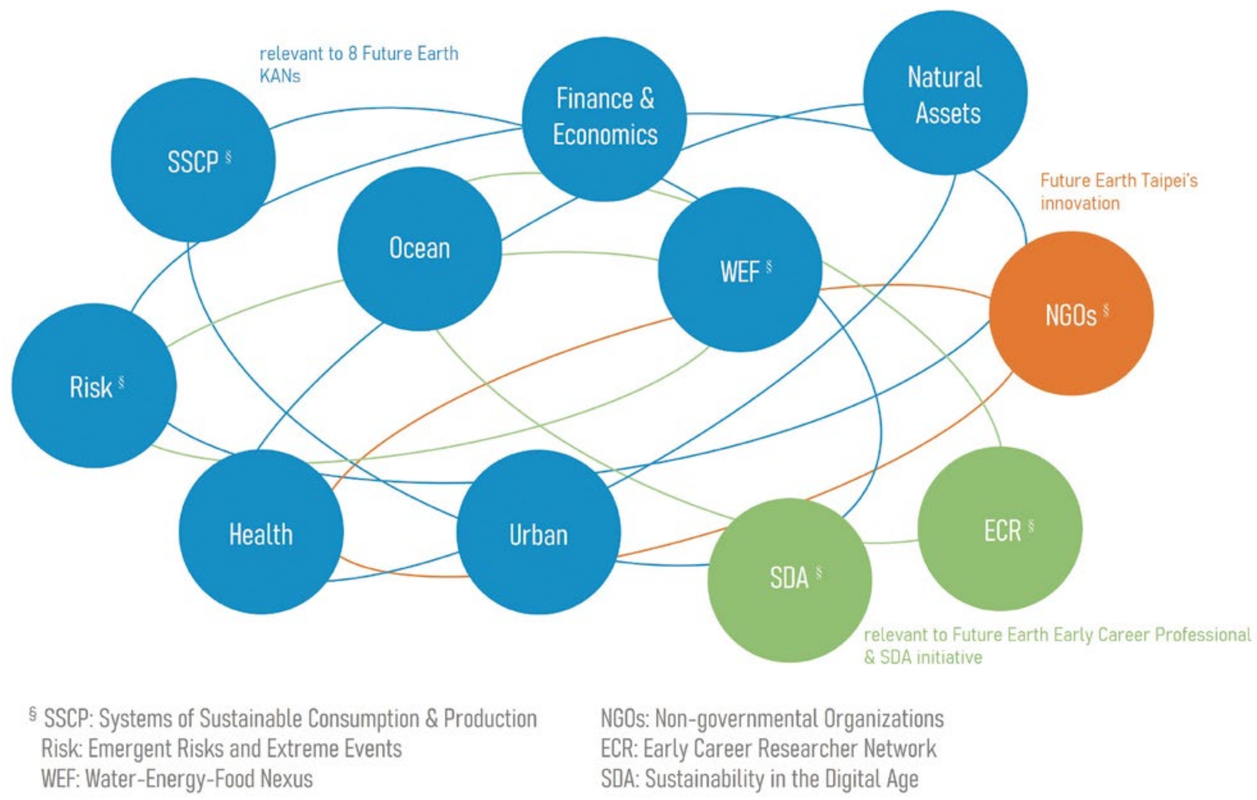


Figure 1. Eleven Working Groups of Future Earth Taipei

Sinica assisted the Future Earth Taipei Secretariat's operations. The Future Earth Taipei Committee features a diverse composition that enhances the link between science and policy/action. The 3rd Committee (2019–2021 term) included a total of 31 members, with 23 belonging to various research communites and 8 representing stakeholders from industry, NGOs, and government agencies (Table 1).

To comply with Future Earth's strategy on network mobilization, Future Earth Taipei had established 11 Working Groups (WGs) by 2020, comprising more than 125 members (Figure 1 and Table 2). Among the 11 WGs, eight correspond to the Future Earth KANs; one corresponds to Future Earth's emerging initiative-Sustainability in the Digital Age; one corresponds to Future Earth's Early-Career Network; the "NGOs WG" is an innovative concept by Future Earth Taipei, which aims to engage NGOs and utilize their actions and resources for scientific knowledge.

Table 1. Future Earth Taipei Committee Members November 2019-November 2021

Ching-Cheng Chang	Wim Y.C. Chang	Yue-Gau Chen
Chen-Tung Arthur Chen	Sophia Cheng	Yu-Chung Chiang
Eugene Chien	Chang-Hung Chou	Tyng-Ruey Chuang
Hsin-Huang Michael Hsiao	Ping-Hui Hsieh	Shu-Li Huang
Fei-yu Kuo	Ling-Ling Lee	Ming-Hsu Li
Tze-Luen Lin	Hsing-Juh Lin	Jiun-Chuan Lin
Neng-Hui Lin	Yu-Pin Lin	Chao-Han Liu*
Ching-Hua Lo	Meng-Fan Luo	Shih-Chun Candice Lung§
Wen-Harn Pan	Daigee Shaw	Huey-Jen Jenny Su
Huei-min Tsai	Jough-Tai Wang	Pao-Kuan Wang
Shin-Cheng Yeh		

*: Chair; §: Executive Secretary

Table 2. Leadership of Future Earth Taipei WGs

Working Group	Coordinator	Advisor
Early Career Researcher Network	Wan-Yu Shih	Jiun-Chuan Lin
Finance & Economics	Ching-Cheng Chang	Daigee Shaw
Health	Shih-Chun Candice Lung	Huey-Jen Jenny Su
Natural Assets	Yu-Chung Chiang	Chang-Hung Chou
NGOs	Young Ku	Eugene Chien
Ocean	Tung-Yuan Ho	Chen-Tung Arthur Chen
Risk	Jian-Hong Wu	Yue-Gau Chen
Systems of Sustainable Consumption & Production	Daigee Shaw	Eugene Chien
Sustainability in the Digital Age	Stephen J.H. Yang	Chao-Han Liu
Urban	Shu-Li Huang	Hsin-Huang Michael Hsiao
Water-Energy-Food Nexus	Yu-Ping Lin	Chao-Han Liu

Highlights in 2020

The COVID-19 pandemic substantially impacted social interactions, particularly in-person meetings. Fortunately, Taiwan contained COVID-19 relatively well that allowed Future Earth Taipei to conduct more than 57 physical and virtual events in 2020. The highlights of 2020 have been detailed below:

1. Being actively involved in Future Earth's reformation

Future Earth Taipei participated in the virtual 2020 Future Earth Summit in June 2020. Immediately after the summit, Future Earth initiated its reorganization (Figure 2). Prof. Yue-Gau Chen, a Future Earth Taipei standing committee member, was elected to join the task force for managing the transition and subsequent implementation team. He was also involved in the Working Group for Secretariat Structure of the Implementation Team, which developed a new Future Earth governance and management structure for improved efficiency, inclusivity, and impact. By actively participating in the reorganization process, we contributed to development of the official document of the Terms of References (ToRs) for Future Earth's Global Coordination Hub, Global Secretariat Hubs, and National Committees. Thus, Future Earth Taipei has been an active contributor to the operation of an international program.

2. Promoting Future Earth's emerging initiative and publications

To ensure that Taiwan keeps abreast of the latest developments in the global sustainability community, Future Earth Taipei attempted to synchronize with the efforts of Future Earth. In 2020, Future Earth published a signature report – *Our Future on Earth*. We organized the satellite launch event and collected local scientists' comments to provide Taiwan's perspectives (see page 58 in this annual report). Furthermore, considering Taiwan's advantage of digital technology, we actively followed Future Earth's initiative "Sustainability in the Digital Age (SDA)." We invited the former executive director, Dr. Amy Luers, to give an inspiring talk at the "Online Forum on Innovative Digital Technology." Future Earth Taipei also officially established "SDA WG" to explore opportunities for collaborations with the Future Earth SDA.

Figure 2. 2020 Future Earth Summit hosted by Future Earth from June 15 to 17, 2020.

3.Facilitating and strengthening domestic networks

To extend local sustainability networks and synchronize the global development of sustainability science, Future Earth Taipei established 11 WGs during 2019–2020. The WGs were tasked with establishing domestic networks and linking with international ones, identifying research focus areas, and organizing activities to promote Future Earth KANs. Numerous activities were conducted in 2020 to mobilize the network and encourage WGs to develop local research priorities. The number of events in 2020 was almost doubled from those in 2019. Twenty-six events were organized by Future Earth Taipei, most of which focused on mobilizing WGs (Figure 3).

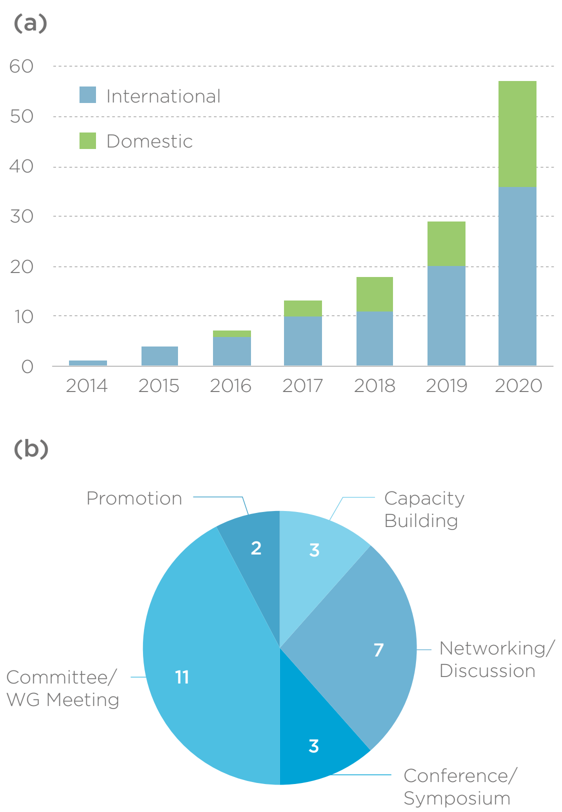


Figure 3. (a) Total number of activities in which Future Earth Taipei was involved.
(b) Activities (by theme) organized by Future Earth Taipei.

4.Cultivating Transdisciplinary research talents

Future Earth Taipei aims to develop transdisciplinary research capability. In collaboration with IRDR ICoE Taipei, Future Earth Taipei Health WG co-organized a three-year international training course – Advanced Institute (AI) on Health Investigation and Air Sensing for Asian Pollution (Hi-ASAP). The course attempted to facilitate transdisciplinary research by bringing together public health and atmospheric science experts. The 2nd AI on Hi-ASAP was held in October 2020, and Hi-ASAP has been endorsed as a regional scientific activity of the Regional Center for Future Earth in Asia (Figure 4). Future Earth Taipei also organized activities for young scientists, such as the Young Scientists Workshop of Water–Energy–Food Nexus WG and Dialogue Series of Early Career Network WG, to facilititate a discussion of their experiences in transdisciplinary research.

Figure 4. AI on Hi-ASAP on the web page of Future Earth Regional Centre for Asia

5.Building partnership with Belmont Forum

Future Earth maintains a close and significant partnership with the Belmont Forum. Future Earth proposed important research topics to the Belmont Forum to form an official international collaborative research call, the Collaborative Research Actions (CRAs). The Belmont Forum circulates funding opportunities and facilitates international cooperation in Future Earth global research networks. This relationship is similar to Future Earth Taipei's strong collective relationship, since 2018, with the Ministry of Science and Technology (MOST) of Taiwan (a member of the Belmont Forum). The common goals of promoting sustainability science in Taiwan and establishing a bridge between Taiwanese researchers and international communities, allowed Future Earth Taipei and the Belmont Forum Project in Taiwan to strenghten their partnership. In the past few years, Future Earth Taipei has participated in the scoping and refining processes of the CRA theme proposed by the Future Earth KAN on Systems of Sustainable Consumption and Production (SSCP). Prof. Daigee Shaw, the coordinator of Future Earth Taipei SSCP WG, joined the steering committee of SSCP KAN and the group of authors for the Belmont Forum SSCP CRA theme proposal. In 2020, Belmont Forum formally approved this CRA theme and is expected to release the call in 2021.

6.Exploring more possibility in social media

Future Earth Taipei also manages Facebook fan page and the Twitter handle, which serve as platforms to share information about Future Earth communities and provide updates pertaining to important achievements in sustainability science worldwide (Figure 5). These fan pages grew steadily in 2020 in terms of the number of fans and messages posted. Future Earth Taipei also promoted the 'Future Earth Membership Portal' in our member community which was established to function as the primary platform for communicating Future Earth's rapid information flow.

Figure 5. Facebook page (left) and Twitter handle (right; *@FutureEarthTPE*) of Future Earth Taipei

Major Activities in 2020

February 13

Break-out and brainstorming sessions facilitated formation of potential collaborative groups and research schemes.

Future Earth Workshop for Taiwan Young Scientists: Water-Energy-Food Nexus

This workshop was organized for young Taiwanese scientists to promote sustainability science in the water-energy-food nexus. In this workshop, we encouraged interactions between participants, and each participant linked their expertise to others through grouping based on diverse disciplines.

February 19

Satellite Launch Event of Future Earth Report 'Our Future on Earth'

Future Earth claimed that 'Humanity is at a critical stage in the transition to a more sustainable planet and society. Our actions in the next decade will determine our collective path forward.' Therefore, Future Earth launched the 1st report 'Our Future on Earth' on February 7, 2020, aiming to clarify our progress on this collective journey by connecting the dots between the present experiences of the society. Future Earth Taipei subsequently organized a satellite launch event. We promoted the report through our local network and collected Taiwan scientists' comments as feedback for global Future Earth.

June 15-17

2020 Future Earth Summit

Future Earth hosted the 2020 Summit, which included discussions on the development strategies of the Future Earth. We actively participated in a survey on governance and communication named 'Network Compass' and presented the context and progress of the establishment and current status of promoting Future Earth in Taiwan.

July 7

IGAC MANGO Online Meeting

In this virtual meeting, members of the IGAC MANGO presented their scientific achievements. Since Hi-ASAP was developed under the IGAC MANGO, Future Earth Taipei also presented a briefing on this research initiative and introduced the training courses organized under the title of AI on Hi-ASAP.

August 19

The 3rd Standing Committee Meeting of the Future Earth Taipei (3rd term)

In collaboration with the 'Sustainable Taiwan in the Post Pandemic Era' forum organized by CSS, Future Earth Taipei invited local networks to attend and hold a standing committee meeting on the same day. The standing committee made decisions on expanding the quota of the committee members to increase the participation of stakeholders and establishing four more WGs in addition to the existing seven WGs.

September 12

The 11th Symposium on Taiwan Wetland Ecosystems

Executive Director of Future Earth Taipei, Dr. SC Candice Lung, gave a talk on the 11th Symposium on Taiwan Wetland Ecosystems and promoted Future Earth.

October 5-6, 8, 15

The 2nd AI on Hi-ASAP

This year, the focus of AI was on the study design and data analysis of sensor evaluation, exposure assessment, and exposure-health evaluation. Currently, research groups from nine different areas in Asia are participating in this virtual training and planning to adopt the identical research methodology on air pollution sensing and health studies to enable comparisons on an international basis.

October 7

Online Forum on Innovative Digital Technology

In response to the Digital Age, we invited Dr. Amy Luers, Global Director of Sustainability in the Digital Age, Future Earth, to deliver a speech on "How to apply Information and Communication Technology (ICT) to promote the societal transformation to a more sustainable society." Additionally, three Taiwanese scholars shared Taiwan's strength, and key developments and achievements pertaining to sustainability in the digital age.

October 16

The Executive Secretary of Future Earth Taipei introduced the transformation and future directions of Future Earth, and the possible response strategies were discussed.

The 3rd Plenary Committee Meeting of Future Earth Taipei (3rd Term)

With the number of WGs increased to 11, Future Earth Taipei invited all WG members (more than 75 scientists and stakeholders) to attend the 3rd Plenary Committee Meeting of Future Earth Taipei, which is regarded as the first Future Earth Taipei summit. The committee encouraged WGs to participate in the activities of the Future Earth KAN and initiatives.

December 16

In the first dialogue event, we invited Ms. Hannah Moersberger— the deputy Director of Future Earth Global Hub, to share her experiences in promoting the early career network at Future Earth.

Dialogue Series 1: Planning and Outlook of Future Earth - Early Career Network

International cross-disciplinary collaboration is a global trend in sustainability science, yet researchers at an early career stage often lack resources to engage with these trends. Thus, we invited coordinators of early career networks in sustainability science from international academic organizations, and participants in early career academic initiatives, to share their experiences.

Belmont Forum

Int'l Belmont Forum

BFPO, MOST

Asia
- Academia Sinica, Chinese Taipei
- JST, Japan
- MEXT, Japan
- MOES,India
- MOST, Chinese Taipei
- NSFC, China
- QNRF, Qatar
- TSRI, Thailand
- TÜBİTAK, Turkey

Africa
- NRF, South Africa
- PASRES, Ivory Coast

Oceania
- CSIRO, Australia

Europe
- AllEnvi, France
- BMBF, Germany
- CNR-DTA, Italy
- European Commission
- Formas, Sweden
- FWF, Austria
- GEO, Switzerland
- IAP, Italy
- ISC, France
- IIASA, Austria
- MESRI, France
- MRI, Switzerland
- NERC, United Kingdom
- NWO, Netherlands
- RCN, Norway
- VR, Sweden

North America
- CONACYT, Mexico
- NSERC, Canada
- NSF, USA
- START, USA
- USGCRP, USA

South America
- FAPESP, Brazil
- IAI, Uruguay
- MINCyT, Argentina

Figure 1. The Belmont Forum's Members and Partner Organizations

Introduction

The Belmont Forum, established in 2009, is a partnership of funding organizations, international science councils, and regional consortia committed to the advancement of interdisciplinary and transdisciplinary science (Figure 1). The funding agencies that are members of the Forum, such as the NSF of the USA, are legally allowed to mobilize resources to promote research on critical global change problems. The Belmont Forum also closely interacts with various partner organizations such as the International Science Council, Science and Technology Alliance for Global Sustainability, and Future Earth.

The operations are guided by the Belmont Challenge, which encourages *international transdisciplinary research providing knowledge for understanding, mitigating, and adapting to global environmental change*. Thus, the Belmont Forum aims to support multinational and transdisciplinary collaborative research, bringing together natural sciences, social sciences, and the humanities as well as stakeholders in co-creating the knowledge and solutions for sustainable development that benefit society. These solution-oriented researches, called Collaborative Research Actions (CRAs), have been covering a wide array of topics since 2012 (Figure 2).

To encourage Taiwanese researchers' active participation in international collaborative research, Taiwan became a Belmont Forum member in 2015 with the cooperation of the Ministry of Science and Technology (MOST) and Academia Sinica. Currently, Taiwan is participating in six CRAs: Food-Water-Energy Nexus (Nexus); Science-driven e-Infrastructure Innovation (SEI); Climate, Environment, and Health (CEH); Disaster Risk Reduction and Resilience (DR^3); Towards Sustainability of Soils and Groundwater for Society (Soils); and Transdisciplinary Research for Pathways to Sustainability (Pathways). Academia Sinica's Center for Sustainability Science (CSS) took over the Belmont Forum Program Office (BFPO) in 2020.

Figure 2. Collaborative Research Action themes since 2012

Highlights in 2020

1. Strengthening the BFPO's Operation

Last year, the BFPO's project investigator was changed to Professor Yue-Gau Chen, CSS executive secretary. In addition, two full-time doctoral science officers and one administrative secretary were recruited. By bringing in the much-needed manpower, the BFPO's operation has been strengthened thus:

- Establishment of a more streamlined project management system, such as regular meetings with MOST, contact with each project team, and new CRAs' scoping process
- Enhancement of the link with partner organizations, such as Future Earth Taipei
- Active participation and sharing of experiences in the Belmont Forum's international meetings. For example: Belmont Forum 14th Plenary Meeting and Belmont Forum Virtual Open House (Figures 3 and 4)

Figure 3. Belmont Forum 14th Plenary Meeting, October 13-15, 2020

Figure 4. Belmont Forum Virtual Open House, December 4, 2020

2. Two New CRA Themes to Promote International Research Collaboration

Last year, the Belmont Forum launched two new CRA themes: "Towards Sustainability of Soils and Groundwater for Society (Soils 2020)" and "Transdisciplinary Research for Pathways to Sustainability (Pathways 2020)." After a thorough review, six Taiwanese research teams were awarded for these two CRAs (Table 1).

Table 1. The Number of Taiwanese Teams Awarded

CRAs	Lead	Joint
Climate, Environment, and Health (CEH)	0	1
Disaster Risk Reduction and Resilience (DR^3)	1	1
Food-Water-Energy Nexus (Nexus)	1	3
Science-driven e-Infrastructure Innovation (SEI)	0	1
Towards Sustainability of Soils and Groundwater for Society (Soils) (New)	0	3
Transdisciplinary Research for Pathways to Sustainability (Pathways) (New)	1	2
Total	3	11

Activities in 2020

June 19

Promotion Briefing: Towards Sustainability of Soils and Groundwater for Society (Soils 2020)

Professor Ming-Hsu Li introduced the objectives, focus, research themes, evaluation criteria, and expected outcomes of Soils 2020

August 11

Briefing: Transdisciplinary Research for Pathways to Sustainability (Pathways 2020)

Professor Teng-Chiu Lin explained to the participants the procedures, timelines, and eligibility for applying for Pathways 2020.

October 27

SSCP Promotion Group Meeting

The meeting focused on introducing the new CRA theme - SSCP, and encouraging academics and practitioners from diverse backgrounds to engage in more collaborations.

November 24

Briefing: Submission of Taiwanese Applications for Soils 2020 and Pathways 2020

This meeting mainly focused on introduction of the Belmont Forum's targets and background, and a description of how MOST participated in the Belmont Forum's activities.

Assessing Health and Economic Benefits of Air Pollution Reduction Policies in Taiwan

Project Starting Year	2018
Project Director	**Hwang, Jing-Shiang**: Distinguished Research Fellow of the Institute of Statistical Science, Academia Sinica. His major research interests include Bayesian statistical inference, environmental health related studies especially on the health effects of air pollution and developing statistical methods for cost-effectiveness analysis and social network analysis.
Hosting Institute	Institute of Statistical Science
Sub-Project PI, Co-PI	Dr. Lin, Hsien-Ho, IEPM, NTU Dr. Kan, Kamhon, IE, AS

Research Objectives

The health implications of ambient air pollution are widely recognized in Taiwan; however, progress in reducing emissions has been slow. Policy makers continue to question the assessment of the disease burden attributable to air pollution because of limited studies on health effects in Taiwan. In other words, the disease burden and health expenditures that can be reduced through emission reduction have seldom been evaluated systematically, especially in Taiwan.

To assist evidence-based policy making for air pollution reduction, this research project estimated the disease burden and subsequent health expenditure attributable to the current exposure to air pollution at the national and subnational levels in Taiwan. We compared three counterfactual scenarios to ascertain whether the proposed targets of air pollution reduction could be achieved. We also proposed an alternative approach for estimating the effects of long-term exposure to air pollution on mortality for the elderly population at the subnational level. Furthermore, we employed a quasi-experimental approach with the closing time and location of a powerplant as an instrumental variable to understand the causal effects of ambient particulate matter on long-term health outcomes.

Main Results to Date

To evaluate the health effects of long-term exposure to air pollution at the subnational level in Taiwan, we first estimated mean air pollution concentrations for all townships and districts over an extended period. Specifically, we developed statistical methods for estimating ground-level fine particulate matter ($PM_{2.5}$) concentrations for all the 3 km × 3 km grids in Taiwan by combining air quality and weather data from the Taiwan Air Quality Monitoring Network (TAQMN) and $PM_{2.5}$ measurements from thousands of microsensors. The $PM_{2.5}$ data from the Airbox microsensors were used to predict daily mean $PM_{2.5}$ levels in the grids in 2017 using a semi-parametric additive model. The estimated $PM_{2.5}$ level in the grids was further applied as a predictor variable in statistical models to predict the monthly mean concentrations of $PM_{2.5}$ in all the grids in the previous year. The modeling–predicting procedures were repeated backward for the years from 2016 to 2006. We provided these estimates to researchers who require information on monthly mean concentrations of $PM_{2.5}$ at the district level in Taiwan (Figure 1), which can be downloaded from https://github.com/ccho415/$PM_{2.5}$-estimation-in-Taiwan.

For the main objective of the project, we designed a Naïve Bayes model that used multiple causes of death data to generate a garbage code redistribution model, considering multiple potential covariates. We therefore obtained the cause-specific mortality and years of life lost (YLL) by considering the garbage code redistribution. Years living with disability (YLD) are calculated by the summation of the prevalence of sequel multiplied by the disability weights adopted from Global Burden Disease (GBD) 2017. To estimate the point prevalence of sequela, we utilized the National Health Insurance Research Database (NHIRD) for stroke, ischemic heart disease (IHD), diabetes mellitus (DM), chronic obstructive pulmonary disease (COPD), and the Taiwan Cancer Registry dataset for lung cancer. The population-attributable fractions (PAFs) for the five selected diseases (IHD, Stroke, Lung Cancer, COPD, and DM) were determined by incorporating the integrated risk functions developed by GBD and the ten-year average of $PM_{2.5}$ exposure at the district level estimated by our team. Note that PAF is the proportion of burden of disease (and associated health expenditures) in a given population that would be avoided if risk factor exposures of that population were shifted to an alternative counterfactual distribution that is more favorable. Finally, the PAF multiplied by the disability-adjusted life year (DALY, the sum of YLL and YLD) and health expenditure to obtain the burden of disease attributable to $PM_{2.5}$ for each selected disease.

The overall PAF for the five diseases ranged from 9.98% to 28.04% among the study districts (national, 18.37%; 95% CI, 17.7%-19.01%). Districts from southwest Taiwan had higher PAF than other counties, with the South District of Chiayi City having the highest PAF (21.86%) in Taiwan. The lowest PAF was observed in Lanyu Township (5.66%). Nationally, $PM_{2.5}$ was responsible for 226,227 DALYs (comprising 137,596 YLLs and 88,631 YLDs) in 2015; the leading cause was DM (95,389 DALYs; 95% CI, 89,967–100,771), followed by IHD (37,394 DALYs; 95% CI, 35,693–39,081), lung cancer (36,097 DALYs; 95% CI, 31,786–40,223), stroke (30,596 DALYs; 95% CI, 28,499–32,711), and COPD (26,751 DALYs; 95% CI, 23,375–29,934). For attributable health expenditure, we observed that 2.29% of

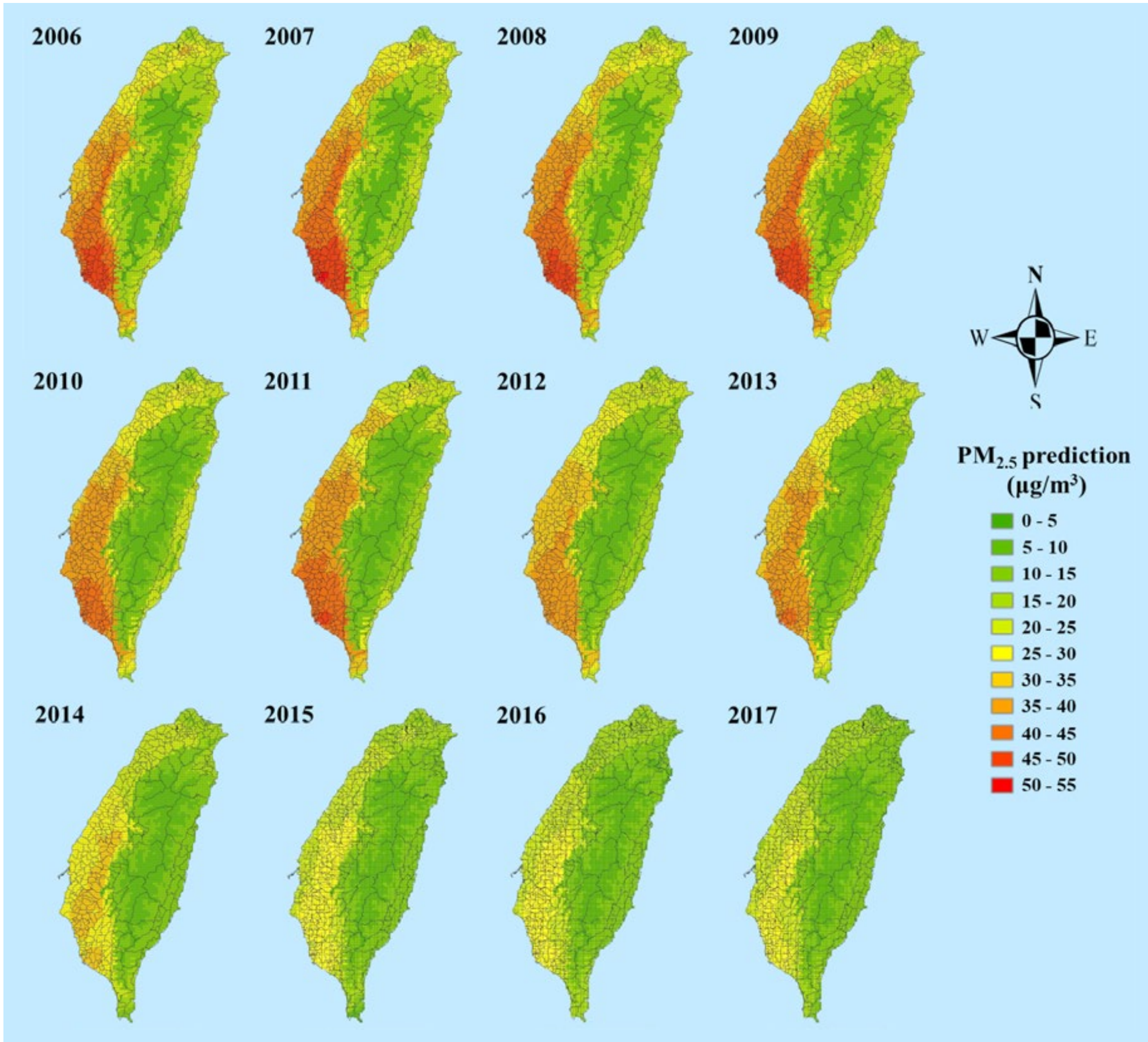


Figure 1. Annual average $PM_{2.5}$ predictions in Taiwan during the 2006–2017 period

the total health expenditure was equal to NTD 10.9 billion in 2015 due to $PM_{2.5}$ exposure (42% from DM, 20.6% from IHD, 9.7% from COPD, 11.9% from lung cancer, and 15.8% from stroke). Compared with the reference scenario (the reality), presented in Figure 2, the counterfactual scenario of Target 15 μg/m^3 by Taiwan EPA standard potentially avoids the burden of disease with 41,033 DALYs (95% CI, 28,545–53,659) and NTD 1.87 billion (95% CI, NTD 1.27 billion-2.47 billion). On the contrary, the counterfactual scenario of Target 10 μg/m^3, determined according to WHO standards, would prevent 73,712 DALYs (95% CI, 59,579–88,925) and NTD 3.42 billion (95% CI, NTD 2.73 billion-4.11 billion) of health expenditure, while the best case scenario (current minimum of $PM_{2.5}$ exposure, 7.5 μg/m^3) would avoid 117,816 DALYs (95% CI, 100,457–135,535) and NTD 5.56 billion (95% CI, NTD 4.70 billion-6.41 billion) of health expenditure. The considerable economic value of ancillary health benefits due to air pollution reduction is an additional impetus for the government to establish stringent pollutant reduction targets and provide air pollution control policy guidance.

We examined an alternative approach to assess the disease burden attributable to long-term exposure to $PM_{2.5}$ by directly estimating the expected life loss due to increased $PM_{2.5}$ exposure. In this study, we used claims data from the NHIRD to create 63 study cohorts of 1.91 million residents aged 60–79 years residing in small areas where stations of TAQMN are situated. The survival status of each person was followed up from 2001 to 2016. We applied an extrapolation algorithm to estimate the lifetime survival function to enable us to directly estimate life expectancy (LE) and lifetime exposure to $PM_{2.5}$ of each cohort. We fit linear models to the estimated LE and lifetime exposure to $PM_{2.5}$ among the 63 cohorts with the adjustment of the effects of socioeconomic factors. The results of the alternative model indicated that older adults who lived in an area with a higher annual average $PM_{2.5}$ of 10 μg/m^3 had a shortened LE by 0.34 (95% CI, 0.22–0.46) years. The expected lifetime exposure to $PM_{2.5}$ of the older adult cohort living in the study area with the worst air quality since 2001 was 38.8 μg/m^3. For this cohort, the estimated years of life lost could have been reduced by 0.96 years under the counterfactual scenario of exposure to the WHO standard of 10 μg/m^3.

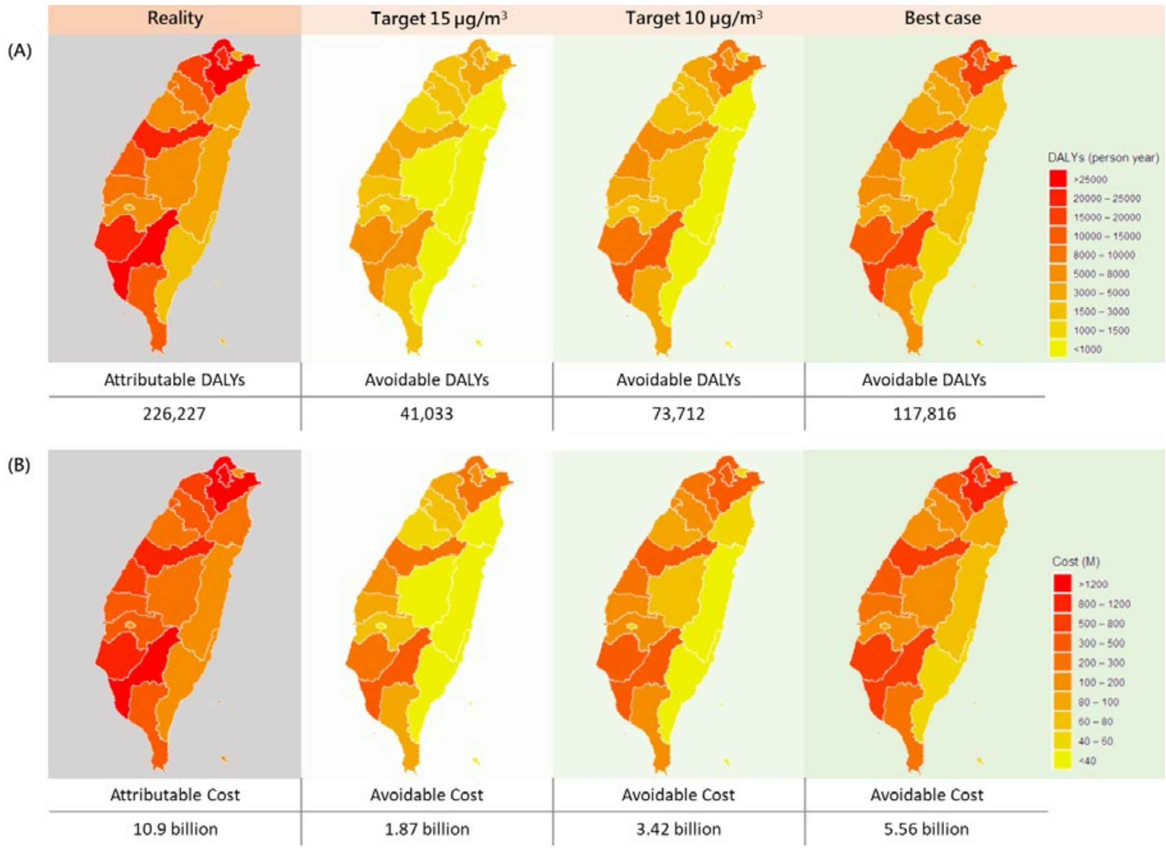


Figure 2. The attributable and avoidable burden of (A) DALYs and (B) health expenditure associated with $PM_{2.5}$ exposure under reality and three counterfactual scenarios in 2015.

In addition to the models on the associations between long-term exposure to air pollution and health outcomes, we used a quasi-experimental approach to identify the causal effects of air pollution on health. We employed population data derived from the NHIRD records and the death registry for 2004–2016. Natural experiments arise from the closure of the Shenao powerplant on September 30, 2007. A new powerplant with generators of greater efficiency and capacity were to be rebuilt on the original site. However, the plan of building a new powerplant was never carried out due to environmental concerns and protests by environmental groups. The closure of the Shenao powerplant provided us with an opportunity to conduct an investigation with difference-in-differences and event study approaches. In the difference-in-differences analysis, the treatment region consists of areas within a radius of 50 kms around the site of the Shenao powerplant, while the control region consists of areas within a 50-km radius around the city hall of Taichung City and Kaohsiung City. The difference-in-differences estimator compares different cohorts of individuals before and after the closure of the powerplant. To check the robustness of the difference-in-differences estimates, we utilize the event study approach. Under the event study approach, we followed fixed groups of individuals and examined how the treatment and control group individuals differ over time. These results suggest that the closure of the Shenao powerplant led to a 7.92% and 9.11% reduction in the log levels of $PM_{2.5}$ and PM_{10}, respectively. The levels of SO_2 and NO_2 decreased by 4.24% and 4.02%, respectively. The drop in $PM_{2.5}$ and PM10 was much larger than that for SO_2 and NO_2. The difference-in-differences results and event study results were consistent with each other. The estimation results indicated that the closure of the Shenao powerplant reduced individuals' utilization of inpatient services due to lung diseases, pneumonia heart diseases, cardiovascular diseases, and psychological disorders. Likewise, individuals also used fewer outpatient services. In particular, they had fewer physician visits due to cardiovascular diseases, dementia, heart diseases, Parkinson's disease, and psychological disorders. These effects were stronger for men and in the long run. However, the closure of the Shenao powerplant did not affect the residents' mortality rate.

To further examine the sources of $PM_{2.5}$ that were more responsible for the health effects, we sought to identify realistic pollution source profiles and quantify the contributions of atmospheric particulate matter. Specifically, we formulated a multivariate source apportionment model by using a Bayesian framework for latent source profiles to incorporate expert knowledge regarding emissions that can facilitate source profile estimation, and atmospheric effects, such as meteorological conditions, and can improve source concentration estimations. This approach can maintain the positivity and summation constraints for source contributions and profiles. Furthermore, existing expert knowledge regarding source profiles is incorporated as prior knowledge to avoid restrictive assumptions regarding the presence or absence of chemical constituent tracers in source profile modeling. We applied long-term $PM_{2.5}$ measurements collected from two sites in downtown Taipei and the coastal district of Shimen in northern Taiwan to demonstrate the feasibility of the proposed model and demonstrate its better performance compared to the popular positive matrix factorization model by using simulated data. The empirical results from the data collected at the two locations during the 2003–2006 period, illustrated in Figure 3, indicated that the three major contributors to $PM_{2.5}$ concentrations in Taipei City are vehicle exhaust, road dust, and long-range transport. In the northern coastal district of Shimen, the three main contributors to $PM_{2.5}$ concentrations are sea salt spray, road dust, and long-range transport.

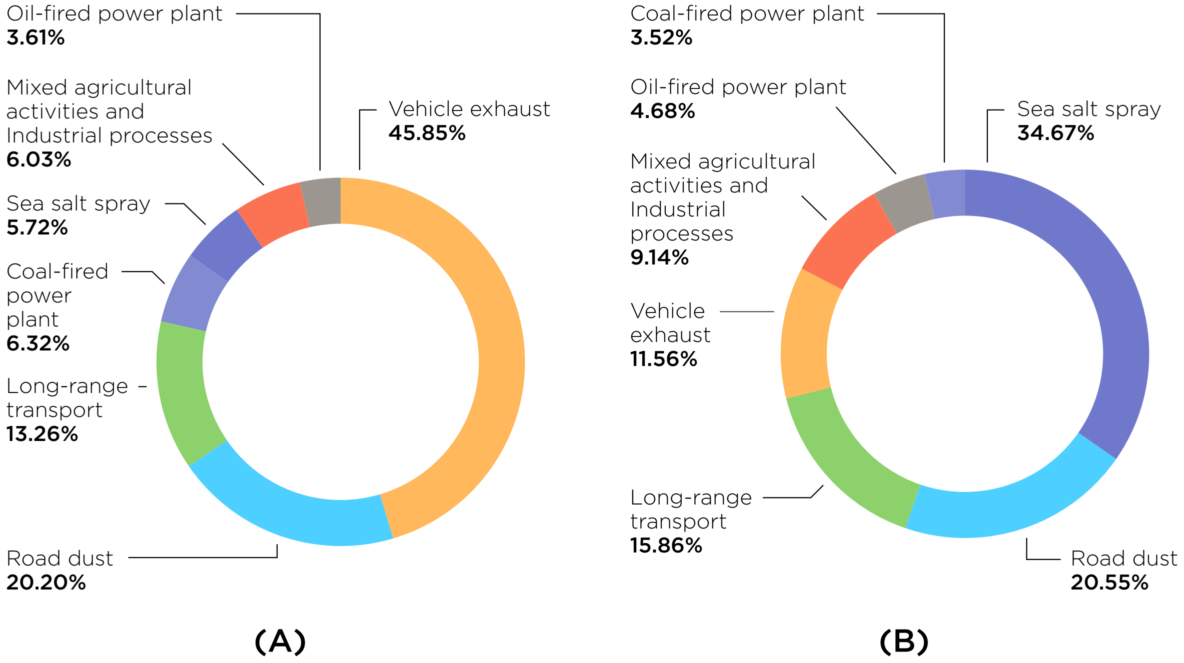


Figure 3. Mean percentage of source contributions for (A) Taipei City and (B) the Shimen district. The results were based on 25 chemical constituents in 196 samples collected at Taipei City during the period January 2003–February 2006 and 172 samples collected at the Shimen during the period January 2003–April 2005.

Future Research Plan

Although people live longer, the elderly often live with disability and chronic diseases, such as cardiopulmonary disease. The indicator of health adjusted life expectancy (HALE), which considers both morbidity and mortality of specific diseases, can be a useful metric for health professionals, policy makers, and the general public. We intend to present an approach for directly estimating the HALE of a specific cohort using claims data from the NHIRD. With the new approach and big data, we can examine potential risk factors related to HALE and quantify the effect sizes of the identified factors. In particular, we will be able to quantify the effect of lifetime exposure to $PM_{2.5}$ air pollution on HALE related to cardiopulmonary disease in older adults.

With the source apportionment method developed by our team, we will further explore the health effects of short-term exposure to sources of $PM_{2.5}$, to identify the pollution sources that are more toxic to our health. The proposal is particularly relevant for any findings that will provide solid evidence for the development of air pollution reduction strategies.

Publications

1. Ho, C. C., Chen, L. J., & **Hwang, J. S.** (2020). Estimating ground-level $PM_{2.5}$ levels in Taiwan using data from air quality monitoring stations and high coverage of micro-sensors. *Environmental Pollution*, 264114810. https://doi.org/10.1016/j.envpol.2020.114810.
2. Ng, T. C., Lo, W. C., Ku, C. C., Lu, T. H., & Lin, H. H. (2020). Improving the use of mortality data in public health: A comparison of garbage code redistribution models. *American journal of public health*, 110(2), 222-229.
3. **Hwang, J. S.**, & Hu, T. H. (2020). Later-life exposure to moderate $PM_{2.5}$ air pollution and life loss of older adults in Taiwan. *International Journal of Environmental Research and Public Health*, 17(6), 1873. doi:10.3390/ijerph17061873.
4. Tang, J. H., Lung, S. C. C., & **Hwang, J. S.** (2020). Source apportionment of $PM_{2.5}$ concentrations with a Bayesian hierarchical model on latent source profiles. *Atmospheric Pollution Research*, 11, 1715-1727.

An Economy-Wide Assessment of Taiwan's Renewable Energy Development Strategies as It Transitions to a Low-Carbon Society

Project Starting Year	2018
Project Director	**Chang, Ching-Cheng**: Research Fellow in the Institute of Economics at Academia Sinica and Professor of Agricultural Economics at National Taiwan University. Her recent work focused on integrated assessment of climate change impact and policy response, decision making of climate risk management, modeling of food-energy-water nexus, and household food consumption and dietary changes related to food and nutrition security policies.
Hosting Institute	Institute of Economics, Academia Sinica
Sub-Project PI, Co-PI	Lin, Hsing-Chun, Dept. of AE, NCYU Chen, Po-Chi, Int'l Bus., CHU Lin, Hsuan-Chih, ECON, AS Hsu, Shih-Hsun, AGEC, NTU Lee, Duu-Hwa, Dept. of AE, NTOU Tseng, Wei-Chun, Dept. of AE, NCHU Sheu, Sheng-Jang, Dept. of AE, NUK

Research Objectives

Against the backdrop of widespread challenges posed by climate change, this study aims to conduct an integrated social-economic-environmental assessment of policies related to developing a low-carbon society in Taiwan. We adopted the dynamic computable general equilibrium approach (General Equilibrium Model for Taiwan Economy and Environment, GEMTEE), which includes an input-output table, regional population module, and resource-environmental module, as the basis for modeling and simulation work in the following four areas (sub-projects):

1. Make a baseline forecast of greenhouse gas (GHG) emissions in six major sectors (energy, manufacturing, transportation, residential, agriculture, and environmental) and identify the most cost-effective sector for priority setting.

2. Study the impact of green tax reform and the structural transformation of Taiwan's oil and petrochemical industry.

3. Evaluate the feasibility of Taiwan's renewable energy development goal and the socio-economic costs and benefits of its industrial adjustment strategies.

4. Examine the socio-economic benefits of policies related to the promotion of low-carbon technologies and lifestyles incorporating consumers' behavioral changes.

The results of this project consist of projections of the social-economic-environmental outcomes of a set of policy recommendations for Taiwan's low-carbon transformation.

Main Results

1. Sub-project 1 takes into account various established policies as well as industrial growth to construct a framework for baseline forecasting. The likely business-as-usual scenario toward 2050 is defined and used as a reference against which the effects of alternative de-carbonization pathways can be estimated. The main components of the baseline include annual gross domestic product (GDP) projections and the associated main drivers, such as population, labor force, capital stock, and total factor productivity.

   Figure 1 shows the baseline forecasting results from GEMTEE on GHG emissions, expected to increase from 299 million tons of carbon equivalent in 2017 (excluding carbon sinks) to 363 million tons in 2025, which is 92 million tons (+34%) higher than the Environmental Protection Agency's second-phase regulatory target of 271 million tons by 2025. Moreover, $PM_{2.5}$ is expected to grow from 78,000 tons in 2017 to 82,000 tons in 2025 at an average annual growth rate of 0.63%.

   As demonstrated in Figure 2, there is a significant asymmetry in the correlation (or coupling) between GDP and carbon dioxide (CO_2) emissions under each period of prosperity and depression between 2005 and 2020. A recent review and assessment of the environmental impacts of the COVID-19 pandemic by Helm (2020) concluded that "[t]he evidence from the pandemic is that it is not the case that decoupling has occurred at the global level, or even at the European level. Emissions and GDP have both fallen sharply."(p.3) Taking Taiwan as an example, this study provides local evidence to support Helm's proposition.

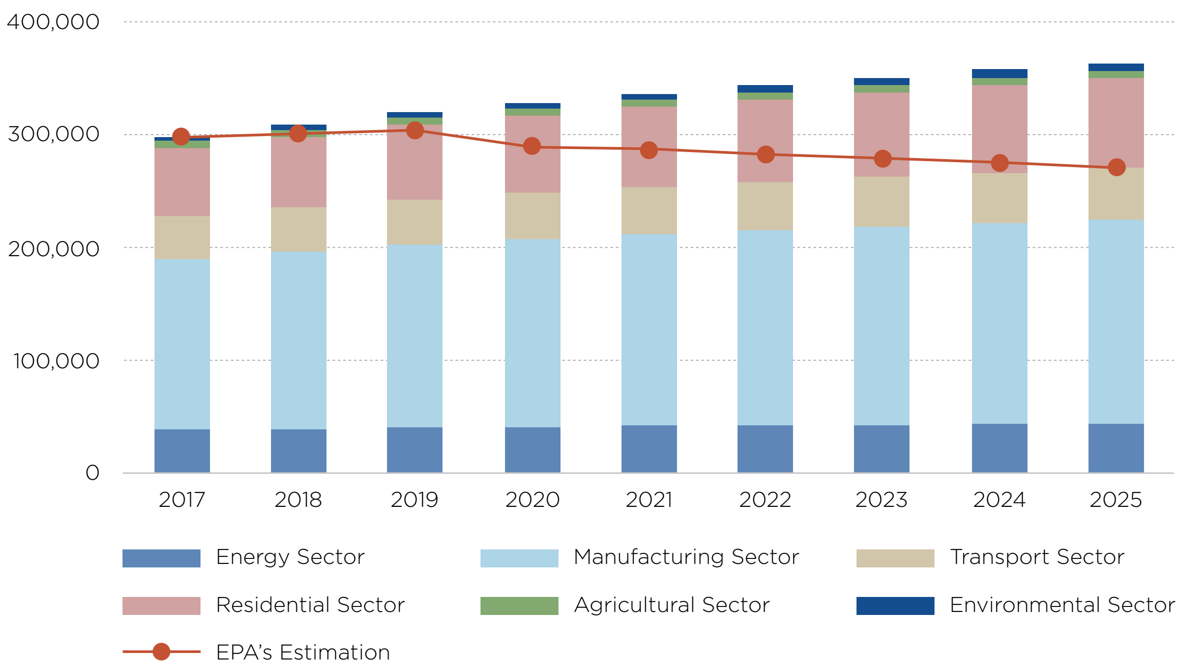


Figure 1. Baseline forecasting of greenhouse gas emissions in Taiwan's six major sectors, 2017–2025

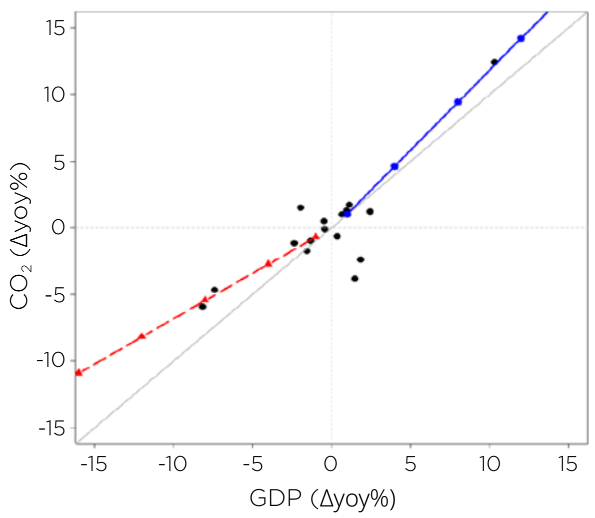


Figure 2. Relationship between GDP and CO_2 emission in Taiwan, 2005–2020

   Taiwan's GDP and emissions have been highly correlated during the COVID-19 situation. In this regard, the causal link between CO_2 emissions and GDP under the depression period cannot be considered a trivial duplicate of the analysis under the boom period.

2. In Sub-project 2, we examine the role of environmental taxation as a policy tool from a macroeconomic perspective. A carbon tax is applied to examine the economic impacts and carbon reduction benefits. Simulation results from GEMTEE reveal that a carbon tax of USD 24–30 per ton will cause reductions in the average annual growth rate of real GDP of 0.56% to 0.57%, the average annual reduction of CO_2 of 2.49% to 2.50%, and the average annual growth rate of $PM_{2.5}$ emissions of 2.05% to 2.06%. Therefore, the human health co-benefit provides a clear economic incentive for redirecting energy investment toward low-carbon technologies.

   According to the High-Value Petrochemical Industry Promoting Project, during the de-carbonization process, the petrochemical industry will play an important role until alternative energy sources become more economical and accessible. However, GEMTEE simulation results show that the overall impact on the petrochemical industry is much greater than on other sectors. The output of the petrochemical supply chain is expected to decline by 0.88% to 3.20% per year. This slower growth implies a significant reduction in workforce by 2.69% to 4.99% because of continued productivity gains that outpace output growth. Therefore, disputes over low economic contribution and high energy consumption of the petrochemical industry should be addressed carefully to retain a competitive edge in dealing with the challenges of low-carbon transition.

3. Sub-project 3 examines the new 20-30-50 energy policy for attaining a "Nuclear-Free and Sustainable Taiwan," which increases our renewable-based electricity generation to 20% of total generation by 2025 with a target of installed capacity of 20 gigawatts (GW) of solar energy and 3 GW of offshore wind. We constructed the sectors of solar and offshore wind power and related technology bundles in GEMTEE to evaluate the impact of achieving the goal. In addition, considering the high degree of uncertainty associated with renewable energy due to climatic conditions, electricity shortage possibilities are also analyzed to address concerns with regard to the discrepancy between electricity

generation and demand. Amendment bills for renewable energy development article along with major electricity usage clauses are also proposed in the belief that major electricity users with a capacity of over 5,000KW will need to be regulated to fulfill the obligation to convert 10% of their capacity to renewable energy in order to increase renewable energy development and reduce air pollution.

Simulation results show that either electronic manufacturers using green energy or major electricity users fulfilling obligations could incur an increase in energy costs, affecting their profits. However, the positive benefits from environmental and human health perspectives can offset the negative impact, resulting in an overall positive benefit to society. Therefore, the government may implement policies to provide incentives for green energy innovation that target the cost competitiveness gap while also helping major electricity users fulfill the requirement to meet international standards.

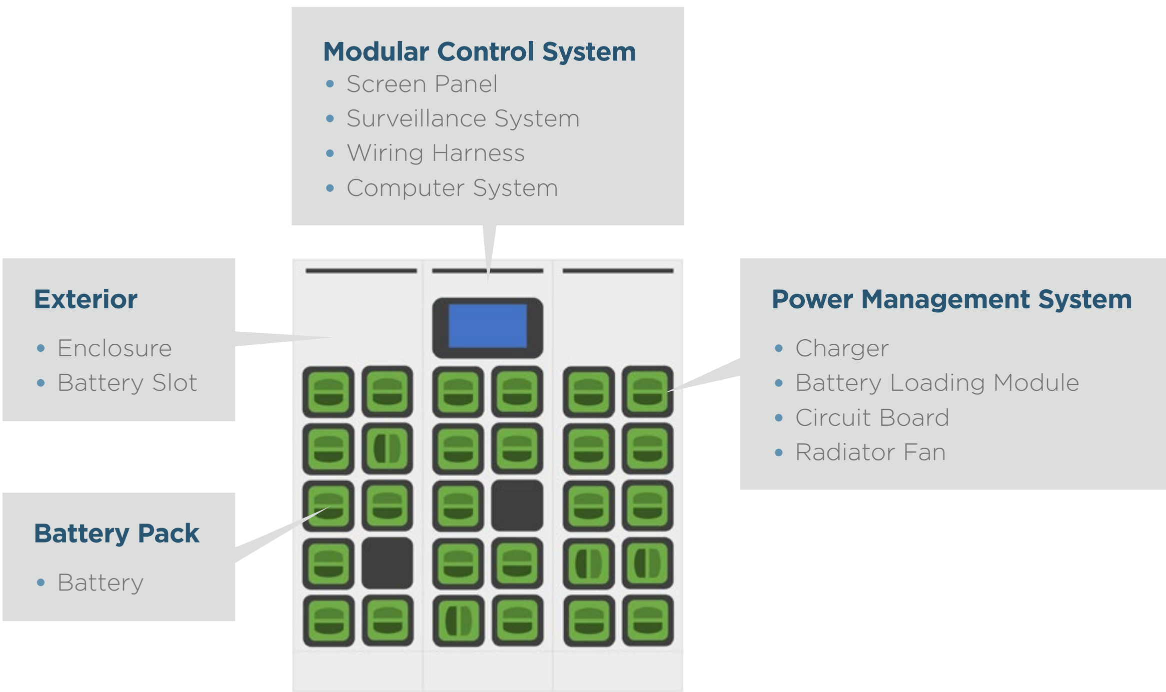
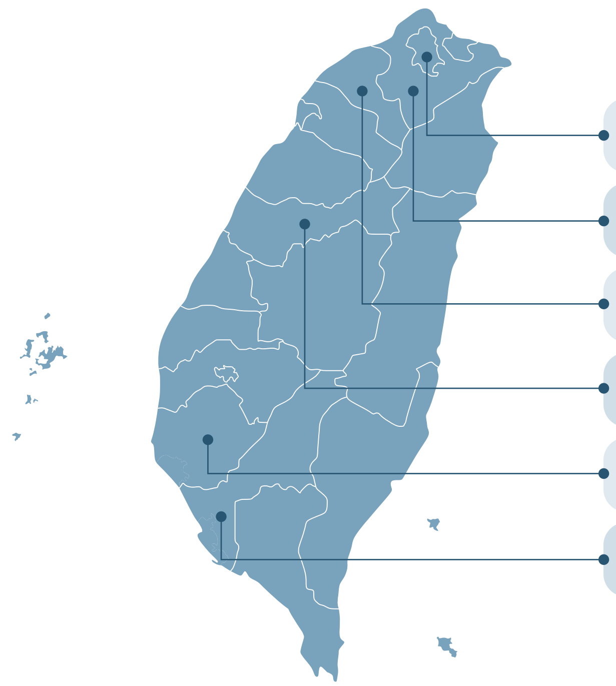


Figure 3. The structure of an electric motorcycle battery exchanging station (Source: Gogoro, Personal Interview, 2020)

4. Given the impact and consequences of global warming, the development of electric vehicles has been identified as one of the major mitigation strategies for governments to reduce emissions from the transportation sector. Sub-project 4 conducts an impact assessment of adopting electric motorcycles (EM) on Taiwan's economy and environment. We review the domestic EM market structure and construct a new database to evaluate the policy impact of accelerating the transition from conventional vehicles to EM.

Taiwan launched EM research and development in 1995. The rapid growth era of EMs commenced in 2015, when Gogoro introduced its first motorcycle, which also led Taiwan to adopt the battery-swapping system for charging batteries (Figures 3, 4, and 5). Our GEMTEE simulation results show that the motorcycle electronification policy, in conjunction with the 50-30-20 energy transition plan, can reduce 1.08 million tons of CO_2 emission by 2025 and accomplish the 43.22% carbon reduction target in the transportation sector. Additionally, the development of the EM value chain is expected to increase GDP by 0.03–0.05% every year and create up to NTD 50 billion in GDP by 2025. Moreover, the increasing labor demand in the EM and battery swap station industry will offset the decline in the gas-powered motorcycle industry. The workforce in the conventional gas-powered motorcycle industry is expected to drop by 1% per year. The answer lies in whether the domestic-made battery sector can grow and become one of the key enablers of this transition.

In summary, this project provides a comprehensive policy impact assessment of the low-carbon transition in Taiwan from the industrial, power supply, and end user perspectives. The costs and benefits of different policies on the economy and carbon reduction are discussed. We believe that this modeling development work affords us a new capability to investigate fundamental policy questions that have not been addressed by existing studies on cost-benefit grounds.



	Electric Motorcycles	Battery Exchanging Stations
Taipei City	39,927	232
New Taipei City	48,006	422
Taoyuan City	69,833	317
Taichung City	43,649	347
Tainan City	34,777	277
Kaohsiung City	46,610	333

Figure 4. The number of electric motorcycles and battery exchanging stations in major cities in Taiwan (Sources: Directorate General of Highways (2020); Industrial Development Bureau, Ministry of Economic Affairs (2020))

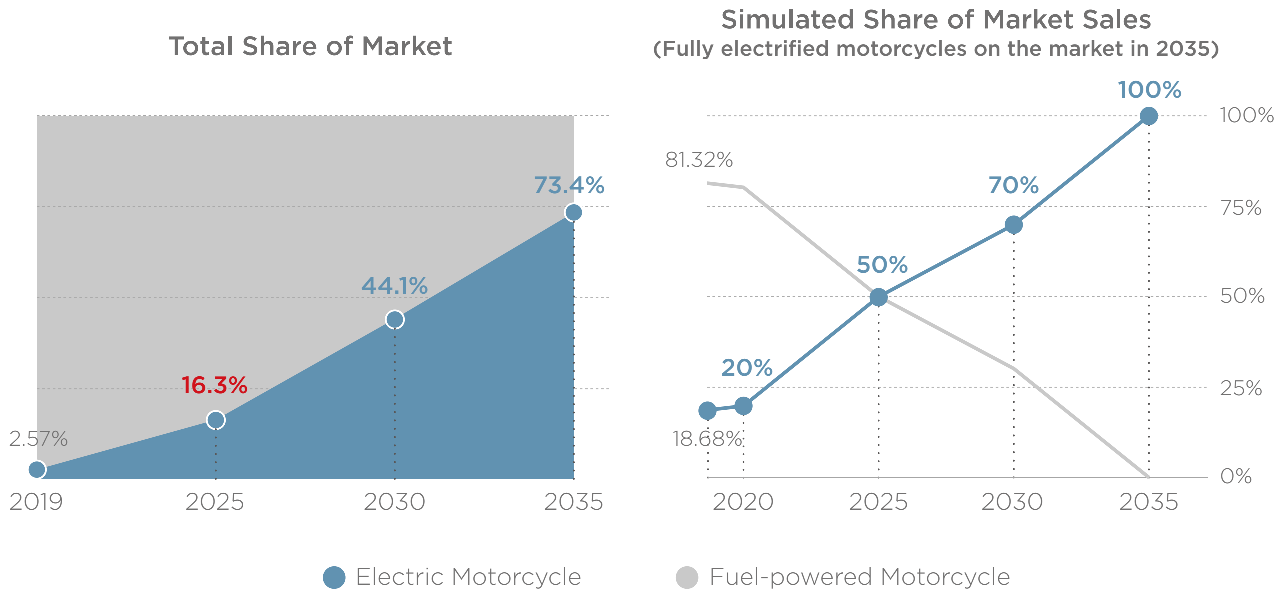


Figure 5. The milestones of fully electrified motorcycles in Taiwan (Sources: Industrial Technology Research Institute (2018); Bureau of Energy, Ministry of Economic Affairs (2018))

Note: The market shares in the left panel are based on total stocks, while the shares in the right panel are based on total annual sales.

Future Research Plan

Owing to potential carbon leakage and its comprehensive impact, the proposed carbon tax mechanism should be further evaluated by incorporating certain adaptive strategies, such as the green certification system. It is imperative for future research to include assessments of rewarding private investment in R&D, creating an international brand, or setting up a petrochemical zone through the design of the tax system or the green certification system, in order to achieve the long-term goals of industrial upgrade, energy conservation, and GHG emission reduction. Moreover, the *ex-post* analysis of the asymmetric relationship between CO_2 and GDP may be compelling when official values are announced after 2020. A more rigorous statistical testing of asymmetric coupling could prove to be valuable for future studies.

Finally, considering an aging population and the declining birthrate in Taiwan, the effects of changes in lifestyles (such as the usage of electric vehicles) on human health could be further investigated. Government revenue and expenditure scenarios (e.g., subsidizing electric vehicles or eliminating two-stroke motorcycles) using the SAM-extended GEMTEE model and database may also be evaluated to obtain further insights into the industrial development of electric motorcycles in Taiwan.

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Trans-disciplinary $PM_{2.5}$ Exposure Research in Urban Areas for Health-oriented Preventive Strategies

(Shorten as Urban-$PM_{2.5}$)

Project Starting Year	2018
Project Director	**Lung, Shih-Chun Candice**: With academic training in atmospheric science and public health, Dr. Shih-Chun Candice Lung has focused her research on environmental health science, which investigates environmental mechanisms, pathways, and factors affecting public health. She has taken an integrated approach to link pollution source characteristics and atmospheric chemistry with human exposure and adverse health effects. Her research also expands to evaluate societal impacts of environmental and climate change and to explore adaptation strategies to reduce such impacts.
Hosting Institute	Research Center for Environmental Changes, Academia Sinica
Sub-Project PI, Co-PI	Chen, Ling-Jyh, IIS, AS Chen, Meng-Chang, IIS, AS Chuang, Tzu-Yao, CMU Hospital Lee, Shih-Yu, RCEC, AS Liao, Mark, IIS, AS Lin, Yi-Chiu, TTFRI Pan, Wen-Harn, IBS, AS Su, Chih-Wen, Dept. of ICE, CYCU Tsai, I-Chun, RCEC, AS Wang, Da-Wei, IIS, AS Wu, Chih-Da, Dept. of Geomatics, NCKU Yang, Hsin-Chou, ISS, AS

Research Objectives

The overall goal of Urban-$PM_{2.5}$ is to evaluate neglected $PM_{2.5}$ community pollution sources and peak exposures in order to provide scientific evidence for formulating preventive strategies and health promotion tactics to reduce health risks due to $PM_{2.5}$ exposure in Taiwan. The specific scope is to apply mature and innovative scientific tools to evaluate controllable factors considering the progression of $PM_{2.5}$ emissions to health impacts for the purpose of formulating effective preventive strategies. A multi-disciplinary team with experts on environmental, information, social sciences, and public health has been formed to undertake a holistic approach to this trans-disciplinary project.

Main Results to Date

Urban-PM$_{2.5}$ produced significant outcomes in four aspects: scientific tool development, controllable PM$_{2.5}$ exposure factor assessment, exposure-health relationship evaluation, and intervention exploration. The scientific tools developed include low-cost PM$_{2.5}$ micro-sensors, a traffic analysis system, and methodologies for PM$_{2.5}$ exposure assessment and exposure–health relationship evaluations. These tools are used in panel studies to evaluate environmental, community, socio-demographic, behavioral, and physiological factors extracted from observations of a cross-scale PM$_{2.5}$ monitoring framework and other heterogeneous data; these evaluations are the scientific basis for policy recommendations (Figure 1, from bottom to top). These scientific tools can be further expanded for various purposes, such as policy option evaluation, community source quantification, health promotion, and early warning for pollution episodes.

The core technology of Urban-PM$_{2.5}$ is the integration and application of the low-cost PM$_{2.5}$ micro-sensor devices, AS-LUNG (Academia Sinica-LUNG) sets, with three different versions available (outdoor, indoor, and portable, Figure 2(a)). They were evaluated in the laboratory and field against sophisticated instruments to obtain correction curves that were used to convert sensor readings to research-grade observations, addressing the drawback of data accuracy of sensors (Wang et al., 2020.07; Lung et al., 2020.05). In addition, a novel method using machine learning techniques was established to correct the in-field data of the PM$_{2.5}$ sensor networks using laboratory-calibrated data (Wang et al., 2020.09b). These methods/tools can be used to enhance the applicability of PM$_{2.5}$ sensor networks worldwide.

Using AS-LUNG sets, a cross-scale PM$_{2.5}$ monitoring framework was established in Taiwan with 8 sets in ambient sites (approximately 12 to 15 m above ground, complementary to the monitoring stations of the Taiwan Environmental Protection Administration [TEPA]), 47 sets in community sites (at street levels close to specific community sources), 30–50 pairs in indoor/outdoor household microenvironments during intensive monitoring campaigns, and 30–50 sets for personal monitoring during exposure–health relationship evaluations. With research-grade AS-LUNG observations in unprecedentedly high spatiotemporal resolutions, this cross-scale PM$_{2.5}$ monitoring framework allows us to evaluate the contributions of exposure sources in communities and indoors. For example, it was found that incremental contribution from the stop-and-go traffic, market, temple, and fried chicken vendor to PM$_{2.5}$ at 3–5m away were 4.38, 3.90, 2.72, and 1.80 μg/m^3, respectively (Lung et al., 2020.05). Significant spatiotemporal variations and community source impacts revealed the importance of assessing neighborhood air quality for public health protection. This again demonstrates the unique contributions of micro-sensor networks to air pollutant monitoring.

In order to further evaluate the most prevalent community source, that is, traffic emissions, another scientific tool was developed, an automatic traffic analysis system (YOLOv3-tiny-3l) established with deep learning techniques. This system was applied to analyze low-resolution images (352 × 240 pixels) from government videos to classify and count vehicles in five categories (motorcycle, sedan, bus, truck, and trailer, Figure 2(b)). Using data fusion of vehicle counts and PM$_{2.5}$ at community sites, roadside PM$_{2.5}$ concentration increments due to on-road sedans were estimated to be 0.0027–0.0050 μg/m^3 per vehicle (Wang et al., 2020.09a). This methodology has great potential for application in developing countries to assess the exposure contribution of vehicle emissions.

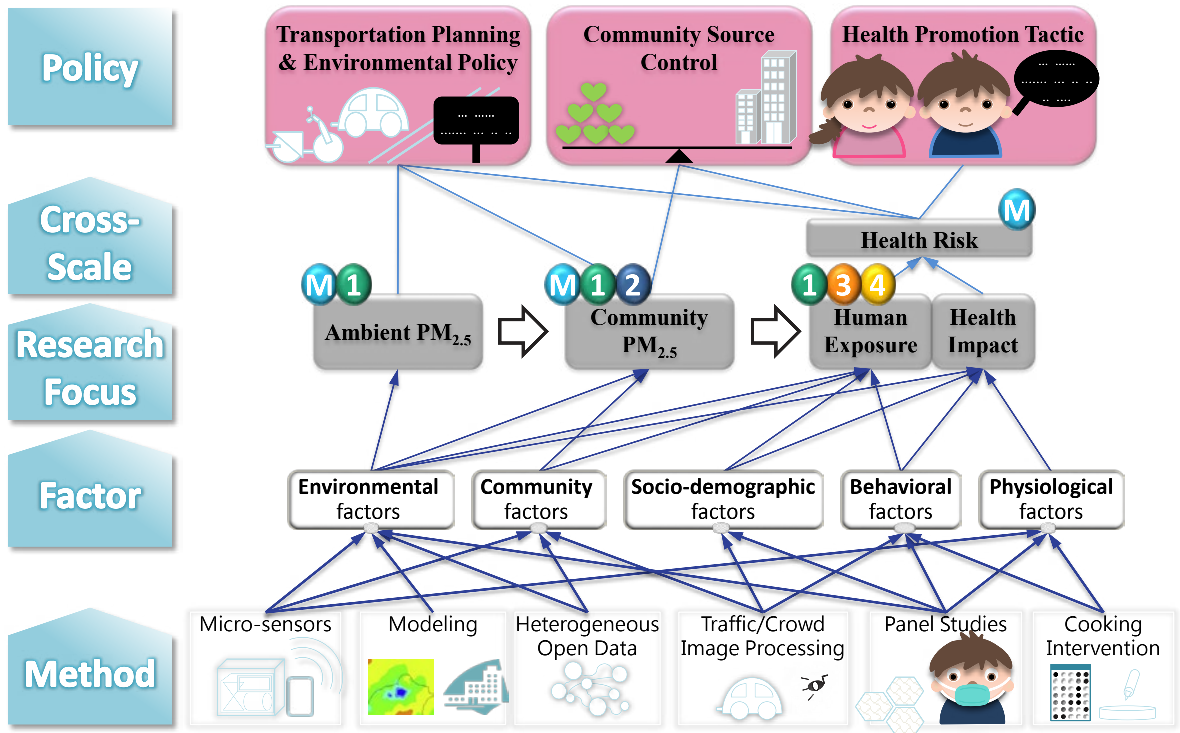

Figure 1. Research framework of Urban-PM$_{2.5}$. Layers from the bottom to the top show that our team applied the developed/validated scientific tools/methods in evaluating various factors extracted from the observations of a cross-scale PM$_{2.5}$ monitoring framework covering ambient, community, household indoor/outdoor, and personal scales combined with other heterogeneous data; these evaluations provide scientific evidence for feasible policy recommendations.

Moreover, refined methodologies for PM$_{2.5}$ exposure assessment in communities and indoors were established. The indoor and outdoor PM$_{2.5}$ concentrations in the households of 90 recruited subjects were simultaneously monitored for 6 weeks during two seasons, along with consecutive 7-day personal PM$_{2.5}$ and 2-day health-indicator monitoring. With high resolutions of PM$_{2.5}$ and detailed time-activity diaries, the impacts of sources and indoor ventilation options on their personal exposures were assessed in detail. For example, for a panel of 26 non-smoking healthy adults in one community, we observed that cooking occurred most frequently; cooking with

Figure 2. Scientific tools developed in this study including (a) outdoor (AS-LUNG-O, left), portable (AS-LUNG-P, middle) , and indoor (AS-LUNG-I, right) $PM_{2.5}$ micro-sensors, and (b) a traffic analysis system that classifies/counts vehicles in five categories (motorcycle in red, sedan in blue, bus in purple, truck in yellow, and trailer in green).

and without solid fuel contributed to high $PM_{2.5}$ exposures of 76.5 and 183.8 μg/m^3 (1-min), respectively. Among all single sources, incense-burning had the highest mean $PM_{2.5}$ indoor/outdoor (1.44 ± 1.44) ratios at home and, on average, the highest 5-min $PM_{2.5}$ increments contributing to indoor levels (15.0 μg/m^3). Certain events accounted for 14.0–39.6% of the subjects' daily exposures (Lung et al., 2020.10). Closing windows and turning on air conditioning reduced $PM_{2.5}$ exposures infiltrated from outdoors by approximately 1.56 and 0.947 μg/m^3, respectively.

Another scientific tool developed is the methodology for $PM_{2.5}$ exposure–health relationship evaluation which combines observations from AS-LUNG and micro-sensors of heart rate variability (HRV). The methodology was established with a panel of 36 non-smoking healthy subjects aged 20–65 years recruited from all over Taiwan (Lung et al., 2020.11). After adjusting for confounding factors, the standard deviations of all normal-to-normal intervals (SDNN, one of the HRV indicators) decreased by 3.68% (95% confidence level (CI) = 3.06–4.29%), and the ratio of low-frequency power to high-frequency power increased by 3.86% (CI = 2.74–4.99%) for an inter-quartile range of 10.7 μg/m^3 $PM_{2.5}$, with impacts lasting for 4.5–5.0 hours. This is a pioneering study in demonstrating the application of novel micro-sensors to assess close-to-reality $PM_{2.5}$ exposure and exposure–health relationships. Significant HRV changes were observed in healthy adults even at low $PM_{2.5}$ levels (12.6 ± 8.9 μg/m^3, lower than the $PM_{2.5}$ standard of the TEPA). This methodology was further applied to 90 panel subjects recruited from several communities in northern and southern Taiwan. It was confirmed that adverse HRV variations were observed at low $PM_{2.5}$ levels, especially in overweight/obese subjects.

Additionally, the impact of $PM_{2.5}$ on HRV during routine cardio exercise was assessed for a panel of 60 routine runners (one high-risk sub-population) recruited from central and southern Taiwan. Significant SDNN reduction during outdoor exercise was observed with an increase in $PM_{2.5}$ exposure. Although 83% of the subjects were concerned about the health impacts of air pollution, less than 10% of them checked the air quality index before participating in outdoor exercise. They followed the same exercise routines unless an extremely unhealthy warming (purple flag) alert was issued. To our knowledge, this is the first assessment of exercise behaviors and physiological responses regarding air quality in Taiwanese runners.

For the most common indoor exposure source (cooking), methods for evaluating cooking emissions from oils were established. Among the three studied oils (palm, olive, and soybean oils), palm oil emitted the highest number of total PM and the highest polycyclic aromatic hydrocarbon concentrations (a class of human carcinogens), whereas soybean oil emitted the highest concentration of gaseous aldehydes during deep-frying. Olive oil had lower toxic emissions than the other two oils. Moreover, two antioxidants, vitamin E and sucrose acetate isobutyrate (SAIB), were evaluated for the impacts of emission reduction of aldehydes and PM from heating soybean oils at 180 °C for 2 hours. The results revealed that vitamin E had better antioxidant effects than SAIB in protecting against oxidation for the studied oils, with lower emissions of aldehydes and PM (Figure 3).

Based on the aforementioned scientific findings, feasible policy recommendations are provided for health-oriented transportation planning, source-control strategies, health promotion tactics, and behavioral changes. Vehicle quantification provides field evidence for the direct $PM_{2.5}$ exposures of pedestrians and roadside households from on-road traffic and demand the acceleration of health-oriented transportation planning. The evaluations of community and indoor sources identify control priorities in $PM_{2.5}$ exposure sources and emphasize the importance of the TEPA's enforcement on community source control to reduce $PM_{2.5}$ exposure. Health promotion focusing on air pollution should be enhanced for high-risk sub-populations such as regular runners to reduce their $PM_{2.5}$ exposure. Furthermore, recommendations on behavioral changes in indoor ventilation and cooking practice options are tactics to reduce $PM_{2.5}$ exposure and associated health risks.

In summary, with a unique multi-disciplinary approach, this team has provided a competitive edge in the global $PM_{2.5}$ research arena, as evidenced by the publications. Most importantly, the integration of the data obtained from these innovative scientific tools provides a scientific foundation for policymakers in various agencies to formulate preventive strategies to reduce health risks due to $PM_{2.5}$ in Taiwan. Overall, this trans-disciplinary, co-designed, and solution-oriented project achieves the aims of advancing science while contributing to society.

Future Research Plan

We will further expand the application of $PM_{2.5}$ micro-sensors in environmental health science internationally. We will scale up the scope of the research in personal and community levels to urban levels in Taiwan using advanced data analysis methods and modeling approaches to assess $PM_{2.5}$ source contributions in cities with high resolution. We will also explore intervention strategies in behavioral changes and nutrition options to reduce $PM_{2.5}$ exposure and health risks in Taiwan.

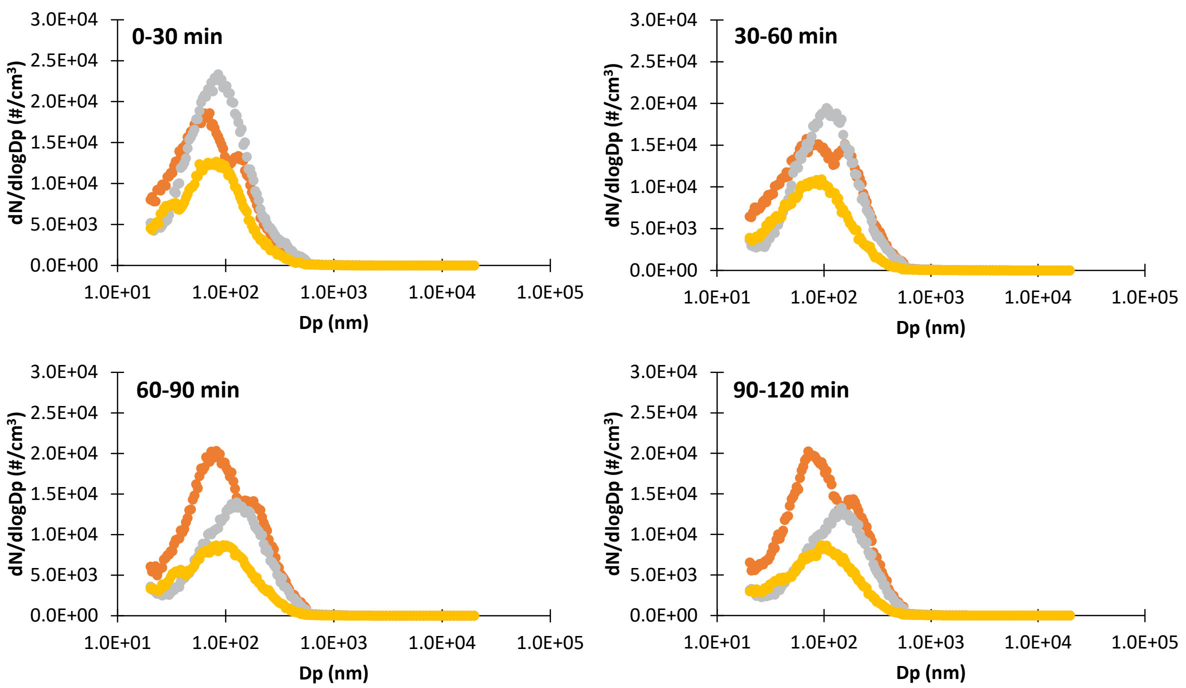

Figure 3. Effects of two antioxidants (sucrose acetate isobutyrate [SAIB] and vitamin E [VE]) on $PM_{2.5}$ number concentrations during deep-frying of soybean oil for different time durations. Orange, gray, and yellow lines denote soybean oil only, soybean oil with SAIB, and soybean oil with VE, respectively.

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Study of Energy Transition Governance in Taiwan: Critical Issues, Governance Needs, and Developing a Human Resource Inventory

Project Period	September 1, 2019 to December 31, 2020
Project Director	**Carl K. Y. Shaw**: Distinguished Research Fellow and the Director at the Research Center for Humanities and Social Sciences, Academia Sinica. His research has focused on the history of political thought and contemporary political theory, with special attention to the issues of republicanism, communitarianism, and modern idea of the state. His scholarly publications include articles in American Political Science Review, History of Political Thought, Politics, and many Taiwanese journals. He won Award for Outstanding Research from Ministry of Science and Technology and National Science Council twice (1997, 2017).
Hosting Institute	Research Center for Humanities and Social Sciences, Academia Sinica
Sub-Project PI, Co-PI Name, Institute	Kuei-tien Chou, Director, RSPRC (Risk Society and Policy Research Center), National Taiwan University; Professor, Institution of National Development, National Taiwan University

Research Objectives

In recent years, Taiwan has been facing a critical period of energy transition amidst the global trend toward low-carbon energy development. Therefore, the governing party has decided to move toward renewable energy and non-nuclear energy structure. However, judging from the referendum results and public opinion, Taiwan's current consensus on the future energy transition is still inadequate, and Taiwan's energy policy should focus more on social communication on key issues, which also reflects the inadequacy of scientific research on energy governance in the country. Therefore, this study is divided into three themes: Taiwan's key energy issues, Taiwan's energy transition technology and governance needs assessment, and energy governance talent database inventory. Based on the governance research of issues, needs, and human resources, this study grasps the complex issue of Taiwan's energy transition governance in three dimensions.

Main Results to Date

This pilot study was conducted in the area of energy governance, communication, and gaps in energy governance. An inventory of human resources in the field of energy transition has been developed under the three components of this project. This study not only provides directions for future research but also promotes the development of an interdisciplinary network of experts and establishes an important contribution to future interdisciplinary research and academic cooperation.

The first outcome identified the critical issues of energy transition and provided guidance for future studies and surveys. First, the research team collected important previous energy surveys and analyzed their questionnaires, methods, and results. The surveys included but were not limited to the Taiwan Energy Usage and Energy Transition Survey in 2019, Moving toward a Deep Carbon Reduction Society: Social Behavior and Institutional Transition Survey in 2019, Survey of Taiwanese's Support of Energy Transition and Cost Payment in 2018, Survey of Taiwanese Resident Energy Usage Behavior in 2017, and Green Energy Barometer in 2017. Second, the outcomes from important previous conferences on energy, climate change, and technology were analyzed to identify the critical issues highlighted. The results of the analysis are compiled into key issue alignment (Figure 1) and key issue governance needs identification (Figure 2).

There are 20 items in the Critical Issues Governance Needs Assessment. Governance needs of socioeconomic and policy implementation, hierarchical mechanisms, market, and network mechanisms were analyzed based on Keast et al.'s (2006) method.

Nine Major Issues:

- 01 **Scientific risk assessment of various energy development and generation methods**
- 02 **Energy policy and target setting**
- 03 **Energy policy communication and participation**
- 04 **Renewable energy development**
- 05 **Tariff issue**
- 06 **External costs**
- 07 **Energy conservation**
- 08 **Promotion of transformation of energy-intensive industries**
- 09 **Central and local energy governance**

Figure 1. Key issue alignment. According to the analysis, there are nine major issues and 36 subthemes.

Therefore, we made two recommendations. First, as the Taiwanese public mainly relies on television and social media for energy information, there is a need to examine how these channels can be used to promote energy transition governance in the future. In addition, the survey shows that social media, apart from being used to receive energy information, is an important platform for discussing energy issues; therefore, text mining and sentiment analysis should be conducted to understand online public opinion. Second, while there are many energy perception surveys, their themes are too diverse to allow for comparative analysis over multiple years. Therefore, the research team recommends that future energy surveys should include the following questions to track the long-term energy perception of citizens: energy knowledge, level of support for energy policies, channels for energy information, and the opinion of carbon taxes and electricity prices.

This project also completed the Human Resource Inventory for Energy Transition (on Governance Research) and compiled a list of about 240 experts in the fields of energy technology, economy, policy, law, and society in Taiwan (Figure 3).

An initial evaluation of energy transition and governance needs was completed in the project. In January 2020, the project team also organized a meeting, "SINICA Energy Transition Expert Consultation Meeting," to consult with energy experts on their views on energy governance and transition (Figure 4). In December 2020, the workshop, "The Carbon Neutrality

1	Carbon Pricing, Tax and Market
2	Public Invesment on energy transition
3	Power Ancillary Service : energy storage, demand-side management, power dispatch control center, natural disaster response and early warning
4	Power stability
5	Reasonable and Stable Energy Price
6	Energy Efficiency
7	Energy Demand
8	Regular review and monitoring of the long-term energy policy
9	Regional Inventory of Possible Renewable Energy Development
10	Strengthen the enforcement of regulations and enhance the communication of regulations

Figure 2. Ten of the 20 key issue governance needs identification

Energy Regulation and Law	9
Policy and Public Communication	8
Spatial Planning and Resource Utilisation	3
Economics Cost Benefit Analysis	19
Industry and Technology Policy	14
Industrial Technology Research Institute	14
National Energy Program Phase I and II	55
Bureau of Energy	7
And more than 100 related Expert	

Figure 3. Number of human resources for energy transition (on Governance Research)

in 2050 Workshop: To Study Carbon Emission Reduction Paths and Relevant Legislative Instruments," was conducted where energy experts were invited to discuss energy technology development and governance (Figure 5). The topics discussed included the analysis of net zero carbon emission pathways and their policy implications, challenges in developing a green new deal in Taiwan for net zero carbon emissions, and amendments to the Greenhouse Gas Reduction and Management Act. Experienced experts were invited as keynote speakers for the workshop, which was also attended by 49 early career experts and young researchers. The workshop had two objectives. First, it provided a necessary platform for discussion on the governance of the energy transition. Second, it created a network of energy transition experts and stakeholders.

Four recommendations for Taiwan's energy transition were developed from consultations. First, many countries have committed to 2050 net zero carbon emission goals, but Taiwan's carbon emission reduction target has not caught up. Therefore, Taiwan should pursue a net zero carbon emissions target, establish carbon emission reduction policies based on strengthening its scientific foundations and market mechanisms, and involve public participation. Second, the main agency overseeing Taiwan's climate change policy, Taiwan's Environmental Protection Administration, does not have authority over other agencies. The experiences of Britain and Germany point to the importance of mainstreaming climate policy, but this can only be effective if a new high-rank climate change agency is established directly under the president or Executive Yuan, with legislated authority over other ministries. Third, according to estimates by the Pacific Northwest National Laboratory (PNNL), Risk Society and Policy Research Center, and the Green Citizen Action Alliance, net zero carbon emissions by 2050 in Taiwan can be achieved by reducing emissions in the power generation, manufacturing, and transportation industries. However, there is currently a lack of clear and detailed policies regarding these issues. Finally, given that these industries are under pressure to reduce their carbon emissions, just transition needs to be planned to prepare for the impacts,

Figure 4. SINICA Energy Transition Expert Consultation Meeting

Figure 5. The Carbon Neutrality in 2050 Workshop

such as unemployment, which will require comprehensive policy packages to address.

Future Research Plan

In the future, the research team expects to conduct the project "Governance Transition toward a Sustainable Society: The Analysis and Practice of Governance Transition toward Taiwan 2050 Net Zero Society." This project integrates three cross-disciplinary subprojects that focus on developing innovative governance in Taiwan (Subproject 1), a net zero carbon reduction model incorporating the local context (Subproject 2), and a case study of the plastic industry to identify the barriers to climate solution (Subproject 3). Therefore, this study aims to produce breakthroughs in the field of science and technology and paradigm shifts in social, political, economic, and cultural practices to develop more effective and practical solutions for the drastic mitigation of carbon emissions.

This study has three innovations. First, the study will develop a pathway of transformative governance and sustainable transformation toward a net zero carbon emission society. Second, it will go beyond the scientific and engineering focus of previous studies in Taiwan to provide a social science perspective of climate change governance. Finally, the emphasis of this study is on innovative governance and involves stakeholder participation to bolster support for transformations and provide in-depth and diverse contextual knowledge.

Comments on *Our Future on Earth* from Taiwan's Perspectives

Foreword

Shih-Chun Candice Lung, Research Fellow, Research Center for Environmental Changes, Academia Sinica; Executive Secretary, Future Earth Taipei (sclung@gate.sinica.edu.tw)

The year 2020 was definitely historical, considering that: 1) climate impacts and disasters emerged globally on all continents, 2) public awareness and media attention rapidly rose to call for climate actions, and 3) COVID-19 forced all countries to realize that the world with alternative developmental pathways may not be as dreadful as skeptics anticipated. In addition, 2030, the target year of the Sustainable Development Goals (SDGs), is only 10 years away; 2020 was a time for us to adjust pace and resume efforts in achieving the SDGs.

In February 2020, Future Earth published a synthesized scientific report on sustainability – *Our Future on Earth: Science Insights into our Planet and Society 2020* (Future Earth, 2020). To effectively communicate with stakeholders, this report provides the most updated and synthesized knowledge and discusses the obstacles and potential solutions of social transformation toward a more sustainable world. There are 12 sections focusing on different topics, including global risk, climate, politics, ocean, forced migration, media, biodiversity, finance, food, transformation, and digital innovation. As part of the global effort to publicize this report, Future Earth Taipei and Academia Sinica organized a satellite launch event in Taipei on February 19, 2020. Experts in the respective topics in Taiwan shared their viewpoints, followed by intensive and fruitful discussions with attending scientists, experts, government officers, and funders. Here, we collect their comments with revisions from feedback to show the perspectives of Taiwanese scientists on these topics. These comments by no means represent comments from a comprehensive bird's-eye view; they merely show diverse opinions from Taiwanese experts with different scientific, governance, or practical viewpoints. This commentary article aims to present certain synthesis scientific findings in Taiwan and diverse viewpoints from Taiwanese professionals as a basis for interactive dialog between Taiwan and international experts. The following comments correspond to the twelve sections in the report.

Section 1 Global Risks

Commentator Kuei Tien Chou, Professor, Graduate Institute of National Development, National Taiwan University (ktchou@ntu.edu.tw)

1.1 Comparison between two representative global risk reports

Comparison points

Here, two reports, the global risk section of ‘Our Future on Earth’, and the Global Risks Report 2020 (WEF, 2020), have been compared. Based on the top 30 global risks identified in the Global Risks Report 2019, the ‘Our Future on Earth’ report was intended to explore global risk perceptions held by scientists, and, as was done for the Global Risks Reports for leaders in business, NGO, academia, and government sectors, it has evaluated these risks, in terms of likelihood and impact. The survey results contained in these reports differ, however, as presented in Table 1.

Facing interconnected systemic risks

In spite of these dissimilarities, both the *Global Risks Reports* and *Our Future on Earth* highlight that transboundary research is required, if systemic risks at all levels are to be tackled effectively.

Encourage transboundary research

At the global level, Our Future on Earth suggests that global agreements such as the United Nations Framework Convention on Climate Change (UNFCCC), United Nations Convention on Biological Diversity (UNCBD), and United Nations Convention to Combat Desertification (UNCCD), among others, must be coordinated in order to ensure that transboundary and interconnected risks are considered in a systematic way.

Transboundary risk research in Taiwan

At the national level, it is important that the government implements policies to help develop transboundary research. In Taiwan, the Department of Natural Sciences and Sustainable Development（自然科學及永續研究發展司）of the Ministry of Science and Technology (MOST) has initiated multiple schemes to promote trans-disciplinary research (TDR). For instance, between 2020 and 2024, its Discipline of Sustainable Development（永續學門）aims to integrate both social and natural sciences, and include stakeholders in the research and policy-making processes, through the principles of co-design, co-production and co-delivery.

Table 1. Comparison between *Global Risk Report 2020* and *Our Future on Earth*

Report	*The Global Risks Report 2020*	*Our Future on Earth*
Publisher	World Economic Forum (WEF)	Future Earth
Interviewees	The Global Risks Report compiled answers from over 1,000 respondents from the business, NGO, academia, and government sectors	Future Earth surveyed 222 scientists[1]
The most interconnected risks	Five Most Interconnected Risks: (based on ‘*Figure IV: The Global Risks Interconnection Map*’ in *The Global Risks Report 2020*) • Climate action failure • Extreme weather • Social instability • Cyberattacks • Biodiversity loss	Top Five Global Risks[2]: (based on the *Our Future on Earth* figure ‘*Interconnected Risks*’) • Failure of climate change mitigation and adaptation • Extreme weather events • Major biodiversity loss and ecosystem collapse • Food crises • Water crises
Survey Results	Global Risks in Terms of Likelihood (Table 2) 1. Extreme weather 2. Climate action failure 3. Natural disasters 4. Biodiversity loss 5. Anthropogenic environmental disasters	Global Risks in Terms of Likelihood (Based on the figure ‘*Likelihood and Impact*’ in *Our Future on Earth*) 1. Extreme weather 2. Biodiversity loss 3. Water crises 4. Climate change 5. Urban planning
	Global Risks in Terms of Impact (Table 2) 1. Climate action failure 2. Weapons of mass destruction 3. Biodiversity loss 4. Extreme weather 5. Water crises	Global Risks in Terms of Impact (Based on the figure ‘*Likelihood and Impact*’ in *Our Future on Earth*) 1. Extreme weather 2. Water crises 3. Climate change 4. Biodiversity loss 5. Food crises

Source: WEF (2020) and Future Earth (2020)

Table 2. Risk Landscape in *The Global Risks Report 2020* (Global Risks in Terms of Likelihood and Impact)

Global Risks in Terms of Likelihood		Global Risks in Terms of Impact	
2019	2020	2019	2020
1. Extreme weather 2. Climate action failure 3. Natural disasters 4. Data fraud or theft 5. Cyberattacks	1. Extreme weather 2. Climate action failure 3. Natural disasters 4. Biodiversity loss 5. Anthropogenic environmental disasters	1. Weapons of mass destruction 2. Climate action failure 3. Extreme weather 4. Water crises 5. Natural disasters	1. Climate action failure 2. Weapons of mass destruction 3. Biodiversity loss 4. Extreme weather 5. Water crises

Source: WEF (2020)

[1] In the *Our Future on Earth*, ‘scientists’ were defined as respondents having at least a master’s degree and more than one year of experience in a scientific field. In the end, responses from 222 scientists from 52 different countries were analyzed.
[2] The *Our Future on Earth* survey drew from a list of WEF top 30 global risks.

1.2 Comments

Perspective of systemic risks in Taiwan

At the moment, research teams in Taiwan have also embarked on systemic risk studies. For instance, in 2019, the Risk Society and Policy Research Centre (RSPRC) team carried out independent research to understand risk perceptions among people in different sectors, using the Delphi method, as part of its 'Taiwan 2050 foresight research' project. The results are listed in Table 3.

This report mixed the perspectives of scientific finding, social scientific empirical observation, and future foresight

- It presented the need for societal transformation (*Section Transformation*)
- It mostly used normative thesis, while partly using empirical observation (*Section Politics, Media, and Forced Migration*)
- It included a foresight thesis (*Section Digital Innovation*)
- It envisaged a new future (*digital sustainability*)

Actions needed to enhance the social scientific perspective

- Enhance governance risk analysis
- Enhance cosmopolitan governance analysis
- Enhance the trans-generation justice perspective
- Enhance the transitional justice perspective
- Explore the challenge of societal transformation
- Explore the path dependency of societal transition

Observations in relation to an East Asian perspective on social transition / transformation

- There are high carbon societies in East Asia (China, Japan, South Korea, Taiwan)
- These are carbon locked-in societies
- There are hidden risks in societies / governance as challenges to transition
- Innovative governance is needed, involving improved transparency, public engagement, and democracy in science

Table 3. Taiwan Systemic Risk Perception Landscape, from Dynamic Delphi Research, 2019

Systemic Risk Perception in Terms of Urgency	Systemic Risk in Terms of Perceived Research Priorities
1. Food security	1. Trans-national cyberattacks
2. Trans-national cyberattacks	2. Extreme weather events and compound disasters
3. The spread of epidemic diseases	3. Water crises
4. Water crises	4. Food security
5. Biodiversity loss	5. Biodiversity loss
6. Financial crises	6. Environmental degradation
7. Extreme weather events and compound disasters	7. Ethical issues associated with the application artificial intelligence
8. Environmental degradation	8. The spread of epidemic diseases
9. Cross-strait military conflicts	9. Financial crises
10. Ethical issues associated with the application artificial intelligence	10. Cross-strait military conflicts

Source: RSPRC (2019)

Section 2 Climate

Commentator **Huang-Hsiung Hsu,** Distinguished Research Fellow, Research Center for Environmental Changes, Academia Sinica (hhhsu@gate.sinica.edu.tw)

This section focuses on global heating and its impacts that are rampantly occurring and will continue to worsen, as projected by IPCC reports. Similar trends in the climate of Taiwan have been observed (TCCIP, 2020). Surface air temperature has risen by more than 1°C since the initiation of meteorological measurements in 1895. The number of days with daily mean temperature exceeding 35°C reached a record high of 87 days in the summer of 2020, exceeding the previous record in 2016 by 10 days (TCCIP, 2020). During the period of 1965–2014, the summer season in Taiwan lengthened continuously at a rate of 7–13 days/decade, whereas the length of the winter season shortened at the rate of 3–8 days/decade (Lee et al., 2018). The number of rain days has decreased steadily, but the intensity of rainfall has increased over the past few decades.

Future climate change in Taiwan is projected to be as significant as that in other parts of the world. For example, under the RCP8.5 scenario, the number of typhoons affecting Taiwan is projected to decrease by more than 40% by 2075–2100, whereas the rainfall within 200 km of a typhoon center may increase by about 50% (Tsou et al., 2016). Typhoons often cause devastating damage in Taiwan. On average, they contribute about 40% of Taiwan's annual rainfall and are a necessary "evil" for Taiwan's water resources. Although having fewer typhoons renders the landfall in Taiwan to be less impactful on the nation as a whole, the significantly increased rainfall associated with typhoons would likely result in more severe episodic natural disasters, such as flooding, landslides, and debris flows. A reduction in the number of typhoons would reduce available water resources. Spring rainfall, an important water resource for rice implantation, is projected to be significantly reduced during 2040–2060 (Hsu et al., 2018). Heat waves by today's standard would become a new normal and last for as long as 5 months in the warmer future, and the length of winter might be shortened to one month (Lee and Hsu, 2017).

As reported by the IPCC, the extent of future climate change and the severity of its impact are proportional to the extent of future warming and the amount of accumulated greenhouse gas concentration. This is also true for Taiwan according to our studies. To lessen the potential impacts, taking necessary and urgent measures to reduce greenhouse gas emissions in Taiwan by diligently following the international "Dialing Down the Heat" trend is unavoidable. We also need to rapidly develop more advanced, systematic, and complete research methodologies in Taiwan to have a clearer picture of the likelihood of potential climate changes, their impacts, and the necessary adaptation measures based on various scenarios. This effort would provide a scientific basis for risk assessment and adaptation planning.

Section 3 Politics

Commentator **Thung-Hong Lin,** Research Fellow, Institute of Sociology, Academia Sinica (zoo42@gate.sinica.edu.tw)
Hsin-Huang Michael Hsiao, Adjunct Research Fellow, Institute of Sociology, Academia Sinica; Senior Advisor to the President (Taiwan) (michael@gate.sinica.edu.tw)

From the perspective of the Taiwanese scientific community, the Politics Section of *Our Future on Earth* report sheds light on our understanding of the politics of climate change, especially on the populist origins of push-back in some developed countries. In addition, it also illustrates the potential for progressive political coalitions, especially emphasizing the active role of civil society with environmental concerns around the world. The report, therefore, gave us a political road map for combating climate change.

In the report, Calland and Jane Calland revealed associations among populist parties and politicians, energy business groups, and the rise of push-back in the climate change debate. According to this report, although the rise of populism might have resulted from other problems, such as the Great Recession and increasing economic inequality in the world, climate change push-back was also nourished through a mobilization supported by some big energy industry businesses. That is to say, the carbon emission industry has also become a part of the political coalition of populism, and has applied its resources and influence to promoting push-back. The authors also reinforced that grassroots movements with environmental concerns needed to consolidate, to both resist the populist coalition, and to support progressive political alliances in the world. In 2020, the presidential election in the United States has become a historical moment of confrontation between populism and environmentalism.

In addition to agreeing with the report, we would like to add two notes from the perspective of Taiwanese readers. First, populism is not an exclusively Western phenomenon; it is also rising in Asia. In recent elections, some populist politicians waged popular campaigns, and while these politicians did not openly deny the existence of climate change, they lobbied for the nuclear power industry rather than green energy as an alternative to reducing carbon emissions without changing lifestyles. On the contrary, most environmental civil associations, who view nuclear power as a risky and costly industry, support public policies targeting sustainable production and consumption. By refuting the need for a changing economy and lifestyle, populism in Taiwan has turned to nuclear energy, and is heading towards confrontation against grassroots movements.

As a second issue, the report noted that, nowadays, the People's Republic of China (PRC) has replaced the US as the major global source of carbon dioxide emissions. Although Beijing has claimed that it will fulfill the goal of carbon neutrality by 2060, this dubious promise sounds like a diplomatic strategy to placate those who fight against populism in the West. It should be noted that environmental grassroots movements have experienced serious suppression in China during the last decade. As such, we should stay focused on the promise of authoritarian regimes such as the PRC, which historically have not always been dependable when it comes to environmental issues.

The experiences noted during the pandemic undermine the trustworthiness of both Beijing and populists in the West—but have also shown that changing our heavy carbon dioxide emission lifestyle might be easier than we had previously thought. After the impacts of populism and the pandemic have been put behind us, there might be a window of opportunity for civil society in democracies. Following the suggestions in the report, we would like to connect grassroots movements and facilitate Taiwan's participation in global action to mitigate climate change.

Section 4 Ocean

Commentator **Chen-Tung Arthur Chen,** Distinguished Chair Research Professor, Department of Oceanography, National Sun Yat-sen University (ctchen@mail.nsysu.edu.tw)
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This section is a very narrowly-focused manuscript with little to do with global change. Four items, namely fisheries, biodiversity/marine protected areas, plastics, and seabed mining are the central themes yet the last two have nothing to do with either climate change or global change. In fact, "global change" is not even mentioned. It is said in the introduction that climate change is leading to more acidification. The truth is, ocean acidification is related mostly to CO_2, not climate, although it does play a role in deep waters (Chen et al., 2017). No effects of ocean acidification are mentioned. Further, many central themes of global change, such as warming of seawater, sea level rising, de-oxygenation, bleaching of coral reefs, destruction of habitats such as mangroves, decreasing marine productivity, and wide spreading of red tides, etc., should be included.

Other than the scientific issues there are social-economic concerns that should be addressed. For instance, given the 'freedom of the high seas' prevails, the high seas, covering 64% of the ocean, are potentially subject to unsustainable exploitation of marine resources. Therefore, enhancing ocean governance in the high seas is important in terms of the conservation and sustainable use of marine resources therein. It is encouraging to see that the United Nations (UN) has embarked on negotiations, in the form of international conferences with four sessions scheduled, on the conservation and sustainable use of biological diversity of areas beyond national jurisdiction (BBNJ).

The focus of these negotiations is on four core issues: 1) area-based management tools (including marine protected areas, MPAs), 2) marine genetic resources (including questions about the sharing of benefits from the use of those resources, 3) environmental impact assessments, and 4) capacity building and the transfer of technology (Clark, 2020). Worth mentioning is that the first issue is quite relevant to Taiwan since Taiwan has a huge fishing fleet in the high seas. Taiwan is a key player in the use of marine resources of the high seas particularly in terms of high sea fisheries (e.g., tunas, tuna-like species, squids, etc.) (Chen, 2012). While regional fisheries management bodies (RFMOs) are the main bodies to regulate high-sea fishing activities, the BBNJ has the potential to exercise impact on our high sea fisheries if MPAs have been established under the BBNJ.

While the BBNJ draft text was proposed by the UN on 17 May 2019 (A/CONF.232/2019/6), some issues remain unsolved or not agreed upon. It, if adopted, will serve as the third Agreement implementing the United Nations on the Law of the Sea (UNCLOS). Taiwan needs not only to closely check the progress of BBNJ negotiations but also to seek opportunities to participate in the negotiation meetings. One issue of particular interests for Taiwan is creating a 'status' in the BBNJ for Taiwan to participate in the BBNJ. In this regard, our government should be more active in pushing for this endeavor. The other issue is keeping up with information regarding the potential sites that might be identified as MPAs and analyzing their potential impacts on Taiwan's fishing activities.

Section 5 Forced Migration

Commentator **Chih-Ming Hung,** Assistant Research Fellow, The Third Research Division, Chung-Hua Institution for Economic Research (cmhung@cier.edu.tw)

Three comments are expressed as follows: First, it seems that 'climate refugee' (or 'climate-related refugee') is not considered a legal term by international conventions, which means that people who flee their home due to climate-related disasters will not be recognized or accepted as refugees by host countries. A clear and legal definition of a 'climate-related refugee' is needed, for countries that are willing to accept such people. The UN is responsible for solve such legal issues at the international level.

Second, the *Our Future on Earth* report reminds us that the relationship between climate change and migration and the ties between migration and conflicts are not clear. However, we can still take action before science affirms this complicated relationship. A country like Taiwan, which lacks experience in dealing with unconventional migrations such as movement of climate refugees, may initially panic. Facing the threat of climate change and more natural disasters, people have become more aware of a changing earth, and governments must be prepared for the challenge. Public education and discussion about correctly recognizing and treating unconventional migration should be the initial government response, as both people and governments need to learn and adapt to the new state of the environment.

Finally, as the *Our Future on Earth* report indicates, 'Migration may be thought of as a universal adaptive human strategy for pursuing wellbeing', which is an excellent concept regarding adaptation strategies for the world. Taiwan's labor supply has fallen short of demand for many years, which suggests that accepting climate refugees and providing them with skill training could be a win–win solution for both Taiwan and the refugees. More importantly, Taiwan will be more integrated with the world, not only in economic terms, but also in terms of social consciousness.

Section 6 Media

Commentator **Mei-Ling Hsu,** Distinguished Professor, College of Communication, National Chengchi University (mlshiu@nccu.edu.tw)
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Today, we are facing changes to the media landscape. Digital platforms, specifically social media, are becoming increasingly important in influencing public perceptions, attitudes, and behaviors. Considering the instant, emotion-loaded, and unedited content presented on digital platforms, the authors of *Our Future on Earth* report, Owen Gaffney and Bruce Mutsvairo, seem to endorse mainstream print media a lot more than digital platforms, as the former have been perceived as being more accurate with higher ethical standards in transmitting information.

Nevertheless, disinformation is not new and is not merely caused by the popularity of online platforms. Social media are a double-edged sword; when it comes to the issue of climate change, traditional news media are no less notorious for presenting unbalanced and distorted views than digital platforms. Taking the liberal and conservative political camps in the US, as mentioned by Gaffney and Mutsvairo, each has its own echo-chamber loop, linked to big corporations, research groups, think-tanks, politicians, NGOs, and to media—in both traditional and digital forms. Conservative views are typically represented by skeptics, who hinder collaborative efforts focused on mitigating and adapting to climate change.

Empirical findings in Taiwan can support the role of traditional media in shaping public opinion regarding climate change. Hsu et al. (2018) surveyed public opinions on climate change, using nationally representative samples every other year since 2009 (N for 2009 = 1,204; N for 2011 = 2,002; N for 2013 = 1,007; N for 2015 = 1,202; N for 2017 = 1,203). They found that the most important communication channel through which Taiwanese people obtained information regarding climate change was always television—as was reported by > 80% of the survey respondents. However, since 2015, the internet has replaced newspapers to become the second most important information source on climate change, rising from approximately 30% to > 60%. Judging from this changing pattern, digital platforms may eventually become the primary channel for climate change communication. However, considering the current situation, the role of traditional media should not be overlooked.

Although social media have assumed an increasingly important role in communicating climate change information, such platforms also face significant challenges. The first challenge relates to the emergence of disinformation, which decreases public trust. According to a survey conducted by the Taiwan Institute for Governance and Communication Research (TIGCR), in 2018, less than half of the Taiwanese population (46.1%) believed that information regarding politics or public affairs obtained from their regularly used online platforms was true. Taiwanese people who supported the pro-reunification parties were more likely to perceive online information as more accurate than the independents, suggesting that perception of reality may have become a partisan issue in Taiwan (TIGCR, 2018).

Governments around the world and major social media platforms have taken measures to tackle disinformation, including fact-checking or flagging false information. However, more empirical research is needed to examine the effectiveness of these measures, as studies have shown that corrections may unintentionally strengthen individuals' impressions of fake news (Scheufele and Krause, 2019). In addition to the efforts made by the government and social media companies, crowdsourcing represents another potential measure for confronting disinformation. To illustrate this point with an example, in August 2009, when Typhoon Morakot was causing severe damage to southern Taiwan, several Facebook groups were formed voluntarily, to serve as information hubs, relying on the efforts of individuals scattered around different cities in the disaster area (Cheng, 2014). In a similar vein, the veracity of online information may be confirmed or refuted through collective wisdom.

The second challenge facing online media today is a more "polarized public." The same TIGCR survey found that approximately one third of the Taiwanese respondents (34.1%) had "never" or "seldom" been exposed to public affairs information on social media that ran contrary to their perspectives. Furthermore, 71.2% of these respondents "never" or "seldom" searched for information on social media which countered their own views. These results resonated with the "echo chamber" phenomenon, as described in the report.

In light of these general public and media environment characteristics, when it comes to climate change communication, what matters the most is not whether traditional or digital media are responsible, but rather how to empower the public in using the media wisely, including strengthening media and information literacy. As part of the effort to confront circulated disinformation, this should be a major mission for modern society. In addition, more empirical research is needed to include other avenues of disinformation, and to examine the effectiveness of fact-checking. Finally, irrespective of the format in question, the media should no longer be treated as merely gatekeepers, and should be more dedicated to the role of facilitators. This would provide public forums which could be navigated by the public, enabling more fact-based discussion and even debate, about mitigation and adaptation of climate change.

Section 7 Biodiversity

Commentator **Ling-Ling Lee,** Professor, Institute of Ecology and Evolutionary Biology, National Taiwan University (leell@ntu.edu.tw)

Despite a global effort to implement the Strategic Plan for Biodiversity 2011–2020, and the Aichi Biodiversity Targets, which were approved by the 10th Conference of the Parties to the Convention on Biological Diversity (CBD) in 2010, none of the 20 Aichi biodiversity targets have been fully achieved globally after 10 years. This was confirmed in the Global Biodiversity Outlook[3] 5 report (GBO 5) (Secretariat of the Convention on Biological Diversity, 2020) and emphasized in the Biodiversity section of this report.

The information revealed in GBO 5 echoed the key findings from the summary of the global assessment report on biodiversity and ecosystem services for policymakers (Díaz et al., 2019); more specifically, it was stated that "Nature across most of the globe has been significantly altered by multiple human drivers, with the great majority of indicators of ecosystems and biodiversity showing rapid decline."

GBO 5 also concluded that based on its current trajectory, "biodiversity, and the services it provides, will continue to decline until 2050 and beyond, jeopardizing the achievement of the Sustainable Development Goals". This will occur if we fail to address the direct and indirect drivers of biodiversity loss, which include the increasing impacts of land- and sea-use change, overexploitation, climate change, pollution, and invasive species, which are in turn driven by unsustainable patterns of production and consumption, population growth, and technological developments. In other words, the current trend of rapid biodiversity decline cannot be altered unless there are "transformative changes across economic, social, political and technological factors" (IPBES, 2019), which need to be brought about by integrated and holistic approaches in planning and implementing strategic plans for biodiversity conservation and sustainable use in all sectors and at all levels.

[3] Global Biodiversity Outlook (GBO) is a periodic report published by the Convention on Biological Diversity (CBD) that summarizes the latest data on the status and trends of biodiversity and draws conclusions relevant to the further implementation of the Convention (https://www.cbd.int/gbo/).

Therefore, we call for the following actions:

- Effective mainstreaming of biodiversity conservation in all sectors, including the scientific community, and improving science–policy linkages, in order to identify and implement appropriate solutions to address the challenges of biodiversity loss.
- More innovative ideas and means to promote and encourage inter- and trans-disciplinary collaboration, and holistic approaches in finding and implementing appropriate solutions to address the challenges of biodiversity loss.
- Innovative ideas and means to communicate relevant scientific information to members of the public more effectively, to help them understand the issues, know their responsibilities, and review their behavior towards sustainability.

Section 8 Finance

Commentator **Sophia Cheng,** CIO, Cathay Financial Holdings; Chair, Asia Investor Group on Climate Change (sophiacheng@cathayholdings.com.tw)
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8.1 Overall Comments

The report summarized the important progress and challenges for financial industry in responding to risks and opportunities from climate changes. Indicated in the report, rising awareness, improving quality in sustainability reporting and higher willingness to contribute should provide the foundation for more solid collaboration among government, academia and business.

On the financial side, "making money work for green goals" is not an easy task for all the investors and investees to understand in reality. Although this document states that efforts the United Nations and European countries have made to push the financial sectors forward, in reality, there is still a long way to go if the investors do not learn the relationships between the amount of investment and the return, and if the investees do not learn the relationships between the possible profits and its own sustainable behaviors (UK HM Government, 2019). Therefore, in order for the money to work for the green goals there are more issues to clarify, including:

- How can we define a sustainable firm? For example, is it enough for an enterprise to simply replace energy-saving equipment, perform waste separation or sewage treatment adequately to become an environmentally sustainable enterprise (OECD, 2020)?
- How can we provide specific KPIs to a firm to change their behaviors? For example, how to reach the establishment of 100% water recycling, zero emissions, 100% of the products materials to be recycled, or 100% renewable energy and zero waste goals?
- How can we educate the investors to take the sustainability into financial considerations?

In addition, to achieve a green economy, sustainable production and consumer behaviors are the most important element for the private sector to get involved. To help establish this element, a road map clearly identifying the ways to achieving the sustainability and the proper position of green finance would be very helpful (UK Green Financing Taskforce, 2018). The followings are the areas worth noting on financial industry's participation in green finance.

8.2 Many financial institutions are active in fund supports and engagement

Rising awareness from much broader areas has been taking place in the past few years, including banks, insurance companies, asset managers, sovereign wealth funds, pension funds and regulators (OECD, 2016). Frequent interactions among stakeholders have resulted in the broader consensus on pursuing solutions for climate risk mitigation and adoption. The combined efforts from all stakeholders created strong pressure on financial industry to fulfill its duty of influencing stakeholders' Environmental, Social, and Governance (ESG) performance. Especially, the following factors will be key to the success of the growing green finance.

Education on awareness
Many companies and financial institutions, especially in emerging markets, remain passive in responding to calls on climate actions, and some still view ESG as marketing disclosure. It is believed that the communication from creditors, supply chain customers, NGOs and network of government can help to present the urgency of need for ESG.

Narrowing the knowledge gap beyond own expertise
Financial industry, supply chain, NGOs and government have devoted tremendous efforts in green finance but each group seems to work within own network and have limited knowledge on the progress of others. A platform connecting all resources is critical to the collaboration and can help to define priority and allocation of resources.

Localization of actionable solutions
Many initiatives started in western countries may need to adjust in Asia and emerging countries in terms of form of communication and expectation on speed, as each country's culture and level of knowledge imply different learning curve.

Mandatory measurement required
Many profit-driven companies may feel unsecure if their competitors do not also commit to initiative such as reducing carbon emission, increasing usage of renewable energy, applying carbon pricing, disclosing environmental scenarios or setting climate actin targets.

Selected mandatory requirements would be needed for industry consensus in order to lead industry to basic effective performance such as the mandatory disclosure on material ESG issues and emission.

Affordable and applicable tools

In countries whose economy consist more small and medium enterprises, smaller corporates may view the budgets for tools on climate scenarios as heavy burden. Companies may also complain that the experience in other continents may not apply to local given different geographic landscape. Therefore, it is worthwhile for government to encourage a platform providing localized tool with database and scenarios template to make it affordable to companies.

Making green projects financeable

Government, NGOs, or public may urge financial institutions to support green projects through project finance, green loans, green bonds and investments. It is important to ensure projects can provide sufficient sense of securities especially credit quality, even if financial institutions are willing to accept lower return. Government, regulators and industry association could play the important roles in facilitating dialogues.

Section 9 Food

Commentator **Ming-Che Shih,** Distinguished Research Fellow, Agricultural Biotechnology Research Center, Academia Sinica (mcshih@gate.sinica.edu.tw)

The section on "Food-Rethinking Global Security" declared that problems need to be solved to sustain global food security. Several points stand out: First, the section notes that we not only need to increase food production, but also allocate food to people in need. One starting point is that the global total number of undernourished people in 2018 was 820 million. However, at the same time, it was estimated that some 1.9 billion people were overweight and 650 million were obese. In Taiwan, undernourishment may not be a major problem, but overconsumption is definitely a problem. Second, the section also pointed out that our current food system is unsustainable, as it is wasteful, harmful to the environment, and cannot deal with the increase in extreme weather events resulted from global warming. Third, the section emphasized that we need to rethink the food system, by continuing to improve food production while reducing environmental impact, implementing food delivery systems to reach people in need more efficiently, reducing meat consumption, and increasing protein sources. With respect to increasing crop production, several points need to be considered:

- Tester and Langridge (2010) reported that global cereal production has to increase from 2,351 million metric tons in 2007 to over 4,000 million metric tons by 2050—an increase which could not be sustained using current farming and breeding technologies. In addition, climate change due to global warming has resulted in extreme weather patterns. Extreme weather has caused stress conditions for growing crops, such as temperature stress, floods, and drought, which have resulted in significant crop losses worldwide (Baily-Serres et al., 2012).
- To increase crop production to meet the needs of the growing population, we need to develop a new generation of crops which have desirable traits, such as the ability to adapt to changing environments. The traits needed include heat stress tolerance, pest and pathogen resistance, drought and salinity tolerance, and flood tolerance. However, current breeding techniques, which require 10 or more years to establish a new breed, will not be able to achieve such advances in time.
- We need to develop efficient breeding platforms that can generate new breeds with different combinations of desirable traits in shorter periods. We are conducting research to establish next generation sequencing-based breeding platforms for important crops in Taiwan, with the aim of developing new breeds within 3–5 years.

Section 10 Transformation

Commentator **Shu-Li Huang,** Distinguished Professor, Graduate Institute of Urban Planning, National Taipei University (shuli@mail.ntpu.edu.tw)
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10.1 Overall Comments

The chapter introduced the mindsets and strategies necessary for carrying out systemic transformation (a.k.a. "spurring radical change," as presented in the title). The SDGs stated in the report titled "Transformation Our World: The 2030 Agenda for Sustainable Development" were the exemplary demonstration of a global collective effort to drive a systemic conversion or renovation from the status quo to transformation systems (T-systems). The United Nations (United Nations, 2015) defined a process for achieving SDGs from 2016 to 2030. Given all of the challenges facing humanity with clear/prompt or anticipated/potential consequences in the coming years, adaptation is not enough for human beings to respond to environmental shifts, social maladjustment, and economic imbalance. To survive and thrive, we need to transform the status quo, which involves changes in fundamental norms and assumptions. While many discussions related to differences between the two systems (status quo vs. T-systems), strategies, and steps supporting the transformation were presented, it was clearly argued that resetting our mindset would be essential as the systems are defined, designed, and operated by people following the natural rules.

One important concept for us to initiate and further the transformation is that we need to learn T-systems, as for many, perhaps most, people, the "business as usual" (BAU) scenarios have been what we take for granted for a period of time, even though this was not the case if we looked back just a few decades ago. For example, the modern smartphones with operating systems such as iOS or Android we use daily did not exist until the iPhone was introduced in 2007. In the late 1990s, people did not even use portable cellular phones with simple functions. If the transformation of personal communication facilities is an example of a T-system, the change agents, that is, the IT companies, have been nudging our behaviors assisted by improved internet infrastructure. While T-systems are focused on change and innovation such as smartphones, the status quo emphasizes stable production, consumption, and administration. Thus, finding efficient approaches and productive paths supporting the purposeful transformation is the key to success.

The chapter presented four strategies, three steps, and five leverage points as the general ideas for conducting transformation or large-systems change. In brief, we need to understand and "see" the system undergoing deep transformation. Mapping the system using visualization techniques can help bring stakeholders together. Once these stakeholders or actors in the system are connected, their viewpoints, observations, interests, and transformation strategies can be collected and discussed. Relatively radical action or experiments can then be identified and implemented to achieve certain goals. Steps in this process are cyclical, which can be interpreted using the process-do-check-act (PDCA) framework. The idea and practices of a "living lab" promoted and implemented since the 2000s can be a convincing illustration (Schumacher and Feurstein, 2006).

As for the strategies driving transformation, multiple and diversified perspectives exist, which can be the basis for designing the "scripts" in furtherance of the intentional goals. "Warrior," "lover," "entrepreneur," and "missionary" were the four proposed strategies that demonstrated how intentions, roles, and interpersonal dynamics can be integrated in different ways to facilitate transformation. The five leverage points or 5 P's, that is, "perspectives," "purposes," "performance matrices," "practices/policies/processes," and "power relations" have been useful for diagnosing the critical issues to deal with so that the nudges can be applied at precise and accurate points in a desired direction.

10.2 Suggestions

To make intentional transformation become a reality, some feedback and suggestions are offered as follows:

Values are the real core

The SDGs are a "shared blueprint for peace and prosperity" for the world and an agenda to end extreme poverty, combat inequality, and conserve the environment, as stated in the chapter and the UN report. As the SDGs themselves are a system showing new mindsets, framings, and viewpoints for mapping the world, the values or core concepts rooted or embedded in the SDGs, not limited to the operational and technical details, should be emphasized. For example, diversity, inclusion, and "no one left behind" are among the key core values of the SDGs. These also apply when we formulate the agenda of transformation by considering the different situations and viewpoints of the stakeholders. Both forward-looking mindsets and ground-touching strategies are needed at the same time to nudge the status quo. This means that we need to learn from people with as many geographical, academic, cultural, and social backgrounds as possible.

Tasks need to be prioritized

Many tasks, items, and corresponding sectors such as energy, city planning, transportation, food supply, and water management would be the focus of the T-systems. These need to be prioritized, with optimized resource allocation, timeline settings, agent selection, and strategy designs. For example, the items for immediate, short-term, and long-term transformation should be identified clearly.

Key competencies, especially system thinking, are required

Taking a systemic view or system thinking is the key to spur transformation. As addressed in the chapter, transformation typically involves social, cultural, technological, political, economic, and environmental processes. The likely cause–effect relationships between sectors, places, or stakeholders must be identified, and the successful transformation requires synergy and co-benefits among sectors or stakeholders involved. System thinking, together with critical thinking and six other key competencies, were mentioned in a report promoting "education for sustainable development goals" (ESDGs) (UNESCO, 2017). These are the components of an innovative and transformative mindset.

Communication matters

The case of Extinction Rebellion (XR) is a new and aspirational example showing that academic communities are also capable of changing the policies, redefining the terms, and shaping the future scenarios of climate actions in the UK and EU, and then the globe, if they work together with effective social communications. These middle-class academics renamed climate change as "climate emergency" and held large-scale gatherings and demonstrations in public places such as museums and squares. Fluorescent green and blood-red decor was selected as the visual theme, which offered excellent conceptual and visual disruptions and was hence noticed by the general public and the media.

Section 11 Digital Innovation

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The development of artificial intelligence (AI) has brought great benefits to humanity. This can be seen in several of the SDGs, including those associated with food, health, water, education, and energy, which are all positively impacted by the development of AI (Vinuesa, et al., 2020). AI can facilitate the development of a circular economy and smart cities for enabling the efficient use of resources. Through 5G/6G technology, AI will be able to connect driverless cars and smart home appliances to realize the goals of a smart city. In addition, smart grids have already been implemented in practice. The main significance of utilizing smart grids in renewable energy management is that current power generation becomes diverse, and smart grids are required to reach the goal of best planning and management of renewable energy considering the uncertainty of natural factors such as solar energy, wind, and tides.

The aforementioned examples are good examples of applications of AI; however, such applications will result in consequences. First, the application of AI requires computing, and a large amount of computing consumes a large amount of energy. According to estimates (Jones, 2018), information and computing technology will require 20% of the world's electricity supply by 2030, which is an extremely large difference in comparison to the current 1%. If no comprehensive power and energy solutions are developed, there will be an energy crisis throughout the world. In response to this problem, green growth is perceived as a valuable solution (Karnama et al., 2019). Green growth refers to more efficient and widespread use of renewable energy. For example, because the cooling system is the most power-consuming system, some data centers have moved to cold-climate locations such as Finland to take advantage of the local natural environment.

As AI algorithms become more powerful, their ability to assist humans in making judgments and decisions is enhanced. However, in such cases, it would be easier to create an algorithmic bias, especially with regard to ethnicity and gender. When algorithms tend to optimize in pursuit of a perfect solution, absolute prejudice and unfairness lurk within them. The world is already inherently unfair, and AI can amplify this unfairness. As AI becomes more powerful, only large countries and companies will have the ability and financial resources to develop it, which will lead to competition between large nations and companies. If these technologies fall into the hands of dictatorial regimes or unscrupulous corporations, they will be as dangerous to the future of humanity as destructive weapons or addictive commodities are today.

The future job market will have a greater reliance on data analysis, and future job seekers will need many AI skills to obtain jobs, which will create obstacles and burdens for low- and middle-skilled workers. In addition to job inequality, gender inequality also demands much attention. Gender inequality affects AI because the datasets used for AI training are mostly derived from general news bulletins and other articles that include many stereotypes against minorities. In addition, there is a lack of women and minorities in the workforce of the AI job market. If the industry cannot increase the number of women and minorities in the field, the inequality will worsen.

With an understanding of the aforementioned issues, we should consider ways to solve these problems. The first issue is how to conduct AI risk management and accountability, as well as AI self-surveillance. Next, is how to avoid algorithmic bias and misuse of AI. To avoid algorithmic bias, AI requires sufficient interpretability, but the current AI algorithms are inadequate in this regard. Explainable AI and interpretable machine learning are two emerging fields of research, which can explain how algorithms work, while providing explanations and comprehensibility; this will allow humans to understand how AI algorithms actually make decisions.

Concluding Remarks

As mentioned in the report, "In 2020, we can no longer claim that we are unaware of environmental change;" climate impacts have rampantly affected every environmental component of the earth (air, water, soil, and biota) on all continents. Intertwined with technological, socio-economic, political, and cultural factors, the resulting turmoil has been amplified to affect all levels of modern society. In response to SDG 17 Partnerships of the Goals, scientists have to collaborate with societal stakeholders and provide scientific evidence to facilitate social transformation toward sustainability. That is why Future Earth emphasizes solution-oriented, transdisciplinary, and stakeholder-engaged sustainability research. This report attempts to streamline science-policy dialog internationally; this commentary article attempts to provide Taiwan's perspective in this dialog.

This report is likely to be the first in the *Our Future on Earth* series, which will be published annually. Future Earth Taipei and Academia Sinica will respond to this global effort by organizing launch and discussion events to enhance the visibility of this report and facilitate real changes in global and Taiwanese society with scientific evidence. We will also share Taiwan's knowledge and experiences with the international academic arena via various channels such as CSS annual reports or scientific publications. Most importantly, this report and commentary article call for proactive actions to tackle challenges in global transformation. It is our hope that implementation plans for making real changes in social transformation can be put forth by the public or the respective sectors as stimulated by the report and these comments. Thus, these scientific findings can make real contributions to our goal: societal transformation toward sustainability.

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