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Water Security in a New World

Eunhee Lee · Benno Böer ·
Lawrence Surendra · Jong Ahn Chun ·
Makoto Taniguchi *Editors*

The Water, Energy, and Food Security Nexus in Asia and the Pacific

East and Southeast Asia

Springer

Water Security in a New World

There is a greatly heightened sense of awareness amongst politicians, policymakers, researchers and the general public that water security is a new and emerging threat. Just in the past few years, a number of high-level meetings involving the world's leaders and thinkers have focused on water security. With water security now commanding global attention, specific questions are posed on the likelihood of armed conflict and war over shared water resources, on the continuing availability of water resources to produce sufficient food for 9 or 10 billion people, on the probability of providing safe drinking water to every man, woman and child, and on the impact of climate change to create extreme water events – such as typhoons, floods and droughts – for which we are not prepared. By bringing together inputs from the world's leading thinkers, experts, practitioners and researchers, the Water Security in a New World series aims to provide evidence-based and policy-relevant responses to these and many other questions related to water security. The volumes in this series will provide in-depth analysis of the various dimensions of water security and are meant to be used by researchers, policymakers and practitioners alike.

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Jong Ahn Chun · Makoto Taniguchi
Editors

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Editors
Eunhee Lee
Korea Institute of Geoscience and Mineral Resources
Daejeon, Korea (Republic of)

Lawrence Surendra
Environmental and Development Economist
Science and Technology
The Sustainability Platform Asia (TSP Asia)
Bangalore, India

Makoto Taniguchi
Research Institute for Humanity and Nature (RIHN)
Kyoto, Japan

Benno Böer
UNESCO Office in New Delhi
New Delhi, Delhi, India

Jong Ahn Chun
APEC Climate Center
Busan, Korea (Republic of)

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SHORT SUMMARY

Nexus approach is key for Water, Energy, and Food Security in East and Southeast Asia

Countries in East and Southeast Asia are experiencing rapid economic growth and environmental challenges with global impacts in economic, environmental, and social aspects. Home to about 30.3% of global population, the region is responsible for significant consumption of water resources and food production. The diverse range of geographical, political, and economic conditions of the region combined with global climate change and urbanization is posing a new set of challenges.

The Water-Energy-Food Nexus (WEF) approach has received significant attention as a key to achieving sustainable development. Interconnectedness between WEF elements demonstrates that an improved nexus understanding is necessary to underpin the successful implementation of the nexus approach to policy making and governance spheres. Unfortunately, our current understanding and knowledge of the nexus is insufficient to capture the dynamic situation. The economic integration of the region demonstrates that a regional scale analysis of the WEF resource security is becoming critical.

Home to about **30.3% of global population,** the region is responsible for significant consumption of water resources and food production.

This book undertakes a comprehensive analysis of the WEF nexus of East and Southeast Asia. Individual chapters introduce complex links between WEF security and explore socioeconomic implications of the nexus approach.

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"Since wars begin in the minds of men and women it is in the minds of men and women that the defences of peace must be constructed"

Foreword by Oyun Sanjaasuren

The current decade 2020 to 2030 is crucial. It is a decade of *nature and climate* action. The need to halve emissions by 2030, halve again the decade after, and then reach net zero by 2050 and also the need to reverse biodiversity loss are enormous tasks. But it is also likely to be a *disruptive decade*: the innovations and technologies that will be needed to achieve these goals and ambitions can also bring major opportunities for more sustainable future.

In the last year and a half, we have seen a major momentum that is being built around the world: the carbon neutrality net zero pledges by 140+ countries, including China, USA, European countries, Japan, Republic of Korea, and India (covering now cca. 90% of the global economy and 80% of GHG emissions) indicate a stronger political will to address the most pressing challenges that the world is facing. We are also seeing a huge public pressure and support to address the global climate and environmental issues, especially from the new generation.

Therefore, this publication is a very timely intervention in the discussions regarding the water, energy, and food security nexus which is at the centre of both the challenges *and* the solutions to climate change and sustainable development path. It is a privilege to write a foreword for this excellent volume on the subject that is requiring our urgent focus. I have been informed that work on this volume started almost a year before the current COVID-19 pandemic struck the world.

The COVID-19 pandemic brought unprecedented humanitarian and health crisis, has taken more than 5 million lives, has driven the global economy down, millions have lost their jobs which is leading to rising poverty, and there is a risk of default in many countries. Developing countries are especially hit hardest—and these are countries already most vulnerable to climate change. At the same time, we know that we have to come out from this pandemic more resilient, build back better, and choose a new path for growth and development.

Scientists are now seeing the pandemic as an outcome of forest destruction and human destruction of the environment and biodiversity. John Vidal, an environment editor of The Guardian, writing in Ensia—a solutions-focused media outlet that reports on our changing planet—writes that "a number of researchers today think that it is actually humanity's destruction of biodiversity that creates the conditions for new viruses and diseases like COVID-19, the viral disease that emerged in China in December 2019, to arise…. In fact, a new discipline, planetary health, is emerging that focuses on the increasingly visible connections among the well-being of humans, other living things and entire ecosystems".

In warning us that this may be just the beginning of mass pandemics, he refers to the celebrated author and journalist, David Quammen, whose books include "Spillover: Animal Infections and the Next Human Pandemic." Quammen, writing in the New York Times, in January 2020 (just after the outbreak of the COVID-19 pandemic in Wuhan, China), had this to say: "We invade tropical forests and other wild landscapes, which harbour so many species of animals and plants—and within those creatures, so many unknown viruses. We cut the trees; we kill the animals or cage them and send them to markets. We disrupt ecosystems, and we shake viruses loose from their natural hosts. When that happens, they need a new host. Often, we are it."[1]

In such a background and dire forebodings for the future, this book is an excellent example of international intellectual and research cooperation working to bring solutions for sustainable futures in the East Asian and Southeast Asian regions. This volume is a timely intervention in the context of climate crisis and the outcomes of the recent COP26 in Glasgow COP26. The COP26 triggered many conversations on whether human beings, societies, and governments are doing enough to prevent their own doom. As Vaclav Havel once said that even the planet and other natural species may still survive the impacts of climate change, but not human beings. He reminded us that human beings could very well be committing collective suicide if they do not change the trajectory of their current activities that is resulting in damaging Planet Earth. He raised the moral question as to what right does the current generation have in denying a future for future generations, our grandchildren, and their children. That is precisely the question young people world over have been asking the world leaders. Issues of intergenerational and intragenerational equity and justice that is being posed to all of us and demanding urgent action to reduce the global warming help vulnerable nations to adapt to the changing climate and move on a trajectory that takes us away from a pandemic-ridden and warming path.

The WEF's global risks report indicates that the top risks are dominated by inability to respond to climate change, natural disasters, and extreme weather and biodiversity loss.[2] Competition over the limited resources is also likely to exacerbate regional and global conflicts. These are very relevant concerns in the context of East and Southeast Asia. Regions that have experienced unprecedented socio-economic growth, population changes, and growing urbanization contributed their share to climate change. These fast-growing economies thus also extended their ecological footprint beyond their own regions to other regions with serious implications for not only the rest of the Asia-Pacific region but other developing regions as well.

The security of water, energy, and food resources—the three essential elements for human survival are seriously threatened by unsustainable resource consumption.

[1] (Quammen D 2020) We made the coronavirus epidemic. New York Times. Retrieved from https://www.nytimes.com/2020/01/28/opinion/coronavirus-china.html.

[2] WEF (2021) Global Risks Report.

Realizing the centrality of water, energy, and food (WEF) security, the concept of WEF nexus has received increasing attention from the global community.[3] Since the Bonn 2011 Nexus Conference that highlighted the nexus approach towards the green economy and sustainable development, numerous studies have been conducted to understand the complex and systemic interlinkages across and between the nexus components. These studies have pointed to holistic approaches while also factoring the trade-offs and synergies between these resources, as well as cautioning us to the potential conflicts in managing these resources. In East and Southeast Asia, for example, water plays a pivotal role for sustaining agricultural productivity which in turn is critical for food security. Water also plays an important role in energy generation. Addressing food and energy security cannot be achieved without a consideration of water security and vice versa.

In this volume, I am very encouraged to see the contributors from East Asia and Southeast Asia present in-depth analysis and a vast amount of empirical evidence as to where countries in these regions stand with respect to water, energy, and food security. They also provide the course corrections and systemic approaches that need to be adopted by understanding the nexus linkages between these three critical resources on which human survival hinges upon. The opening chapter by Eunhee et al. succinctly presents the agenda and the scope of the volume. The concluding chapter by Lawrence Surendra et al. both pulls together the discussions in the volume by the contributors in the preceding chapters and excellently distils the opportunities and challenges before us not only in East and Southeast Asia but for the global community. I want to also record my appreciation for the work done by the editors on this volume on "*Securing Water, Energy and Food in East and Southeast Asia*" and in particular the labours of Dr. Eunhee Lee of KIGAM, the chief editor, Dr. Benno Boer of UNESCO, and Prof. Lawrence Surendra from TSP Asia.

I congratulate UNESCO mandated to work in the intersecting domains of Education, Science, and Culture and KIGAM, a leading global geoscience research institute based in the Republic of Korea, for their hard work and contributions in bringing together such an impressive group of scholars to present their research and analysis on the WEF Nexus. Contributions, that I am sure it will catalyse very profound reflections on how we may address the nexus challenges. I am equally confident that this volume will be an important contribution and inspiration in our efforts globally to achieve the UN SDG agenda.

January 2022

Oyun Sanjaasuren
Green Climate Fund, Incheon,
Republic of Korea

[3] Hoff H (2011) Understanding the nexus. Background paper for the Bonn2011 Conference: The water, energy and food security nexus.

Foreword by Kyung Koo Han

Today, the world faces environmental challenges that we have never encountered before. The growing risks of natural disasters and increasing demands on Earth's resources pose a critical concern for sustainable development. Competition over limited resources exacerbates regional and global conflicts, while the increasing effects of climate change, biodiversity loss, and global pandemics have created new dimensions to global challenges. These issues are of particular concern for East and Southeast Asia areas that have experienced unprecedented socio-economic growth, population changes, and urbanization in recent decades, while investments in infrastructure and management have struggled to keep pace.

The security of water, energy, and food resources—the essential elements of human survival—is seriously threatened by unsustainable resource consumption. In East and Southeast Asia, water in particular plays a pivotal role in sustaining agricultural productivity and renewable energy efficiency, showing that the security of food and energy cannot be achieved without considering water security and vice versa. With increasing stress on water, energy, and food security, the concept of the water, energy, and food nexus has received increasing attention from global communities as a key factor for global sustainability. A holistic governance strategy that fully encompasses the relationships among water, energy, and food is no longer an option; it is a necessity for ensuring resilient societies.

This publication, which provides a comprehensive analysis of the socio-economic implications of the water, energy, and food nexus in East and Southeast Asia and includes relevant cases on the water, energy, and food nexus from 15 countries in the region, is therefore a very timely publication that will guide us in terms of where we are and where we should go.

The Korean National Commission for UNESCO (KNCU) exists to promote UNESCO's vision and agenda, both within the Republic of Korea and more widely. A major part of KNCU's work is to raise awareness of the UN Sustainable Development Goals (SDGs), the current global development agenda, and to promote cooperation to achieve these goals, many of which directly concern the water, energy, and food nexus.

As such, I am delighted to introduce this volume, which I believe will be extremely useful to a range of stakeholders worldwide, including policy-makers and politicians, academic and research communities, and practitioners.

I am confident that the information in this book will give readers valuable new insights into the resilient nexus solutions of East and Southeast Asia and that these insights can be put to good use in work to achieve the SDGs and a resilient society.

February 2022

Kyung Koo Han, Ph.D.
Korean National Commission for
UNESCO, Seoul, Republic of Korea

Foreword by Prof. Shahbaz Khan

In China, the Yangtze River made the first great agrarian and urban settlements possible. Similar hydro-geographical settings throughout the world were essential for civilizations to survive and thrive.

In January 2022, humanity has reached a total population of 7.9 billion people.

The availability of water has always been a key-defining factor for sustainable human living. The same is true for the availability of food and energy, and, because of that, it is advisable to look into water, energy, and food security issues individually, but in a concerted fashion, in a nexus, encouraging a dialogue between the different stakeholders, motivating a holistic view and approach for the management of these vital resources.

The availability of water is a necessity for human living, and it directly impacts the attainability of food and energy. In times of a pandemic and climate change, this is even more important.

Geographically, East and Southeast Asia is a special sub-region, including Brunei Darussalam, China, Cambodia, Democratic People's Republic of Korea (North Korea), Indonesia, Japan, the Lao People's Democratic Republic (Lao PDR), Malaysia, Mongolia, Myanmar, the Philippines, Republic of Korea (South Korea), Singapore, Thailand, and Vietnam, with a great diversity of geographical characteristics and socio-economic and cultural evolution, as explained in this volume.

However, the integrated water, energy, and food crisis is a global crisis, with more than four billion people with insufficient water availability for at least one month per year, more than a billion people with limited or no access to electricity, and almost a billion people living a daily struggle of finding enough food to eat. This could be improved via a nexus approach.

Studies predict that climate change will exacerbate the problem, in that by 2050, more than half of humanity could be living in areas of water stress. The first victims of this deficit will be girls and women, a circumstance which is likely to increase gender inequality even further.

In order to achieve the ambitious tasks of the Sustainable Development Goals 2 (Zero Hunger), 6 (Water, Sanitation and Hygiene), 7 (Clean and Affordable Energy), all stakeholders need to do much more and be better coordinated, than ever before. Actions to save the planet and its water will have to involve future generations via education for sustainable development, which is also education about water, food, and clean energy, and about how we can better manage the nexus.

In this volume *The Water, Energy, Food Security Nexus in East and Southeast Asia*, an overview of the sub-region is presented, and the nexus concept is introduced. The volume is a part of a three-volume series to examine in an integrated manner the water–energy–food nexus in the Asia and Pacific Region. It explores the socio-economic implications of the nexus approach with a focus on cross-cutting issues, such as climate change, gender, urbanization, impacts on environment and economy, and transboundary issues. It provides new insights into nexus solutions in the region.

With the key statistics and the dynamics of the sub-region presented here, we conclude that it is time, to readjust global, regional, national, provincial, and local priorities with a clear view towards those parameters that are of the greatest importance for human survivability, in particular the availability of water, energy, and food.

I thank KIGAM for the partnership, jointly producing this volume with UNESCO, and I congratulate the editors and authors of the volume for the production of this well-structured scholarly work, under the able leadership of a formidable woman in science, Dr. Eunhee Lee.

February 2022

Prof. Shahbaz Khan
UNESCO Office in Beijing, Beijing
China

Foreword by Pyeong-Koo Lee

Security of water, energy, and food (WEF) resources are essential elements for sustainable and resilient societies. The WEF nexus security has become the most prominent issue in East and Southeast Asia, which has experienced rapid economic growth and environmental changes. There is abundant scientific data to suggest that without substantial reforms in the policies and practices for WEF resource management, the region will face serious challenges arising from limited resource availability. In the context of East and Southeast Asia, while sharing mutual economic and cultural interests and comparable socio-economic development history, the complexity of WEF nexus relation needs to be addressed both on a country-specific and regional basis.

The security of WEF resources in the region is strongly tied to each other through various nexus relations. As most of the region lies in the monsoon climatic zone with abundant rainfall, water resources play an important role in supporting food productivity and sustainable economic development. The growing frequency of extreme rainfall and droughts, however, creates serious risks for water security and food productivity. The situation may worsen in many parts of the region where infrastructure development has lagged behind population and economic growth.

Given that East and Southeast Asia are responsible for a significant portion of global food production, the issue of food security of the region has a global impact. As many countries in East and Southeast Asia are gradually shifting to renewable energy sources, the nexus linkages between energy and other nexus components (geothermal, biofuels) become even more complex. The transboundary nature of water resources is also closely related to energy security (hydropower, etc.). China, which boasts the largest population in the world and the foremost economic power, has significant and growing impacts on global resource security, suggesting that the analysis of nexus interlinkage at the global level should fully consider China's impact especially in the context of the country's international trade linkages.

The WEF security in the region is seriously threatened by climate change, urbanization, and increasing standards of living. The global COVID-19 pandemic, moreover, is posing a new challenge across all sectors of human livelihood. The competition over finite resources across various sectors and transboundaries will be further intensified. In this regard, the future scenarios of the comprehensive analysis of WEF nexus status and predictions in East and Southeast Asia should be conducted based on state-of-the-art scientific research, technological innovation, policy suggestion, and multi-sectoral cooperation.

This joint publication between Korea Institute of Geoscience and Mineral Resources (KIGAM) and UNESCO aims to provide an overview of the current regional status of WEF security and then identify common themes that interlink the nexus components. Furthermore, we hope to understand how these common threads impact the regional and global nexus security and explore the link between securing the water–energy–food nexus and the attainment of global Sustainable Development Goals (SDGs). On behalf of KIGAM, it is my greatest pleasure to contribute to this joint publication. KIGAM, the world's leading geoscience research institute, has advanced our scientific knowledge and technical innovation for global sustainability and prosperity. Since KIGAM's establishment as the "Geological Survey of Korea" in 1918, our finest researchers and professional members have been devoting themselves to meeting the national goal and the public demands on geoscience relevant to our daily lives. As one of the critical pillars of R&D programmes, KIGAM has been focusing on sustainable development and management of groundwater and geothermal resources to contribute to achieving WEF security. Besides, to effectively respond to global climate change, the development of climate change adaptation technologies for securing groundwater resources and integrated use of shallow geothermal energy and managed aquifer recharge for greenhouse farming facilities are the ongoing researches in KIGAM. Also, the application of modern information and communication technologies (ICTs) for smart allocation, real-time monitoring of groundwater for agriculture, and technology development of sustainable shallow geothermal energy utilization to reduce greenhouse gases are the significant accomplishments of KIGAM. With these achievements, KIGAM is expanding its role to global society by actively participating in international research collaboration for groundwater sustainability for the Mekong region for decades.

Throughout this volume, the contributors from academia, international society, and government bodies have presented interesting nexus linkages between WEF components in the region and explored the socio-economic implications of the nexus with a special focus on the cross-cutting issues. By presenting the most recent science-based evidence and policy advice, this volume presents a glimpse of nexus solutions available across the region. We expect the findings presented in this volume will deepen our understanding of the nexus equations and contribute to sustainable development in the region.

I hope the reader of this book will gain new insight into the resilient nexus solutions of East and Southeast Asia and share this information to achieve global sustainable development goals.

February 2022

Pyeong-Koo Lee, Sc.D.
Korea Institute of Geoscience and
Mineral Resources (KIGAM) Daejeon,
Republic of Korea

Preface: A Message from the Editors

"Shock Resilience"—strengthening knowledge and skills of young people for Water, Energy, and Food Security.

A Coalition of Nature and People

2021 was a year when a global pandemic shook the world and both shocked and reminded all nations and people that they cannot continue with "business as usual" scenarios, in the *Anthropocene* era and continue to disregard nature. The COVID-19 pandemic disease caused a completely new confrontation to humanity, trying to handle multiple global crises at the same time, adding enormous new challenges to the existing crisis, such as biodiversity loss, climate change, and environmental degradation, all of which are closely related to the water, energy, and food (WEF) security nexus. Indeed, the world today faces the unprecedented challenges that we have never encountered before.

Environmental change issues closely relate to WEF security, as well as our common need to sustain the human life support system. Furthermore, population dynamics together with non-responsible production and consumption patterns exacerbate the ongoing trend of unbridled exploitation of natural resources. In order to achieve the Sustainable Development Goals (SDGs) of the Agenda 2030, a whole set of actions and training modules is needed that goes beyond textbook teaching.

We Have Not Tried Hard Enough

A lot of global environmental and socio-economic challenges could have been avoided, if preventive measures would have been put in place and early warning systems and management plans would have been translated into policies. The same can be said about climate change; the evidence that greenhouse gas emissions contribute significantly to climate change and sea-level rise is immense and has been well known for a long time. Still, not enough is being done for a gradual transition from fossil and nuclear energy to clean energy sources, just as if anthropogenic climate change would not exist. Not enough is being done for biodiversity conservation, as well as against plastic and air pollution, and for the availability of clean water and sanitation. The Asia and the Pacific SDG Progress Report 2020 sums it up as: "*The evidence is overwhelming that the Asia-Pacific region is not on track to achieve the sustainable use of the planet's shared resources (air, water, soil, and energy)*"[4] (United Nations 2020). This means we know the issues, we know what needs to be done, and still, we have to do much more to achieve the SDGs, including those that are closely related to the WEF security nexus.

How to Become More Shock Resilient: Youth Engagement Is an Answer

The UN climate summits took place many times, each time with a lot of hopes, and announcements, and promises. COP27 took place in Egypt most recently, and people, especially young people demand to be heard, because they feel that environmental degradation is compromising their future and they have good reasons to be concerned: the global demand for fossil fuel is still on the increase, even though temporarily hampered by the economic downwards trend caused by the COVID-19 lockdown. By far, most vehicles (cars, busses, trucks, ships, and aeroplanes) are still being fuelled with CO_2 intensive fossil fuels. This is true, even though functioning alternatives, such as electric, biofuel, waste, and hydrogen propelled engine technology have been available for many decades. One cannot confirm that there is a huge global success promoting clean energies. 2020 was a year when the global youth disapproved of the slow progress of applying clean energy and clearly expressed its frustration that not enough was done to protect the future, with a focus on anthropogenic climate change. Young people went on strike, in many countries, in many cities, and millions of them. Their voices have been heard but will the needed actions follow fast enough?

Building capacity of young people is the key element towards attaining SDGs and WEF security in this region. Through various learning and dialogue mechanisms, as well as good practices in the real world, many millions of young people will further develop the skills towards climate change as well as other socio-ecological expertise, keeping WEF security in focus. Moreover, it will foster the spirit of peace of the youth via developing a joint mental model of doing this together in an inter-regional approach. The youth will learn about the climate and human rights issues, fund mobilization, and project ownership and associated responsibilities for long-term sustainability. Most importantly, they will acquire useful skills for shock resilience and human survivability.

[4] United Nations (2020) The Asia and the Pacific SDG Progress Report 2020. United Nation, New York. 88 p.

Turning from Rhetoric to Action

The SDGs of the Agenda 2030 very well reflect the hopes and challenges of humanity at this moment of writing, at the beginning of 2022. Climate change, loss of biodiversity, water issues, food and energy security, and capacity limitations for waste management are real. These subjects are clearly mentioned in the SDGs. Accordingly, the United Nations and its specialized agencies suggest local actions for global change issues towards the sustainable and resilient society.

UNESCO was designed and established to foster peace on the platform of education, the sciences and culture. As mentioned, the world is facing the foremost challenges that we have never encountered before. These issues, of course, can only be professionally addressed under consideration of all SDGs and with a solid understanding of issues, such as peace, democracy, and gender. UNESCO is well placed to address these issues and delivering highly valuable capacity augmentation programmes through UNESCO's International Hydrological Programme (IHP), International Geoscience and Geopark Programme (IGGP), World Network of Biosphere Reserves, and science education and youth mobilization. Within the strategic framework of UNESCO's science programmes, the timely publication of this volume was one of the many attempts by the organization to bring together the concerned academia, policy-makers, civil society, and especially youth to become intellectually involved with highly important contemporary issues, such as biodiversity, climate, waste, and water in times of rapid global change.

In this regard, on behalf of the editors, I am happy to present this timely publication, *The Water, Energy, Food Security Nexus in East and Southeast Asia*, to the world. In this book, we address the environmental and socio-economic challenges of East and Southeast Asia regions and capture some important WEF nexus relation. We also suggest key actions that have to be taken urgently for the regional WEF security nexus. Although this book cannot solve all the problems that we are facing these days, we hope at least some of the policy-makers, civil servants, practitioners, and academia in the region will be inspired and take actions towards resilient and sustainable society. We also hope this volume could encourage young people to get more knowledge on the WEF security nexus, mobilize the action of young people in a replicable and affordable way, and ultimately bring together the puzzle pieces needed for the sustainable and resilient society.

New Delhi, India — Benno Böer
Daejeon, Korea (Republic of) — Eunhee Lee
Chanakyapuri, India — Lawrence Surendra
Kyoto, Japan — Makoto Taniguchi
Busan, Korea (Republic of) — Jong Ahn Chun
January 2022

Contents

Contributors

Benno Böer The United Nations Educational, Scientific and Cultural Organisation, New Delhi, India

Kimberly M. Burnett University of Hawai'i Economic Research Organization, Honolulu, HI, USA

Sara Castro-Hallgren United Nations Office for Sustainable Development, Incheon, Republic of Korea

Jin-Yong Choi Department of Rural Systems Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea

Shofwan Al Banna Choiruzzad Department of International Relations, Universitas Indonesia, Depok City, Indonesia

Jong Ahn Chun Prediction Research Department, APEC Climate Center, Haeundae-gu, Busan, Republic of Korea

Iqlima Fuqoha ASEAN Centre for Energy (ACE), Jakarta, Indonesia

Ida Bagus Hendra Gupta Bremen Overseas Research and Development Association, Bremen, Germany

Ramasamy Jayakumar The United Nations Educational, Scientific and Cultural Organisation, Paris, France

Kwansue Jung Chungnam National University, Daejeon, Republic of Korea

Daeha Kim Department of Civil Engineering, Jeonbuk National University, Jeonju, Jeollabuk-do, Republic of Korea

Suduk Kim Ajou University, Suwon, Republic of Korea

Yujeong Kim United Nations Office for Sustainable Development, Incheon, Republic of Korea

Thammarat Koottatep Asian Institute of Technology, Bangkok, Thailand

Eunhee Lee Korea Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, Republic of Korea

Sang-Hyun Lee Department of Agricultural and Rural Engineering, Chungbuk National University, Cheongju, Republic of Korea

Woo-Kyun Lee OJEong Resilience Institute (OJERI), Korea University, Seoul, Republic of Korea

Chul-Hee Lim College of General Education, Kookmin University, Seoul, Republic of Korea

Naoki Masuhara Research Institute for Humanity and Nature, Kyoto, Japan

Eunju Min Ajou University, Suwon, Republic of Korea

Sittidaj Pongkijvorasin Faculty of Economics, Chulalongkorn University, Bangkok, Thailand

Prajal Pradhan Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, Potsdam, Germany;
Bauhaus Earth gGmbH, Berlin, Germany

Muhammad Panji Islam Fajar Putra CDP Europe, Berlin, Germany

Nadhilah Shani ASEAN Centre for Energy (ACE), Jakarta, Indonesia

Kuanyi Shen School of International and Public Affairs, Columbia University, New York, NY, USA

Tharinya Supasa ASEAN Centre for Energy (ACE), Jakarta, Indonesia

Lawrence Surendra The Sustainability Platform Asia (TSP Asia), Bangalore, India

Pongsak Suttinon Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand

Makoto Taniguchi Research Institute for Humanity and Nature, Kyoto, Japan

Hans Dencker Thulstrup The United Nations Educational, Scientific and Cultural Organization, Regional Sciences Bureau for Asia and the Pacific Jakarta, Jakarta, Indonesia

Christopher A. Wada University of Hawai'i Economic Research Organization, Honolulu, HI, USA

Linna Wang Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, China;
University of Chinese Academy of Sciences, Beijing, China

Yonghui Yang Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, China;
University of Chinese Academy of Sciences, Beijing, China

Seung-Hwan Yoo Department of Rural and Bio Systems Engineering, College of Agriculture and Life Sciences, Chonnam National University, Gwangju, Republic of Korea

Pureun Yoon Department of Rural Systems Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea

Zulfikar Yurnaidi ASEAN Centre for Energy (ACE), Jakarta, Indonesia

Xinyao Zhou Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang, China

Chapter 1
An Overview of the Water, Energy, and Food Nexus in East and Southeast Asia

Eunhee Lee, Benno Böer, Lawrence Surendra, Jong Ahn Chun, and Makoto Taniguchi

Abstract This chapter provides a comprehensive overview of the state of the water, energy, and food (WEF) nexus in East and Southeast Asia. In Sect. 1.1, a brief overview of the region is presented, and the concept of the WEF nexus is introduced. In Sect. 1.2, the objectives and outline of each section of this book are introduced. In Sect. 1.3, the key drivers and challenges that have shaped the region's trajectory are reviewed in detail, focusing on economic growth, environmental pollution, and sustainable development. In particular, the relations between the commonalities/connections in the region and WEF nexus security are explored in detail, and the geopolitical aspects are discussed to describe how the region is unique and critically important in the global context. Notably, the uniqueness of the region discussed

Disclaimer: The designations employed and the presentation of material on the maps do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. * Non-Self-Governing Territory.

E. Lee (✉)
Korea Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, Republic of Korea
e-mail: eunheelee@kigam.re.kr

B. Böer
The United Nations Educational, Scientific and Cultural Organization, New Delhi Cluster Office, New Delhi, India
e-mail: b.boer@unesco.org

L. Surendra
The Sustainability Platform Asia (TSP Asia), Bangalore, India

J. A. Chun
Prediction Research Department, APEC Climate Center, Busan, Republic of Korea
e-mail: jachun@apcc21.org

M. Taniguchi
Research Institute for Humanity and Nature, Kyoto, Japan
e-mail: makoto@chikyu.ac.jp

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throughout this chapter and its strong linkages with WEF nexus security offer a rationale for a regional approach in addressing WEF nexus issues in East and Southeast Asia.

Keywords WEF nexus · East Asia · Southeast Asia

1.1 Introduction

This volume on East and Southeast Asia is a part of a three-volume project to examine in an integrated manner the "water–energy–food (WEF) nexus" in the Asia and Pacific Region. The Asia and Pacific Region in this project also covers Central Asia, South Asia, and the Pacific. In this volume, we analyse and introduce general characteristics and complex links between WEF security in East and Southeast Asia. This volume also explores the socioeconomic implications of the nexus approach with a special focus on cross-cutting issues (e.g., climate change, gender, urbanization, impacts on the environment and economy, and transboundary issues). Finally, by presenting the most recent research and science-based evidence, the book provides new insights into nexus solutions in the region.

Geographically, East and Southeast Asia includes the following 15 countries: Brunei Darussalam, China, Cambodia, Democratic People's Republic of Korea (North Korea), Indonesia, Japan, the Lao People's Democratic Republic (Lao PDR), Malaysia, Mongolia, Myanmar, the Philippines, Republic of Korea (South Korea), Singapore, Thailand, and Vietnam. East Timor is often considered both as part of Southeast Asia and the Pacific. In this book series, East Timor's country-level statistics are reviewed in the Pacific volume. East Asia includes China, Japan, Mongolia, North Korea, and South Korea, and Southeast Asia includes Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam.

East and Southeast Asia is characterized by diverse geographical characteristics and socioeconomic statuses. Despite their broad diversity, the countries in the region still share many unique characteristics. In the following sections, the region's uniqueness and the key drivers and challenges are discussed in detail, with a focus on the region's resources, security issues and sustainability.

The countries covered in this volume are shown in Fig. 1.1.

1.1.1 Regional Overview

The East and Southeast Asian regions border the Pacific Ocean in the east, Russia and Kazakhstan in the north, South Asia in the west, and the Indian Ocean in the south. Home to approximately 29.8% of the world's population (as of 2018), this region has experienced remarkable economic growth over the last decades, initially in Japan,

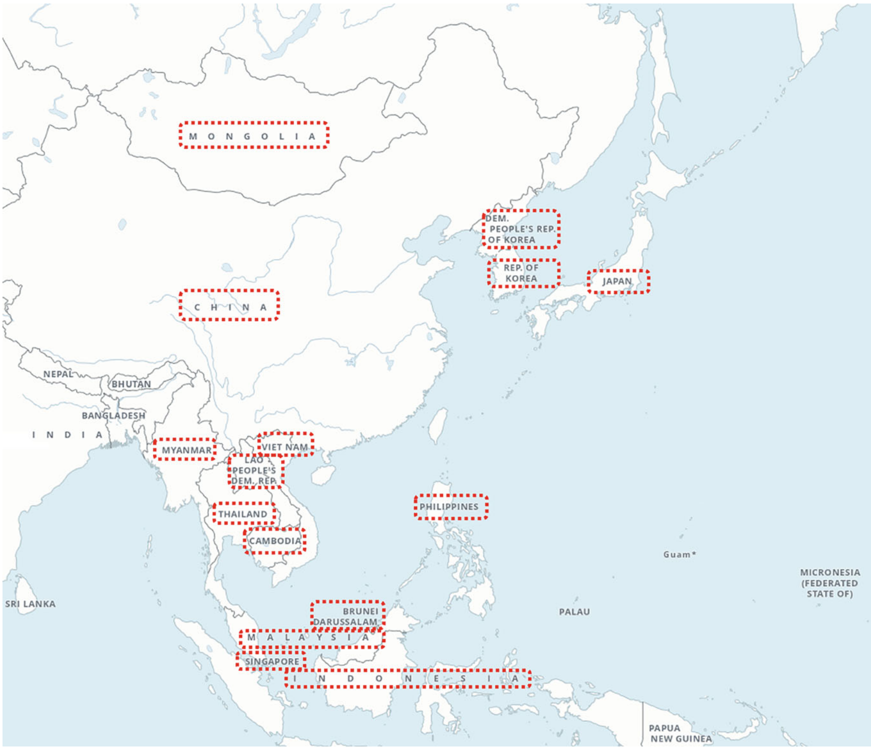

Fig. 1.1 Geographical representation of the East and Southeast Asian regions (*Source* UN Map) adapted by author

Singapore, and South Korea and more recently in China and the countries in Southeast Asia. The region has successfully positioned itself as one of the powerful emerging markets at the global level, serving as a critical part of the world trading system. The success of ASEAN (Association of Southeast Asian Nations) and other organizations, such as ASEAN Plus Three and MRC (Mekong River Commission), has provided a framework for regional collaboration and regional responses to international concerns. Most countries in the region border China, one of the world's largest economies now, and have largely been influenced by China from intraregional trade of goods and services to environmental concerns, including transboundary issues.

The total land area of these 15 countries comprises approximately 12.4% of the global land surface (World Bank 2021), and most of the countries in the region, except for inland China and Mongolia, which are situated in arid and semiarid zones, are located in the monsoon climate zone. Monsoon-dominated rainfall and temperatures largely shape water resource availability, food productivity, and water-centralized economic development in the region. Consequently, the region's economy largely depends on agriculture, despite the countries in the region accounting for an increasing share of global manufacturing. The world's third longest river, the Yangtze

River (China), and the 12th longest river in the world, the Mekong River (mainland Southeast Asia), are located in the region. The Mekong River, which runs through six countries, including China (called the Lancang River), Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam, is considered to be among one of the world's largest transboundary rivers with significant socioeconomic impacts.

As a result of rapid industrialization and population growth, however, many developing countries in the region have serious environmental and social concerns, including inequality, natural hazards, environmental pollution, and climate change. Furthermore, the inefficient use of resources and the large contribution of natural resource-intensive commodities (e.g., agricultural products) to the region's economy have seriously threatened the security of crucial resources such as water, energy, and food (WEF). Compared to dramatic growth, infrastructure and public support systems still lag behind growth for many countries in the region, raising cross-cutting issues such as urban-related issues, environmental pollution, resource depletion, uneven access to basic support systems (e.g., safety, clean water, sanitation systems, food, and education), inequality, and climate-driven disasters. Located near the boundary of geological plates, many countries in the region are extremely prone to natural disasters such as earthquakes, and the region is classified as one of the most vulnerable regions to climate change.

1.1.2 Use of Nexus as a Concept to Link Water, Energy, and Food Security

The notion of the WEF nexus was first used during the Bonn 2011 Conference, organized in preparation for the UN Conference on Sustainable Development (the Rio + 20 summit). During the conference, Hoff (2011) presented initial evidence for how a nexus approach can enhance WEF security by increasing resource efficiency, reducing trade-offs, building synergy, and improving governance. Since then, the nexus approach has been globally recognized as a key to achieving sustainable development in response to population growth, urbanization, globalization, and climate change.

A large body of research has revealed the various interconnectedness between WEF elements and presented the complex and interrelated natures of the nexus resource system (FAO 2014). In fact, the concept of the nexus can vary depending on the scope, objectives, framework, and methodologies adopted, and some researchers even further expanded the nexus concept to include land (Hoff 2011), minerals (Andrews-Speed et al. 2012) and ecosystems (UNECE 2014). Despite its variability, the central aspect of the WEF nexus approach can be summarized as a process to link ideas and actions of different stakeholders, optimize integrated WEF resource efficiency and manage the synergies and trade-offs among different resources by understanding how these interactions are shaped by environmental, economic, social, and political changes (Endo et al. 2017).

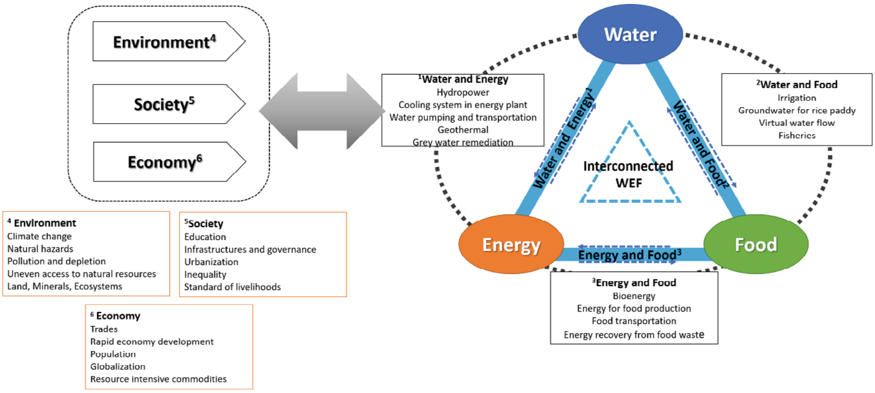

Fig. 1.2 Examples of representative nexus relations in East and Southeast Asia

As described, the interconnectedness between the WEF nexus and the surrounding systems (socioeconomic changes, ecosystems, climate change, mineral resources, and globalization) is complex, dynamic, ubiquitous, and interrelated at multiple levels. In Fig. 1.2, some examples of well-known nexus relations in East and Southeast Asia are introduced. Although the figure presents several important nexus linkages connecting two or three nexus elements, the links between each element are bidirectional, multiple, and connected to outer systems at varying levels.

Therefore, an improved nexus understanding based on scientific evidence and intersectoral research is still necessary to expand successful implementation of the nexus approach to policy-making and governance spheres (Hoff 2011). Unfortunately, our current understanding and knowledge of the nexus indicators and matrix are insufficient to capture the dynamic nexus relations. Furthermore, rapid societal changes in East and Southeast Asia during the last several decades further complicate our understanding of the resource system and its interlinkages internally and externally.

WEF nexus analyses are often conducted at regional and global levels. Regional analyses of the nexus can be useful for capturing the broader impact of human activities on the status of shared resources. Furthermore, regional analyses allow us to better understand regional commonalities and connections among historical, socioeconomic, and environmental points of view and even to catalyse regional efforts to achieve global resource security (Naidoo et al. 2021). Thus, in this book series, we focus on regional perspectives of WEF nexus security in East and Southeast Asia.

1.2 Objectives and Organization of This Volume

The objective of this volume is to provide a comprehensive overview of the WEF nexus, with a regional focus on East and Southeast Asia. Individual chapters of this book will provide interesting nexus dimensions of the region to address the following objectives:

- Provide an overview of the current regional status of WEF security in East and Southeast Asia based on regional experience and scientific evidence;
- Identify key commonalities and connections that interlink the WEF nexus and present how these common connections affect all nexus relations and the socioeconomic development of the region;
- Discuss how WEF nexus security is integrally linked to the achievement of sustainable development goals (SDGs) throughout the region; and
- Identify knowledge and policy gaps and discuss regional implications to achieve nexus security, focusing on what is known, what progress has been achieved, and what lessons can be learned.

The book opens with an introduction and regional overview, offering a rationale for the regional approach to address nexus issues. In the following four sections, an in-depth discussion of the nexus in East and Southeast Asia is provided and focuses on the following different themes:

- *Section I—Regional overview*

This section provides the basic facts about the security of water, energy, and food resources in the region. Statistical data representing water, energy, and food security are presented, and the progress and primary challenges being faced in addressing different nexus elements are explored.

- *Section II—Regional issues*

The second section focuses on regional issues and analyses water–energy–food relationships based on different case studies. This section investigates the socioeconomic and environmental challenges in East and Southeast Asia, focusing on commonalities and connections that define the uniqueness of the nexus relation in the region.

- *Section III—Cross-cutting themes for nexus security*

The third section focuses on all major "cross-cutting themes" as the key drivers of policy, actions and strategies in the region, focusing on climate change, multidisciplinary approaches, the process for sharing of resources across borders, and gender-based disparities.

- *Section IV—Integrated narrative*

The final chapter of the book explores some future scenarios and includes questions on how best to address future challenges using the nexus approach, considering the geopolitical and socioeconomic context of the region. This section examines nexus-based policies and science and technology innovations (STIs) as possible options for practical solutions to the WEF nexus issue and implementation of nexus solutions that are aligned with the 2030 Agenda for Sustainable Development.

1.3 Dynamic Drivers and Regional Challenges in East and Southeast Asia

1.3.1 Geopolitical Aspects

East and Southeast Asia is a unique and critically important region to the global economy. With rapid population growth and fast-growing economies, many countries in the region have successfully positioned themselves as powerful emerging markets globally. The region has benefitted from greater integration with global manufacturing, and export-led growth in many economies in the region has further accelerated trade in manufactured goods in both intra- and international trade. There is a predominance of Asian and intra-Asian trade in globalized production processes and value chain growth (UNCTAD 2020).

Situated among Southern Asia, Central Asia, Oceania, and the Pacific Ocean, the region possesses some of the world's important trading routes that over the centuries have supplied vital commodities from and to the region. For example, the Strait of Malacca, situated among Indonesia, Malaysia, and Singapore, connects the Indian Ocean with the Pacific Ocean and has served as the world's second-largest oil trade checkpoint (EIA 2017).

Despite the region's promise, the region's economy is vulnerable to external factors. Many of the countries in the region are still categorized as developing countries. Moreover, a substantial gap in infrastructure constrains upward trajectories, and this factor combined with rising consumption has led to significant and increasing environmental footprints. Greater integration into the world economy has led to and intensified competition over strategically important natural resources and trade and transport transit routes. The competition of the transit routes has caused intraregional conflicts, while simultaneously, a high level of trade openness has also provided direct transmission channels for global shocks (Alston et al. 2018).

Many economies in the region share common historical, socioeconomic, and environmental attributes. From the perspective of modern world history, the economic and political attributes of most East and Southeast Asian countries have been affected by colonial rule and the struggle for independence. The recovery and growth of the region have been revitalized since post-war construction. Despite the region's rapid progress, the relatively short period of recovery from being a colonial state followed by the traumas of post-World War II situations has meant that many governments in the region have also suffered from residual issues related to old conflicts and tensions as well as political instability.

Table 1.1 in Annex (part of this volume has the data related to issues discussed in Annex) shows the estimate of political stability in East and Southeast Asia. For comparison, index values for other countries (USA, Germany, Sweden, Switzerland, and Afghanistan) are also provided. The table shows that the political stability and absence of violence and terrorism estimates are the highest in Singapore and Brunei Darussalam, whereas Myanmar, the Philippines, Thailand, Indonesia, North Korea, and China still suffer from internal/international tensions. Today's conflicts in the region are mostly products of history, deficits in the development of democracy, continuing tensions partly caused by ethnic and religious identities, and most importantly and centrally competition over the resources leading to the territorial dispute. These political crises at times have been a major barrier to rapid economic growth.

Another important element that has shaped the geopolitical position of this region is the success of regional collaboration frameworks such as ASEAN, ASEAN Plus Three, EAS (East Asia Summit), and MRC. ASEAN is a regional organization established for economic, political, military, educational, and sociocultural integration among its members (Brunei Darussalam, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam). Driven by strong economic integration, this organization has been credited as one of the world's most influential organizations.

The economic integration of East and Southeast Asia through various mechanisms for regional collaboration together with accelerating global trade has resulted in both integrated resource mobilization and the consumption and management of natural resources at a regional scale. This scenario indicates that a regional analysis of resource security is becoming critical for sustainably managing limited crucial resources, especially water, energy, and food.

1.3.2 Rapid Growth

East and Southeast Asia has been recognized as having the world's fastest-growing economy over the last few decades. The industrialization of the region has mostly increased over the last 30 years, including the expansive growth of China's economy and the growing impact of ASEAN. In 2018, East and Southeast Asia accounted for approximately 28% of the global GDP (Fig. 1.3a). The average GDP per capita of the region (Fig. 3b), however, remains below the global average except for that in four countries (Brunei Darussalam, Japan, South Korea, and Singapore), suggesting that the economics of the region are still growing rapidly and that the demands for resources for development will be further intensified. Furthermore, the countries of the region are at different stages of economic development. Cambodia and Lao PDR are still classified as least developed countries (LDCs) by the UN (UNCTAD 2021), and North Korea experiences severe food security issues. On the other hand, Japan, South Korea, and Singapore, which started their industrialization processes in the 1950s, are now ranked as having mature industries. The GDPs per capita of these countries, together with that of Brunei Darussalam, whose economy is heavily dependent on the oil industry, are higher than the global average GDP.

Rapid growth in a short period, however, has also resulted in negative outcomes. Despite the rapidity of its industrialization, developments in social infrastructure and basic social systems have lagged far behind those in many countries in the region. Asian Development Bank (ADB) (2017) reported that investment in infrastructure in the region remains too low to maintain the region's growth momentum, particularly in Southeast Asia. Poorly developed infrastructure has caused various problems, such as urban traffic, inefficient resource utilization and depletion, environmental pollution, disaster-prone economies, gender issues, insufficient education, and inequality, including poverty accompanied by uneven access to clean water, sanitation systems, and food.

1.3.3 Urbanization

Another common feature characterizing East and Southeast Asia is its rapid urbanization. Most of the countries in the region have experienced substantial urbanization. The share of the global urban population in the region has progressively increased since the 1980s, reaching approximately more than 30% as of 2020 (Fig. 1.4). The notable increase in the urban population in this region is mainly attributed to the rapid economic growth of China and Southeast Asia. Furthermore, the projected trend in urbanization indicates that urban expansion in the region will be further accelerated. The UN Environment predicted that ASEAN cities will add 250 million new urban residents between 2015 and 2050. In China, the projected urban population by 2050 will exceed 1 billion (UN Environment 2018).

Not surprisingly, the region holds some of the world's well-known megacities, including Beijing, Seoul, Shanghai, and Tokyo in East Asia and Bangkok, Ho Chi Minh, Jakarta, Manila, and Kuala Lumpur in Southeast Asia. The historical and projected populations of the megacities in East and Southeast Asian countries from 1950 to 2030 (UNDESA 2021) are shown in Table 1.2. The projection suggests that the urban areas of these megacities except those in Japan will further expand, creating a large gap between the megacities and surrounding areas.

Although this rapid industrialization and urban growth have propelled economic development in East and Southeast Asia, it has also resulted in risks and challenges for the region. Unplanned urban expansion has had negative impacts on the surrounding agricultural areas, resulting in the loss of crop production in some countries (e.g., China and the Mekong Delta of Vietnam). Due to rapid industrialization and population growth, the concentrated use of fossil fuel has resulted in high levels of air pollution. Furthermore, poor management of urban wastes has exacerbated water and land pollution (UN Environment 2018). Without proper mitigation and adaptation measures, urban zones are the most vulnerable to natural disasters and climate change in terms of the number of affected people. This is of critical concern to many cities in East and Southeast Asia that are experiencing an increasing number of extreme climate events and natural disasters.

In fact, the security of the urban environment in East and Southeast Asia highly depends on securing water, energy, and food resources. Amid the growth of the urban population, the urban demands for energy, food, and water are notably rising, but the current investment in urban systems in the region has not met this highly increasing demand. Globally, cities are responsible for more than 70% of greenhouse gas emissions and more than 90% of water withdrawals, yet cities only produce less than 10% of their food, thus relying on water, energy, and food from external sources (Ramaswami et al. 2016). Such gaps between demands and investments have further exacerbated urban insecurity, resulting in cities having large environmental footprints. Recent studies on the urban nexus in East and Southeast Asia, therefore, have focused on analysing the following factors: (1) urban demands and resource efficiency, (2) the impact of rapid urbanization on rural supply and transboundary footprints, (3) the process of decoupling growth with resource consumption, and (4) mechanisms to improve urban resource efficiency and achieve a circular economy through advanced management, governance, and technology (Taniguchi 2011; Taniguchi et al. 2017).

1.3.4 Water, Agriculture, and Energy Demand-Growing Recognition of WEF Nexus Security

In East and Southeast Asia, the social and economic benefits of water security are of particular importance to the region's economy. For example, agriculture is the key to the general economic development of the region, particularly in many developing countries. See Fig. 1.5 in Annex for the net contribution of agriculture, forestry, and fishing to the GDP of East and Southeast Asian countries. Comparisons with the world average contributions to GDP clearly show that despite the general decline in the GDP contribution from the agricultural sector, the economies of most countries in the region depend highly on agricultural productivity, especially in Myanmar, Cambodia, Lao PDR, and Vietnam (Fig. 1.5a). This scenario has resulted in substantial increases in the consumption of freshwater in the agricultural sector mainly for irrigation purposes (Fig. 1.5b). Intensive water consumption for irrigation largely occurs in the Mekong Region (Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam), with agricultural water withdrawal accounting for more than 90% of total water usage (FAO 2021). This indicates that the water resource availability of the region has a profound impact on food security and global food trade; thus, the strong interlinkage between water and food needs to be highlighted from the WEF nexus perspective.

Energy security in East and Southeast Asia is also closely linked to water security and vice versa. Energy is required for the provision of water services, and water resources are equally essential in the production of energy (WWAP 2014). For example, a global analysis of water demands for energy supply showed that coal and conventional oil require approximately 10^3–10^4 L of water per toe (tonnes of oil equivalent; 1 toe is equivalent to 11.63 MWh or 41.9 GJ), whereas conventional gas usually consumes 1–10^3 L of water per toe for consumption and withdrawal (WWAP 2014). Biofuels such as soybean, corn, and sugar cane require intensive amounts of water, ranging from approximately 10^3 to 10^6 L of water per toe. In addition, water demand for power generation has accounted for the increasing share of global water consumption and withdrawal. Water is used directly for hydropower generation and all forms of thermal power generation for cooling purposes; thus, approximately 90% of global power generation is water intensive (WWAP 2014).

In East Asia, the total primary energy supply (TPES) is met by coal, feedstock, and natural gas (Fig. 1.6), accounting for approximately 85% of the TPES as of 2017 (for more details, see Chap. 3 in this volume). Using the generally known water consumption factor for different fuel production categories in Table 1.3 (Spang et al. 2014), it was estimated that more than 7000 million m^3 of water per year could be consumed for TPES in the East Asian subregion. In Southeast Asia, the TPES from coal, oil, and natural gas was responsible for more than 70% of the subregion's primary energy supply in 2017, and the water demand for these conventional fuel oil productions was approximately 1000 million m^3 of water per year. The power supply in the region is also highly dependent on coal, oil, and nuclear power in some countries (see Chap. 3 for more details). Considering that these power generation schemes are all water intensive, the increasing risks of water resource security could seriously threaten energy security as well (WWAP 2014). This scenario also indicates that the increasing demand for energy will inevitably require more water be consumed for energy production.

East and Southeast Asia has been steadily increasing its share of renewable energy (RE), and hydropower plays an important role in generating electricity in the region. In fact, this region is known for having the largest technical potential and installed capacity for hydropower generation (WWAP 2014). In Southeast Asia, which has abundant surface water resources, RE accounts for approximately 17% of the total electricity generation, and hydropower is rapidly growing among the various types of RE sources. For example, hydropower generation has increased almost 300% during the last 10 years in ASEAN, mostly contributed by Mekong countries (Chap. 3). In East Asia, China is the world's largest hydroelectricity generating country, and hydropower currently accounts for the largest share of the country's RE. Geothermal power and biofuels are also important renewable energy sources in the region, and the generation capacity of both are highly dependent on water availability. In Southeast Asia, the increasing share of biofuel in the region's energy supply implies that the region will consume more water for the energy supplied by RE. The cost analysis required for biofuel production, particularly associated with competition for water resources, will need increasing attention (FAO 2011; Hoff 2011).

1.3.5 Climate Change

East and Southeast Asia is among the most vulnerable regions to climate change (RIMES 2021; UN ESCAP 2021). The projected climate over the region suggests that East and Southeast Asia will undergo increases in ambient temperatures, more frequent exposure to extreme weather events such as heavy rainfall and droughts, and sea-level rise. The region is mostly exposed to weather-related disasters, including floods, storms, and landslides. The increasing frequency of extreme heat and droughts is also notable, possibly due to climate change.

The climate risk index (CRI) for the countries in East and Southeast Asia (except for North Korea) between 2000 and 2019 is shown in Table 1.4. According to Eckstein et al. (2021), the climate risk index was defined as the weighted sum of average fatalities, average fatalities per 100,000 inhabitants, average economic loss, and average loss per unit GDP. The table reveals that five countries in the region (Cambodia, Myanmar, the Philippines, Thailand, and Vietnam) were ranked as having the highest CRI value (within the top 10% of the global ranking), followed by China, Mongolia, Lao PDR, and Japan. On the other hand, Brunei Darussalam and Singapore were listed as the countries with the fewest fatalities and the least damage.

The consequences of climate change impacts on East and Southeast Asia are severe. Global estimates revealed that between 2000 and 2019, over 475,000 people in the world lost their lives as a direct result of more than 11,000 extreme weather events, and the economic losses totalled approximately USD 2.56 trillion in PPP (Eckstein et al. 2021). With increases in extreme rainfall, developing countries in this region have been hit hardest due to their low capacity to cope with such disasters. The ADB reported that the average total annual losses due to climate-related natural disasters accounted for 0.44% of the GDP in Cambodia, 0.27% of the GDP in Lao PDR and Myanmar, and 0.19% of the GDP in Thailand between 2000 and 2019 (Beirne et al. 2021). The damage caused by the 2011 flood in Thailand was estimated to be 10.9% of its GDP, and the cyclone in 2008 caused significant economic damage in Myanmar (12.6% of GDP) (Beirne et al. 2021).

Increased flooding will also seriously threaten coastal areas, especially heavily populated delta regions such as the Mekong Delta of Vietnam. Despite its high vulnerability to climate change, Southeast Asia is lagging behind in terms of its climate mitigation measures. East Asia is also quite vulnerable to some impacts of climate change, particularly those associated with sea-level rise, cyclones, and flooding. Three cities in East Asia (Guangzhou and Shanghai in China and Osaka/Kobe in Japan) rank among the top 10 in the world in terms of the current population exposed to these disasters (Westphal et al. 2013).

Climate change is closely linked to the water, food, and energy security of the region. The projected increase in precipitation together with greater seasonal variation and more severe extreme weather events will exacerbate the frequency and severity of floods and decrease freshwater availability in many parts of East and Southeast Asia. Inland areas in the region, such as the central part of China, will undergo more droughts and higher daytime temperatures. In Southeast Asia, the increasing frequency of flooding and storms will directly affect water security.

Furthermore, climate change will pose a direct and significant threat to food security by reducing crop yields. Increasing variation in the seasonal pattern of runoff will require more agriculture-related infrastructure (irrigation, dams, etc.). In East Asia, seasonal and interannual water availability due to climate change is the major issue related to securing agricultural productivity. There is a particular concern regarding the increased frequency of droughts, which will be seriously exacerbated by the increased water demands for crop yields. In Mongolia, the increased frequency of droughts and extreme cold weather have led to major losses of livestock (Westphal et al. 2013). The rising temperatures and risks of weather variability will also create an increased burden on the energy supply, including transportation, electricity, and related sectors.

Energy security also has a direct impact on climate change and vice versa. Globally, energy sectors are the main contributors to greenhouse gas emissions. The region was responsible for approximately 38% of the world's energy-related greenhouse gas emissions in 2018 (IEA 2020). The historical plot (Fig. 1.7a) suggests that energy-related CO_2 emissions have grown steadily in the region, driven primarily by population growth, rising standards of living, and growing reliance on fossil fuels for energy supply. This scenario implies that energy security is strongly tied to climate change impacts and that the nexus between energy and other resource sectors (e.g., water and food) could be even more complicated when considering climate change impacts.

In addition to the energy-related sector, which is the largest contributor to global greenhouse gas emissions, the input of greenhouse gases (methane, nitrous oxide, etc.) from agriculture accounts for its considerable contribution to climate change. East and Southeast Asia is responsible for approximately 25% of the world's agriculture-related greenhouse gas emissions (Fig. 1.7b).

1.3.6 Transboundary Rivers and Context

Rivers have been a source of freshwater and food since prehistory, and rivers are currently considered a source of hydropower and energy that can meet the rapid rise in energy demand for industrialization and economic growth. With multiple benefits of rivers and given their transboundary nature across borders, introducing the nexus as an approach in a transboundary context has received increasing attention from academia, policymakers, and practitioners (Keskinen et al. 2016). The strong linkage between WEF elements and their direct impacts on water allocation indicate that the nexus approach could support an efficient resource utilization strategy and harmonized resource management in transboundary river basins.

Among the world's famous transboundary rivers is the Mekong River, which is part of Southeast Asia. The Mekong River Basin covers 795,000 km^2 and stretches approximately 2600 km across Southeast Asia from the Tibetan Plateau to the South China Sea (MRC 2003). The basin incorporates six different countries (Lancang River in China and the Mekong River in Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam), and it is known as one of the largest river basins in the world. Other than its large scale in terms of basin size and volume of water flowing through it, the river presents an interesting case for a WEF nexus analysis due to its large contribution to the region's water, food (rice and fisheries) and energy security. Historically, the abundant availability of water from the Mekong River has enabled the region to become one of the largest rice producers in the world, with a significant contribution to the region's economy (MRC 2003). The Mekong River system also hosts one of the most diverse and prolific freshwater capture fisheries in the world, which includes 1148 species of fish (MRC 2019). These water-related activities have been an important part of the region's economy and the basis of livelihoods and food security for millions of people (MRC 2010).

With rapid industrialization and increased demand for energy, hydropower development in Mekong has significantly increased, opening a new dimension for river governance. The Mekong River is famous for its large hydropower potential; consequently, many dams are currently under operation or have plans for their construction. In 2019, the number of hydropower projects in the lower basin was 89, with 12,285 MW of total installed capacity, and 44 dams were in the planning stage to be in operation by the 2040s. In the upper basin, China has constructed 11 hydropower dams, and 11 dams are being planned or constructed (MRC 2021). Among the six countries, China and Lao PDR account for a large share of hydroelectric development, and in Lao PDR, these hydropower dams are built to generate revenue by exporting electricity to neighbouring countries (Keskinen et al. 2016).

Hydropower development in the Mekong River has had both positive and negative consequences in relation to WEF security. Hydropower power plants have generally improved the energy security of the region and contributed to the stable supply of irrigation water with less seasonal variation. Improved flood management and drought relief are other important benefits of these dams. According to MRC (2018), the lower Mekong Basin expects an economic gain from hydropower development of more than 160 billion USD by 2040. However, dams have also affected sediment and nutrient transport and fish migration, causing a decrease in fisheries and aquaculture. The estimated decline in fisheries due to hydropower dams will be approximately 23 billion USD by 2040, and the loss of forests, wetlands, and mangroves may cost up to 145 billion USD (MRC 2018).

Recently, increasing attention has been given to better understanding the linkage between nexus elements and their socioeconomic implications in the Mekong River (Smajgl and Ward 2013; Keskinen et al. 2015; Pittock et al. 2016; Gao et al. 2021; Wang et al. 2021). As regional coordination mechanisms, the Mekong River Commission (MRC) has provided a platform for discussing WEF nexus states and governance strategies (MRC 2012). However, the structural complexity of the nexus links and the lack of interministerial, intersectoral, and intergovernmental collaboration in the region still make the proper implementation of nexus governance challenging (Lebel et al. 2020).

1.3.7 China's Impact

China is playing a growing and important role in the world economy. China is the largest exporter of goods and services (in current USD terms) and the second largest importer in the world (World Bank 2021). It is one of the fastest growing economies with the world's largest population (18% of the world's population as of 2019). For example, China's share of the world's GDP, in purchasing power parity (PPP), was approximately 3.2% in 1990, whereas the country is now the second largest contributor to the world's GDP (16.3% as of 2019; World Bank 2021).

China has a substantial impact on its neighbouring countries, particularly the East and Southeast Asian regions. Due to its geographical proximity, China and its neighbouring countries have long shared historical and cultural ties. Under the rapid growth of China's economy since the 1980s, the impact of China on East and Southeast Asia has grown markedly in both positive and negative ways. Table 1.5 shows the trade balance of 14 countries in East and Southeast Asia with China. A comparison of the data between 2000 and 2019 revealed that China's influence on the region's economy has sharply increased, and now, China is the largest partner for all 14 countries in terms of both export and import values (in million USD). The data clearly indicate that all economies in this region largely depend on their economic trade with China and vice versa.

China's influence on the region's WEF nexus security requires greater attention and needs to be highlighted. In general, China's extensive consumption of natural resources and production have posed new environmental challenges to surrounding countries. With the largest population in the world and intensive agricultural activity, China is the second largest freshwater consumer in the world (followed by India) (World Bank 2021). Global virtual water analysis of agricultural products (soybean, rice, etc.) revealed that China plays a key role in determining the world's virtual water flow (Hoekstra and Hung 2002). Approximately 73% of China's primary energy is derived from fossil fuel energy (as of 2016), which has led to increased freshwater stress from the energy sector (Niva et al. 2020), as well as shared environmental concerns with its neighbouring countries (Otsuka 2018). The development of renewable energy sources such as hydropower dams in a transboundary river could affect water resource security in downstream countries, and extensive groundwater utilization to meet the water demand would result in transboundary aquifer management issues (Lee et al. 2018).

China's effort to integrate the economies of the region is ongoing. China's Belt and Road Initiative (BRI) is one of the examples that demonstrate China's increasing impact. The BRI launched in 2013 and was initiated by China as an ambitious global infrastructure development project. The BRI involves large-scale investment and infrastructure projects that aim to promote connectivity and cooperation between China and the rest of the world (Zeng 2019). Geographically, the belt includes several different routes, one of which connects China through Southeast and South Asia to the Indian Ocean and the other includes the maritime route that runs from China's coastal ports to the Indian Ocean (Huang 2016). The initiative involves at least 60 countries, which account for 30% of the global GDP and 64% of the world's population (Huang 2016).

Since its first inception in 2013, the BRI has drawn tremendous global attention. The impact of the BRI affects the global community. Analysts, scholars, and policymakers expect the BRI to be part of extended Chinese economic and political influence. The project arguably provides a new economic corridor for different regions and strengthens physical and economic connectivity among these economies. In comparison to other regions, the increasing influence of China in East and Southeast Asia will be more direct and transmissible. This implies that the impact of economic integration on WEF nexus security is likely to have multidimensional impacts in East and Southeast Asian regions and requires in-depth analysis.

1.3.8 COVID-19 Pandemic and the Aftermath

Work on this volume started much before the outbreak of the COVID-19 pandemic globally. It is necessary that we also note the developments in the aftermath of the pandemic in the region and the implications of the pandemic for the WEF nexus. Since the first outbreak in 2019, the COVID-19 pandemic has engulfed the entire world and been a serious concern for many countries, their populations, the economy, and security. As of September 2021, there have been approximately 232 million confirmed cases of COVID-19 and more than 4.7 million deaths. Figure 1.8 shows the COVID-19 cases for East and Southeast Asia as of September 26th, 2021. A comparison with world data shows that the cumulative number of confirmed cases in the region was approximately 6.17% of the global cases.

The COVID-19 pandemic affects basic supply sectors, including water, energy, and food. Media and scientific research have found a casual relation between COVID-19 and the individual WEF sectors (Durodola et al. 2020; Al-Saidi and Hussein 2021). Whereas WEF nexus studies are mostly oriented towards water-centralized nexus relations, recent studies on pandemics have shown that the food sector has been most strikingly influenced by COVID-19 (Durodola et al. 2020; Calder et al. 2021). For example, changes in food consumption patterns associated with social distancing and lockdowns have disrupted both the food supply/demand system and localized food shortages (Calder et al. 2021). Calder et al. (2021) noted that most major infectious diseases throughout history have been zoonotic and emerged in conjunction with animal farming. As a result of travel restrictions and economic downsizing, many people (low-income households in particular) have lost their jobs and are suffering from food insecurity. In addition to the disruption in food security, the COVID-19 pandemic also has many casual relations with water and energy. A lack of household drinking water and congregation around community water sources impede physical distancing, especially in developing countries (Calder et al. 2021).

Increased hygiene practices and biomedical waste collection increase the water and energy demand (Al-Saidi and Hussein 2021). At the same time, a reduction in regular mobility and travel restrictions have decreased energy and water demand. Roidt et al. (2020) presented an interesting case study on this topic, demonstrating that the consumptive water footprint of thermal power plant operation in Europe decreased by 1.77×10^6 m^3/day during the lockdown compared to the average over the past four years, and this scenario was partly caused by the reduced electricity demand. The lockdown also affected the virtual water transfer associated with electricity for several countries, such as Italy (Roidt et al. 2020).

The catastrophic impacts of COVID-19 could be more severe for the least-developed countries that have insufficient infrastructure to address various disasters. This factor indicates that many countries in East and Southeast Asia are vulnerable to the pandemic because many economies in the region still lag behind in terms of their social infrastructure and protection systems. Furthermore, the economic openness of the region could make the region even more vulnerable to supply chain disruption (UN 2020).

It is important to note that the risk of COVID-19 is higher for low-income households that are highly represented in labour sectors. Limited economic activities could expose billions of people worldwide to WEF insecurity (Calder et al. 2021). Abundant global datasets have shown that in comparison to other entities, vulnerable communities, groups, and individuals are exposed to higher levels of health risks and economic challenges, and they often lack access to health services and are left out of formal policy and social protection measures (UN 2020).

Current methods to investigate the impact of pandemics on social systems and resource security are inadequate (Calder et al. 2021). Although some interesting studies have shown the causal relation between COVID-19 and WEF security, there have thus far been few holistic analyses on the cross-sectoral impacts of pandemics (Al-Saidi and Hussein 2021). The stress on the WEF sector during the pandemic has clearly shown that water, energy, and food supply all depend on labour and capital inputs; thus, future studies on this topic should be devoted to determining the interlinkage among the connections of the WEF-human health economy in an integrated manner (Calder et al. 2021).

Finally, the COVID-19 crisis offers an opportunity for reflection on management and governance responses across the WEF nexus sectors. The gaps revealed during the crisis have raised awareness among global communities on the significance of sustainable resource production systems and the need for risk-based perspectives in policy-making and decision-making. A quantitative risk trade-off framework and synthesized analysis tools could improve decision-making and resilient WEF planning (Calder et al. 2021).

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Annex: Supplementary Figures and Tables for This Chapter

See Figs. 1.3, 1.4, 1.5, 1.6, 1.7, 1.8 and Tables 1.1, 1.2, 1.3, 1.4 and 1.5.

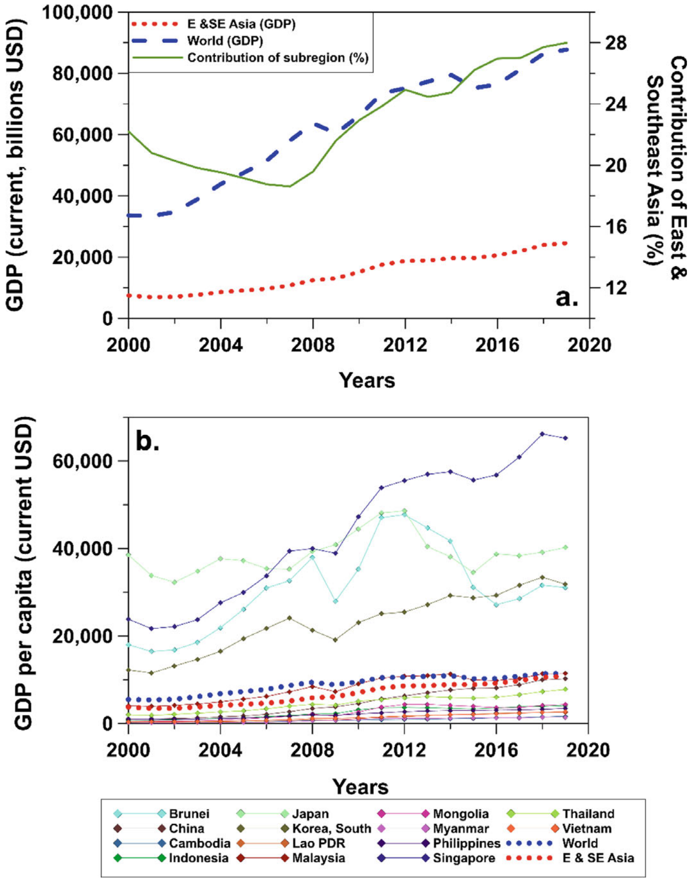

Fig. 1.3 **a** Growth of gross domestic product (GDP), and **b** GDP per capita in East and Southeast Asia (*Source* World Bank 2021) adapted by the author

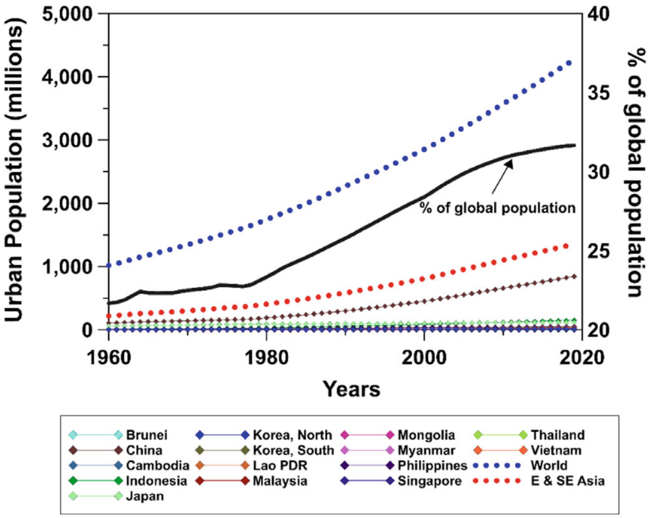

Fig. 1.4 Historical increase in the urban population in East and Southeast Asian countries and the share of the urban population in the region in relation to the global urban population (*Source* World Bank 2021) adapted by the author

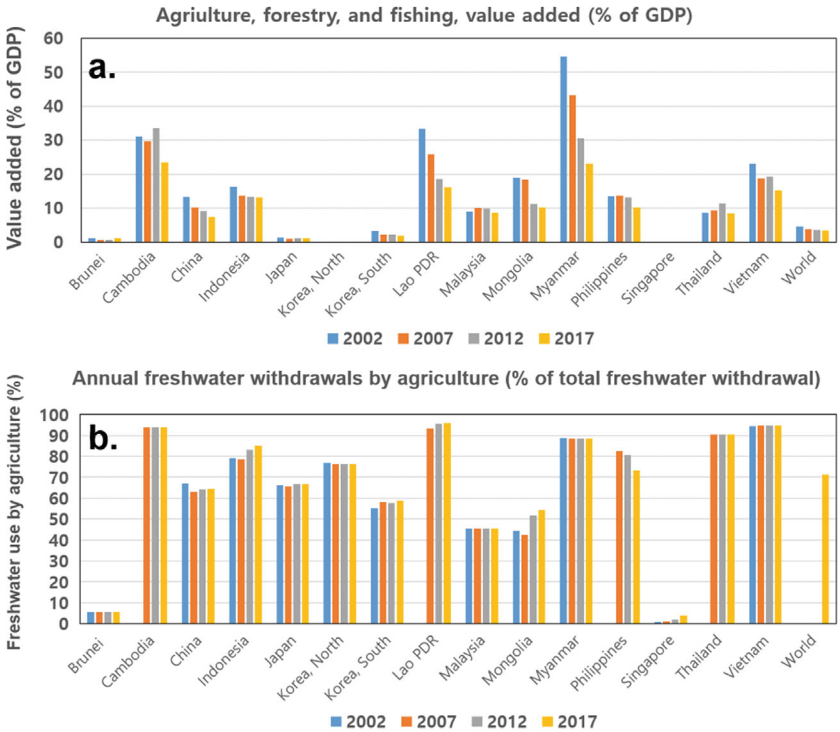

Fig. 1.5 **a** Contribution of the agricultural sector to national GDP, and **b** freshwater withdrawal rates by agricultural sector. Empty bar indicates data unavailable (*Source* FAO 2021) adapted by the author

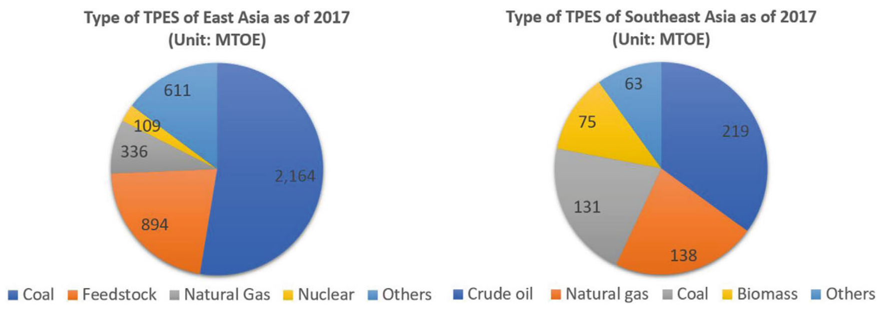

Fig. 1.6 Types of TPES in East and Southeast Asia as of 2017

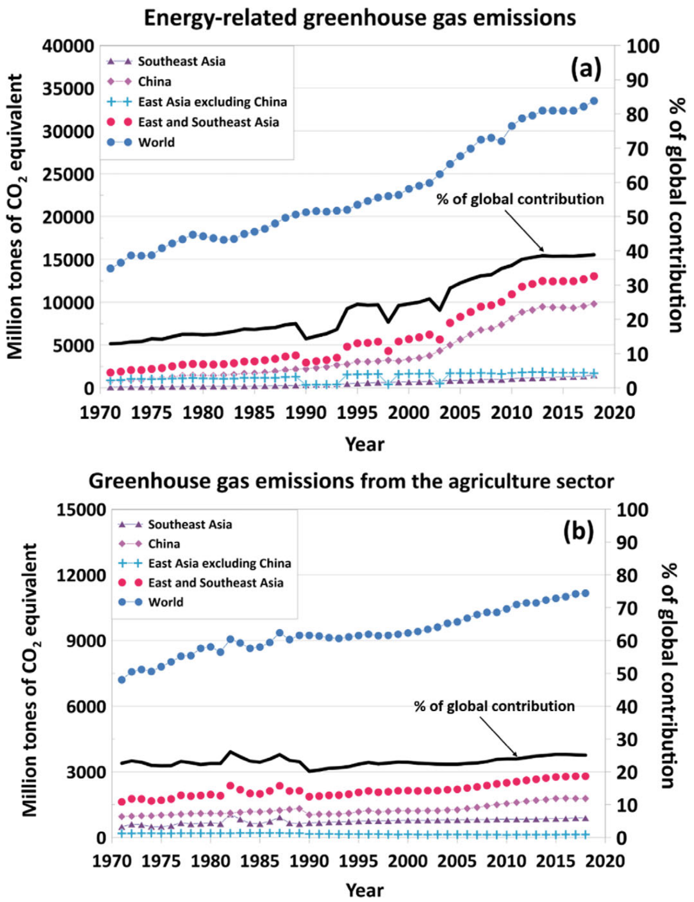

Fig. 1.7 Historical plot of greenhouse gas emissions in East and Southeast Asia from **a** energy (*Source* IEA 2020), and **b** agricultural sectors (*Source* World Bank 2021) adapted by the author

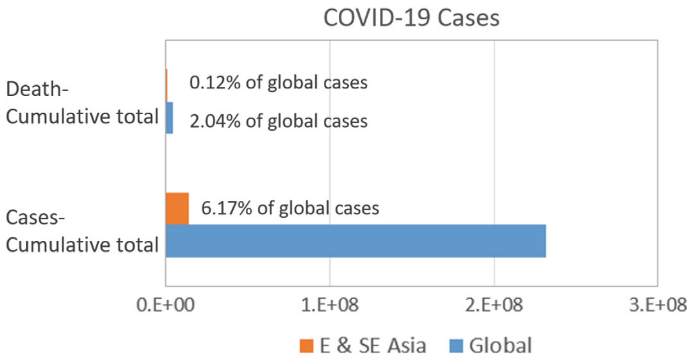

Fig. 1.8 Coronavirus (COVID-19) cases in East and Southeast Asia and a comparison with world cases as of September 26th, 2021 (*Source* WHO 2021) adapted by the author

Table 1.1 Political stability and absence of violence and terrorism estimates for East and Southeast Asia

Region	Country	1996	2000	2004	2008	2012	2016	2019
Southeast Asia	Brunei Darussalam	1.24	1.30	1.37	1.13	0.91	1.15	1.17
	Cambodia	−1.10	−0.78	−0.41	−0.30	−0.10	0.21	−0.08
	Indonesia	−1.13	−2.00	−1.91	−1.06	−0.59	−0.37	−0.48
	Lao PDR	0.37	−0.58	−0.61	0.02	0.03	0.53	0.53
	Malaysia	0.57	0.09	0.35	0.11	−0.01	0.14	0.11
	Myanmar	−1.26	−1.67	−0.99	−1.09	−0.94	−0.80	−1.26
	Philippines	−0.48	−1.39	−1.71	−1.78	−1.19	−1.38	−0.88
	Singapore	1.12	1.14	1.09	1.35	1.37	1.50	1.53
	Thailand	0.47	0.46	−0.72	−1.27	−1.22	−0.99	−0.54
	Vietnam	0.53	0.41	0.15	0.16	0.27	0.23	0.13
East Asia	China	−0.10	−0.21	−0.39	−0.49	−0.54	−0.50	−0.24
	Japan	1.16	1.20	1.03	0.89	0.95	0.98	1.04
	Korea, North	−0.50	−0.01	0.22	0.52	−0.01	−0.68	−0.30
	Korea, South	0.57	0.40	0.43	0.42	0.27	0.16	0.48
	Mongolia	0.75	0.82	0.77	0.54	0.47	0.80	0.64
North America	United States	0.94	1.08	−0.23	0.59	0.63	0.40	0.30
Europe	Germany	1.29	1.41	0.64	0.95	0.78	0.68	0.58
	Sweden	1.46	1.58	1.23	1.22	1.42	1.31	1.34
	Switzerland	1.46	1.39	1.36	1.13	1.17	1.02	1.05
Central Asia	Afghanistan	−2.41	−2.44	−2.30	−2.69	−2.42	−2.67	−2.65

Note Political stability and absence of violence/terrorism measure perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism. An estimate provides a country's score on the aggregate indicator, in units of a standard normal distribution, ranging from approximately −2.5 to 2.5 (*Source* World Bank 2021) adapted by the author

Table 1.2 Historical and projected populations of megacities in East and Southeast Asian countries from 1950 to 2030 (thousands)

Country	Urban agglomeration	1950	1970	1990	2000	2020	2030
Brunei Darussalam	Brunei-Muara	–	–	–	–	279	–
Cambodia	Phnom Penh	364	900	615	1149	2078	2805
China	Shanghai	4288	6052	8606	14,247	27,058	32,869
	Beijing	1671	4426	6788	10,285	20,463	24,282
	Chongqing	1567	2237	4011	7863	15,872	19,649
	Tianjin	2467	3318	4558	6989	13,589	15,745
	Guangzhou, Guangdong	1049	1542	3246	7812	13,302	16,024
	Shenzhen	3	22	875	6550	12,357	14,537
	Chengdu	646	1750	2955	4607	9136	10,728
Dem. People's Republic of Korea	Pyongyang	516	987	2526	2777	3084	3345
Indonesia	Jakarta	1452	3915	8175	8390	10,770	12,687
	Bekasi	14	92	624	1622	3394	4332
Japan	Tokyo	11,275	23,298	32,530	34,450	37,393	36,574
	Osaka	7005	15,272	18,389	18,660	19,165	18,658
	Nagoya	2237	6603	8407	8740	9552	9407
Lao PDR	Vientiane	30	157	283	442	683	861
Malaysia	Kuala Lumpur	262	451	2098	4176	7997	9805
	Johor Bahru	47	136	417	630	1024	1224
Mongolia	Ulaanbaatar	70	298	572	765	1584	1841
Myanmar	Yangon	1302	1946	2914	3573	5332	6389
	Mandalay	167	374	648	847	1438	1757
Philippines	Manila	1544	3534	7973	9958	13,923	16,841
	Davao City	124	395	854	1152	1825	2256
Republic of Korea	Seoul	1021	5312	10,518	9879	9963	10,163
	Busan	948	1813	3778	3673	3465	3532
Singapore	Singapore	1016	2072	3013	3914	5935	6342
Thailand	Bangkok	1360	3110	5889	6395	10,539	12,101
	Chon Buri	27	40	167	577	1399	1580
Vietnam	Ho Chi Minh	1213	1970	3038	4389	8602	11,054
	Ha Noi	261	617	1139	1660	4678	6362

Source UNDESA (2021) adapted by the author

Table 1.3 Fuel production categories with water consumption factors

Energy category	Subcategory	Water consumption factor (m^3/GJ)		
		Estimate	Min	Max
Fossil fuel	Coal	0.043	0.006	0.242
	Conventional oil	0.081	0.036	0.140
	Oil sands	0.114	0.072	0.132
	Oil refining	0.040	0.026	0.048
	Conventional gas	0.004	0.001	0.027
	Shale gas	0.017	0.003	0.221
Nuclear fuel	Uranium mining	0.033	0.000	0.252
	Milling	0.012	0.003	0.030
	Conversion	0.011	0.004	0.014
	Diffusion	0.037	0.034	0.039
	Centrifuge	0.004	0.003	0.006
	Fuel fabrication	0.001	0.001	0.003
	Fuel reprocessing	0.007	0.007	0.007
Biofuel processing	Ethanol	0.145	0.092	0.290
	Biodiesel	0.031	0.031	0.031
Biofuel cultivation	Sugarcane	24.550	0.000	156.000
	Maize	8.090	0.000	554.000
	Sugar beet	9.790	0.000	157.000
	Rapeseed	19.740	0.000	270.000
	Soybean	11.260	0.000	844.000

Note Details on the data source and methodology are described in Spang et al. 2014 adapted by the author

Table 1.4 Climate risk index (CRI) of East and Southeast Asia for 2000–2019

CRI rank	Country	CRI score	Average fatalities 2000–2019 (rank)	Average fatalities per 100,000 inhabitants 2000–2019 (rank)	Average losses in millions of USD (PPP) 2000–2019 (rank)	Average losses per unit GDP in % 2000–2019 (rank)
176	Brunei Darussalam	167.5	167	151	178	179
14	Cambodia	36.17	38	35	53	28
41	China	56.33	5	106	1	60
72	Indonesia	74.0	59	48	65	112
57	Japan	64.83	21	90	4	92
91	Korea, South	85.17	49	101	24	118
52	Lao PDR	60.5	82	66	73	38
116	Malaysia	105.67	64	108	66	144
48	Mongolia	59.17	88	46	83	46
2	Myanmar	10.0	1	1	19	19
4	Philippines	18.17	7	16	8	31
179	Singapore	172.0	172	172	162	177
9	Thailand	29.83	22	60	3	17
13	Vietnam	35.67	15	47	11	47

Note CRI Score = average fatalities × 1/6 + average fatalities per 100,000 inhabitants × 1/3 + average losses in millions of USD × 1/6 + average losses per unit GDP × 1/3
Source Eckstein et al. (2021) adapted by the author

Table 1.5 Export and import values for trade with China for 14 counties in East and Southeast Asia

Country	Trade with China (2000)				Trade with China (2019)			
	Export (USD million)	Import (USD million)	Export share to China (%)[a]	Import share to China (%)[a]	Export (USD million)	Import (USD million)	Export share to China (%)	Import share to China (%)
Brunei Darussalam[b]	147.6	92.5	4.2	8.4	455.0	707.4	6.5	13.9
Cambodia	290.5	372.7	20.9	25.9	1253.0	8127.7	8.5	40.1
Indonesia	4321.9	2364.3	7.0	7.1	30,463.6	48,156.6	18.2	28.1
Japan	57,565.4	56,773.6	12.0	15.0	168,303.8	171,284.8	23.9	23.8
Korea, South	29,162.6	14,059.4	16.9	8.8	168,108.5	108,992.5	31.0	21.7
Korea, North	83.7	519.3	–	–	215.5	2588.9	–	–
Lao PDR[c]	230.7	186.0	12.1	10.1	1731.0	1713.1	29.8	29.6
Malaysia	7463.5	5494.2	7.6	6.7	49,753.7	45,753.8	20.9	22.3
Mongolia	274.3	125.8	51.2	20.5	6779.5	2050.0	89.0	33.5
Myanmar[b]	–	402.3	–	13.9	6084.8	6461.9	33.6	34.7
Philippines	2570.6	2226.7	6.7	6.0	19,439.3	30,527.1	27.4	26.0
Singapore	16,218.5	10,626.6	11.8	7.9	95,996.5	52,524.8	24.6	14.6
Thailand	6291.5	4252.4	9.1	6.9	39,031.0	48,417.1	16.7	22.3
Vietnam	1852.3	1998.5	12.8	12.8	48,595.8	76,908.5	18.4	30.3

Source WITS (2021) adapted by the author
[a]Trade share for each country was defined as the trade value (import/export) divided by the total trade value of each country (in USD millions)
[b]Trade data for Brunei and Myanmar in 2000 were unavailable, and data for 2001 were used instead
[c]Trade data for Lao PDR in 2000 were unavailable, and data for 2010 were used instead

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Chapter 2
Status of Water Security in East and Southeast Asia

Eunhee Lee, Kwansue Jung, and Ramasamy Jayakumar

Abstract In this chapter, the water security status in East and Southeast Asia is investigated by examining some important dimensions associated with water issues. First, the water availability and water use pattern are reviewed and the socioeconomic implication of water resources is analysed in the region. Next, the concept of "water security" and several frameworks that assess, rank, and compare the national water security status of East and Southeast Asian countries are reviewed. This chapter also reviews the progress of SDG 6 in the region and major regional challenges in relation to water security issues, including access to clean water and sanitation, water shortages, water quality, environmental water flow, water-related disasters, and transboundary water. Finally, the chapter ends by presenting good practices in the region towards regional water security.

Keywords Water security · East Asia · Southeast Asia

2.1 Introduction

Water plays a pivotal role in the economic and social development of East and Southeast Asia. Many countries in this region are heavily dependent on water resources for socioeconomic development. Moreover, water provides a basic function for

E. Lee (✉)
Korea Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, Republic of Korea
e-mail: eunheelee@kigam.re.kr

K. Jung
Chungnam National University, Daejeon, Republic of Korea
e-mail: ksjung@cnu.ac.kr

R. Jayakumar
The United Nations Educational, Scientific and Cultural Organisation, Paris, France
e-mail: r.jayakumar@unesco.org

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sustaining lives and maintaining the natural environment. Accordingly, the security of water resources has emerged as one of the top priorities in this region in terms of both environmental and socioeconomic aspects.

East and Southeast Asia has an uneven distribution of water resources and water use conditions, caused by the large range of climates encountered in the region (FAO 2003). Mainland Southeast Asia is mainly governed by seasonal changes between humid and hot summers and relatively cool and dry winters. The majority of the total annual rainfall in this subregion occurs during the wet season, resulting in large seasonal differences in river flow, flooding, and available water resources. The islands in Southeast Asia experience tropical and monsoonal climates characterized by uniform temperature and high humidity. The subregion is liable to experience extensive flooding and typhoon damage, mainly from June to September. Meanwhile, in East Asia, most of the subregion shows four distinct seasons, marked by summer monsoon and cold, dry winter. On the other hand, the northern and central parts of China and large parts of Mongolia suffer from an arid climate and cold winters. In addition to the large seasonal and spatial variety of hydrological regimes, differences in the level of socioeconomic development within the region have led to large variations in the level of national water security.

East and Southeast Asia are global hot spots for water insecurity (Asian Development Bank 2016). Although the region is endowed with relatively abundant water resources in general, the growing population and urbanization, coupled with seasonal variability and uneven water distribution, are causing rapid depletion and pollution of freshwater resources. The issues of water security in the region are further compounded by the increasing risks of climate and water-related disasters (i.e., droughts, and flooding) that greatly threaten people's livelihoods. Unfortunately, the infrastructures and public systems in many economies cannot meet such national and regional demands, putting the region at risk of water insecurity. The development of hydropower dams in transboundary rivers and the extensive groundwater use in transboundary aquifers have raised management issues related to shared water resources (Lee et al. 2018).

Ensuring that water is available, accessible, and safe to all is among the foremost challenges of human society. Understanding the status of water resources, major challenges, and future risks, therefore, would be the first step that we have to take in the discourse of water security. This is of particular importance in East and Southeast Asia, which has received large social and economic benefits from water resources, including agriculture. In this chapter, we explore the water security status in East and Southeast Asia by examining some key dimensions associated with water issues. First, the water availability, the water use pattern and an analysis of the socioeconomic implication of water resources in the region were reviewed. Next, the concept of "water security" and several frameworks that assess, rank, and compare the national water security status of East and Southeast Asian countries were also introduced. In the following subchapter, major regional challenges in relation to water security issues were addressed. Finally, the chapter ended by presenting good practices in the region towards attaining water security in the region.

2.2 Water Availability and Water Use

2.2.1 Distribution of Renewable Water Resources

Table 2.1 summarizes the distribution of renewable water resources in East and Southeast Asian countries as of 2018. The rainfall in the region shows an uneven distribution depending on the location and climate zone. China and Mongolia showed the least rainfall in the region, and the annual rainfalls of these two countries were 79.3 and 29.6% of the global average, respectively. Except for China and Mongolia, other countries in the region are endowed with abundant rainfall (higher than the global average), suggesting that water scarcity from the supply aspect is less serious for these economies. The total renewable water resources of 15 countries accounted for approximately 18% of the total renewable water resources worldwide.

Table 2.1 Renewable water resources in East and Southeast Asia as of 2018

Country	Rainfall (mm/year)	Total internal renewable water resources ($\times 10^9$ m^3/year)	Total internal renewable water resources per capita ($\times$ m^3/year/person)	Total renewable water resources ($\times 10^9$ m^3/year)	Total renewable water resources per capita ($\times$ m^3/year/person)
Brunei Darussalam	2722	8.5	19,815	8.5	19,815
Cambodia	1904	120.6	7421	476.1	29,299
China	645	2812.9	1927	2840.2	1946
DPR Korea	1054	37	2622	77.15	3020
Indonesia	2702	2018.7	7542	2018.7	7542
Japan	1668	430	3380	430	3380
Lao PDR	1834	190	26,963	333.5	47,228
Malaysia	2875	580	18,396	580	18,396
Mongolia	241	34.8	10,977	34.8	10,977
Myanmar	2091	1002.8	18,671	1167.8	21,743
The Philippines	2348	479	4491	479	4491
Republic of Korea	1274	64.9	1267	69.7	1362
Singapore	2497		104	0.6	104
Thailand	1622	224.5	3233.7	438.6	6317
Vietnam	1821	359.4	3761.8	884.1	9253
World[a]	813.7[a]	42,808[a]	5639	54,737[a]	7210

[a]Data for the world average were estimated by combining the country-based annual rainfall, renewable water resources, land area and population extracted from the global dataset of FAO AQUASTAT (2021) adapted by the author

Despite the relative abundance in total rainfall, comparisons of the renewable water resources per capita with the global average show a different result. The amount of renewable water resources per capita for China, the Democratic People's Republic of Korea (DPR Korea), Japan, the Philippines, the Republic of Korea, Singapore, and Thailand were lower than the global average, suggesting that water scarcity from the demand aspect is more challenging in the region. In Singapore, the availability of renewable water resources per capita is notably low (104 m^3/year/person), equalling only 1.4% of the world average.

Some countries in the region showed a considerable difference between the amounts of total internal renewable water resources and total renewable water resources as summarized in Table 2.1. The discrepancy between these two elements is more prominent in the downstream countries in the Mekong River basin (Cambodia, Thailand, and Vietnam), indicating the transboundary nature of the water resources of these countries.

Figure 2.1 shows the historical plot of total renewable water resources per capita for East and Southeast Asian countries. With rapid population growth, the renewable water resource per capita has rapidly decreased. For example, the water resource per capita of Lao PDR in 2017 was 47,228 m^3/year/person, more than three times lower than that in 1962 (150,149 m^3/year/person). With a growing population trend, the water resource per capita of the region is expected to decrease further. The situation could become more serious over the coming decades due to growing incomes, increased per capita water use, and changes in the standard of living.

2.2.2 Water Use Pattern

Figure 2.1 shows the total water withdrawal by sectors for East and Southeast Asian countries over the period between 2007 and 2017. Agriculture was the largest water consumer in the region, accounting for 64.2 and 84.8% of the total water use in the East and Southeast Asian regions, respectively. The share of agricultural water uses was the largest in Cambodia, Lao PDR, and Vietnam, while Brunei Darussalam and Singapore spent the least amount of water for agricultural activity. Industrial uses accounted for 22.0 and 7.4% of the total water consumption for the East and Southeast Asian regions, respectively, and municipal water use accounted for 13.8 and 7.8% of the total water withdrawal, respectively.

In terms of total water withdrawal, China and Indonesia were the major water consumers in the region, mainly due to the large populations of the two countries. The comparison of water withdrawal per capita, however, revealed that Lao PDR, Vietnam, the Philippines, Thailand, and Indonesia used the largest amount of water per capita (Fig. 2.3). This partially represents the high dependence of these countries' economies on water resources, as well as the limited infrastructure to enhance water use efficiency. Notably, the total water use per capita of Singapore significantly decreased, from 434.5 to 115.5 m^3/day from 2007 to 2017.

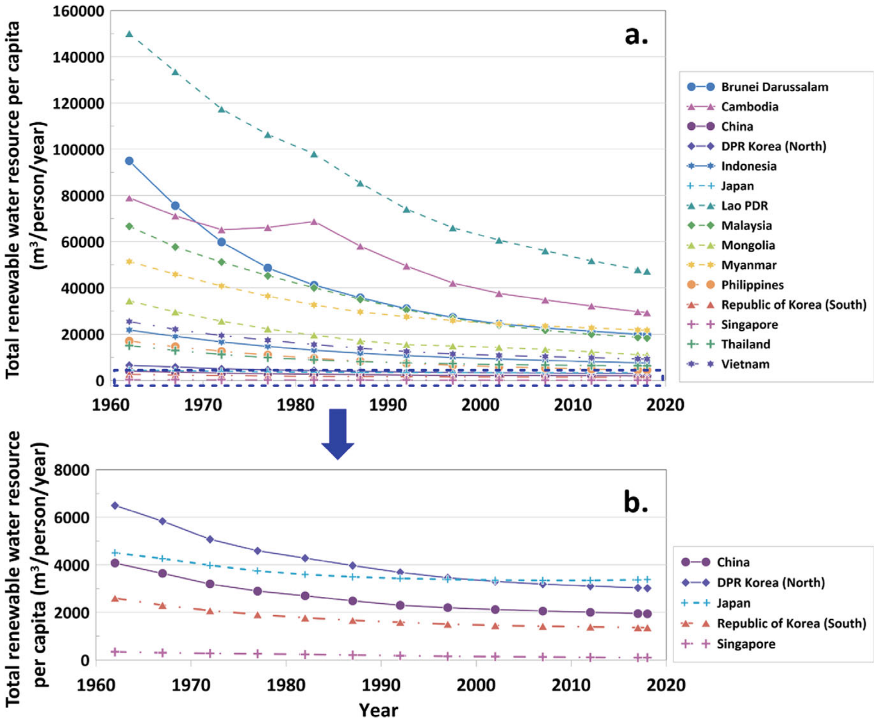

Fig. 2.1 **a** Historical plot of total renewable water resource per capita in East and Southeast Asian countries; **b** enlarged partial section for the five countries having the lowest renewable water resource per capita (*Source* FAO 2021) adapted by the author

2.3 Water Security

The meaning and definition of the term "water security" has evolved over time. Since its inception during the Second World Water Forum (2010), the concept of water security has been widely adopted by global communities, including the UNESCO International Hydrological Programme (IHP), Asian Development Bank (ADB), and World Economic Forum, and has been used to emphasize the need to manage finite water resources in a sustainable way (World Economic Forum 2011; UNESCO 2012a; Asian Development Bank 2013).

There are several definitions of water security. UN Water collected the contributions made by the broad ranges of organizations, agencies, programmes, and institutions and defined water security as "*the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability*" (UN Water 2013). It is notable that according to the definition above, the concept of water security not only lies

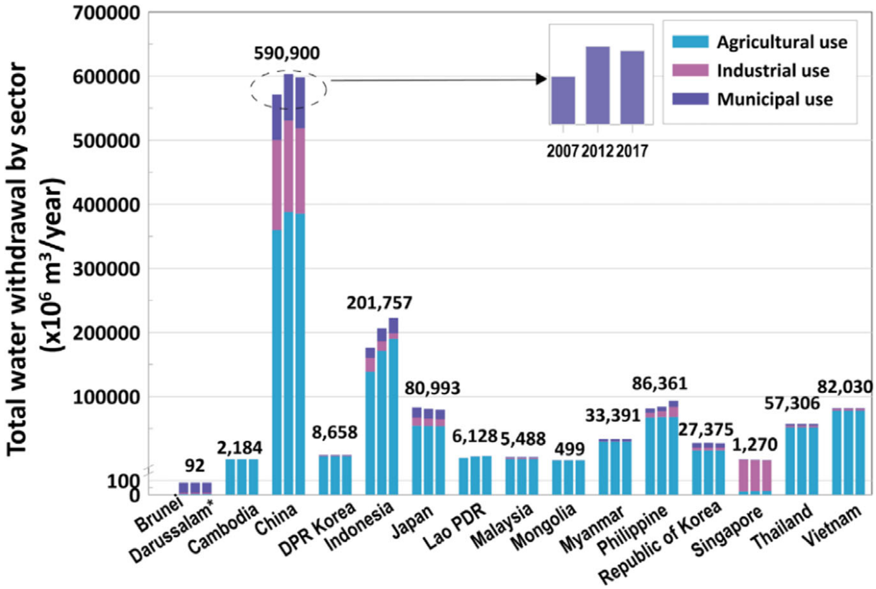

Fig. 2.2 Total water withdrawal by sector during the period between 2007 and 2017. The numbers on the top of the bars represent the average from 2007 to 2017 for each country. *For Brunei Darussalam, the industrial and municipal water represent the commercial and domestic water, respectively (*Source* DPES 2020; FAO 2021) adapted by the author

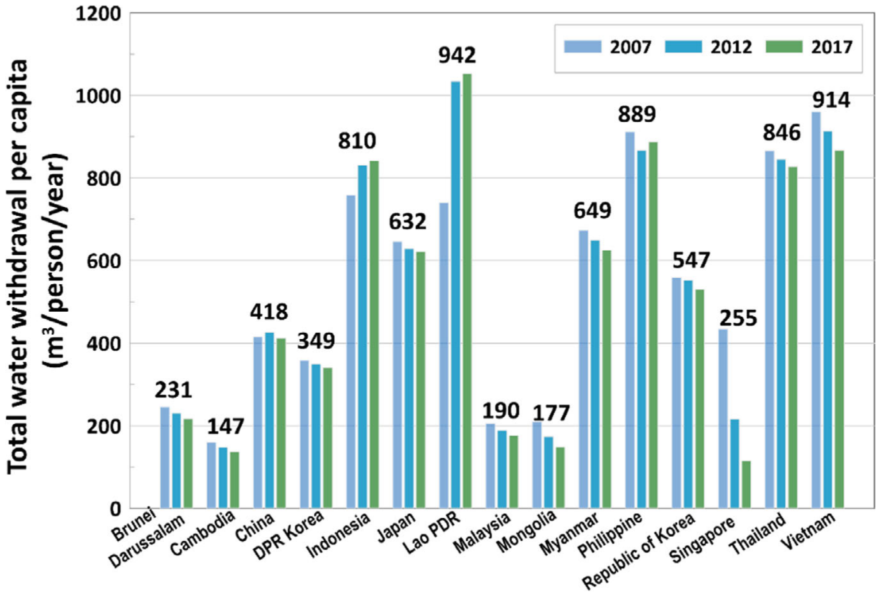

Fig. 2.3 Total water withdrawal per capita during the period between 2007 and 2017. The numbers on the top of the bars represent the average from 2007 to 2017 for each country

inside the field of water, but also includes biophysical, infrastructural, institutional, political, social, and financial aspects.

There are several key components in the water security discourse. Some core elements suggested by UN Water include (1) safe access to clean water and sanitation, (2) protection of livelihoods and human rights, (3) preservation and protection of ecosystems, (4) sufficient water supply for socioeconomic development, (5) proper treatment of used water, (6) collaborative management of transboundary water, (7) the ability to cope with water-related risks, and (8) good water governance and accountability (UN Water 2013). The frameworks to assess water security, therefore, encapsulate the dynamic and varying dimensions of water and water-related problems. Many studies have proposed different approaches to assess water security in which both physical and socioeconomic dimensions are considered (Jiang 2015; Gain et al. 2016; Park et al. 2020; Wang et al. 2020). In this section, some international and regional frameworks are introduced to examine water security, with a regional focus on East and Southeast Asia.

2.3.1 National Water Security Index (ADB)

The ADB suggests that water security means more than just providing enough water for people and economic activities, but also means maintaining a healthy aquatic ecosystem and protecting societies from water-related disasters (Asian Development Bank 2013). According to the recent Asian Water Development Outlook 2020 (Asian Development Bank 2020a), a framework to measure water security is based on five key dimensions (KDs), including rural household water security (KD1), economic water security (KD2), urban water security (KD3), environmental water security (KD4), and resilience to water-related disasters (KD5). Each KD is composed of different components, as shown in Table 2.2. Using these indicators, the ADB evaluated and compared the national water security index (NWSI) for the 50 economies in Asia–Pacific region by combining the five dimensions of water security measured by the KDs.

Figure 2.4 shows the NWSI scores proposed by the ADB for East and Southeast Asian countries except for DPR Korea (Asian Development Bank 2020a). In terms of the rural water security index (KD1), the Republic of Korea and Japan showed the highest score, followed by Brunei Darussalam, China, Malaysia, and Thailand. Rural household water security represents the level of service in terms of sufficient, safe, accessible, and affordable water and sanitation services coupled with an acceptable level of water-related risk in rural households. As expected, the advanced economies in the region showed the highest security for these indicators. On the other hand, rural household water security status for Myanmar and Lao PDR demonstrate that a significant number of households have no access to basic water supply or sanitation, and the water services are unaffordable (ADB 2020a).

In terms of the provision of adequate water for sustainably supporting a county's economic growth (KD2), Singapore, China, the Republic of Korea, and Malaysia

Table 2.2 Framework for assessing national water security proposed by the Asian Development Bank (2020a)

Key dimension (KD)	Index	Composition
NWSI	National water security	• Total of the five dimensions of water security
KD1	Rural household water security	• Access to water supply • Access to sanitation • Health impacts affordability
KD2	Economic water security	• Broad economy • Agriculture • Energy • Industry
KD3	Urban water security	• Access to water supply • Access to sanitation • Affordability drainage (flooding) environment (water quality)
KD4	Environmental water security	• Catchment and aquatic system condition index • Environmental governance index
KD5	Resilient to water-related disasters	• Climate risk (drought), hydrological risk (flood), meteorological risk (storm)

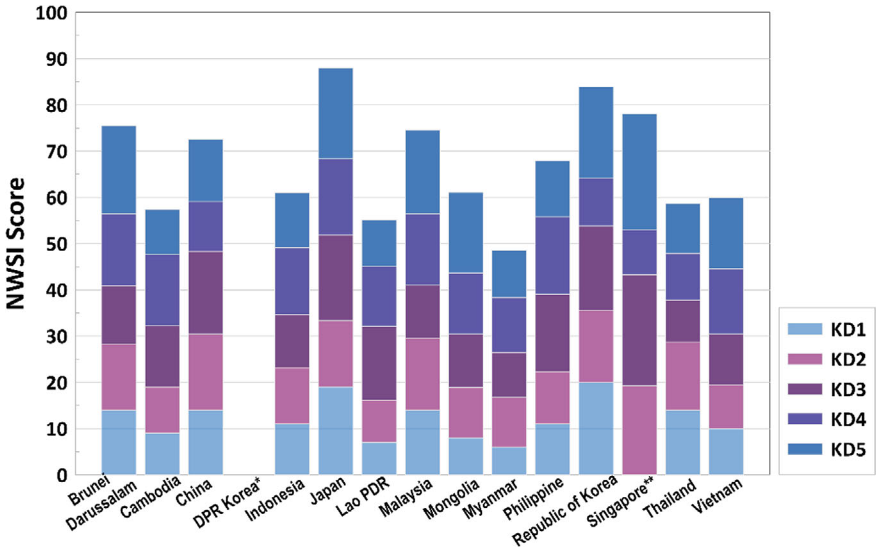

Fig. 2.4 National water security index (NWSI) proposed by ADB (2020a). The index comprises five key dimensions (KD1–KD5), the scores of which range from zero to 20. *Data for DPR Korea were unavailable. **Singapore has no applicable index for KD1. Thus, the NWSI score for Singapore was determined by multiplying the sum of KD2, 3, 4, and 5 by a factor of 5/4

had the highest scores. On the other hand, the economic water security potential for Cambodia, Vietnam, Lao PDR, Mongolia, and Myanmar was low, with few criteria being met. In the case of Mongolia, water insecurity for agricultural activity was the most challenging, while Southeast Asian countries mostly suffered from water insecurity for the energy and the industrial sectors.

The comparison of urban water security (KD3) reveals that countries of Singapore, Japan, the Republic of Korea, and China stood out with high urban water security. The lowest KD3 scores among the countries were mostly attributed to the lack of a safe water supply and sanitation system and the increasing risk of water security under rapid population growth.

The environmental water security index (KD4) was the highest in the Philippines, followed by Japan, Brunei Darussalam, Cambodia, and Malaysia, and the score was the lowest in Singapore, Thailand, the Republic of Korea, and China. This indicator reflects the health of rivers, wetlands, and groundwater systems and measures the progress in restoring aquatic ecosystems.

KD5 represents a nation's recent exposure and vulnerability to water-related disasters and its capacity to resist and bounce back. Figure 2.4 shows that advanced capacity against water-related disasters is urgently needed in Cambodia, Lao PDR, Myanmar, and Thailand, while the risks from water-related disasters are relatively low in Singapore, the Republic of Korea, Japan, and Brunei Darussalam. The report (ADB 2020a) also revealed lower hydrological and climatological risks than meteorological risks in advanced countries, indicating that improving poor flood and drought security is one of the priorities to reduce water-related disaster risks in the region.

By integrating the scores from KD1 to KD5, the NWSI scores for East and Southeast Asian countries were derived (Fig. 2.4). The results showed that among the 14 economies analysed, Japan showed the highest score, followed by the Republic of Korea and Singapore, while most Southeast Asian countries and Mongolia still had much room for improvement. Notably, advanced economies in the region have the highest water security in general, despite their low natural water availability compared to other Southeast Asian countries. For example, Singapore's water availability per capita was extremely limited (exceptionally lower than the global average, Table 2.1), but the country's overall water security scores were the third highest among the countries in the region. This indicates that achieving water security does not just rely on the availability of natural water resources. Taking actions to invest in infrastructure and ensure efficient management can greatly improve water governance and water security.

2.3.2 Water Poverty Index

One of the initial attempts to measure and compare water availability and people's capacity to access water on a global basis was performed by Lawrence et al. (2002). They suggested that the concept of the water poverty index (WPI); the purpose of

Table 2.3 Framework for assessing the international WPI by (©Lawrence et al. 2002)

WPI component	Composition
Resources	• Internal freshwater flows • External inflow • Population
Access	• % of population with access to clean water • % of population with access to sanitation • % of population with access to irrigation adjusted by per capita water resources
Capacity	• Log GDP (gross domestic product) per capita income • Under-five mortality rates • Education enrolment rates • Gini coefficients of income distribution
Use	• Domestic water uses per day • Share of water use by industry and agriculture adjusted by the sector's share of GDP
Environment	• Water quality • Water stress (pollution) • Environmental regulation and management • Informational capacity • Biodiversity based on threatened species

which is to express an interdisciplinary measure that links household welfare with water availability and indicates the degree to which water scarcity impacts the human population. The framework to assess an international WPI comprises five indices: resources, access, capacity, use, and environment. Table 2.3 summarizes the dataset utilized by Lawrence et al. (2002) to estimate each WPI component.

The resulting WPI for East and Southeast Asian countries is presented in Fig. 2.5. For international comparisons, the WPI from some selected countries (the countries with highest and lowest WPI scores) is introduced as well. The results showed that the average scores of East and Southeast Asian countries (except Brunei Darussalam) for resources, access, capacity, use, and environments were 9.4, 13.1, 14.3, 10.7 and 10.5, respectively. The differences between the maximum and minimum scores in East and Southeast Asian countries were the largest in access (Max − Min = 15.1), followed by resources (score = 12.7), use (9.5), capacity (8.1), and environment (3.5). In the case of Singapore, the country scored the highest in access (20) in the region, but at the same time, it showed the least availability of resources (1.2). On the other hand, Lao PDR scored well in resource (13.9), but people's access to water resources had the second lowest score (6.4) in the region.

The research presented by Lawrence et al. (2002) was one of the initial attempts to establish an international measure comparing performance in the water sectors across countries in a holistic way. However, caution needs to be taken when utilizing the results, considering that the WPI was established approximately 20 years ago; thus, it does not reflect recent changes in either physical or socioeconomic factors associated with water security.

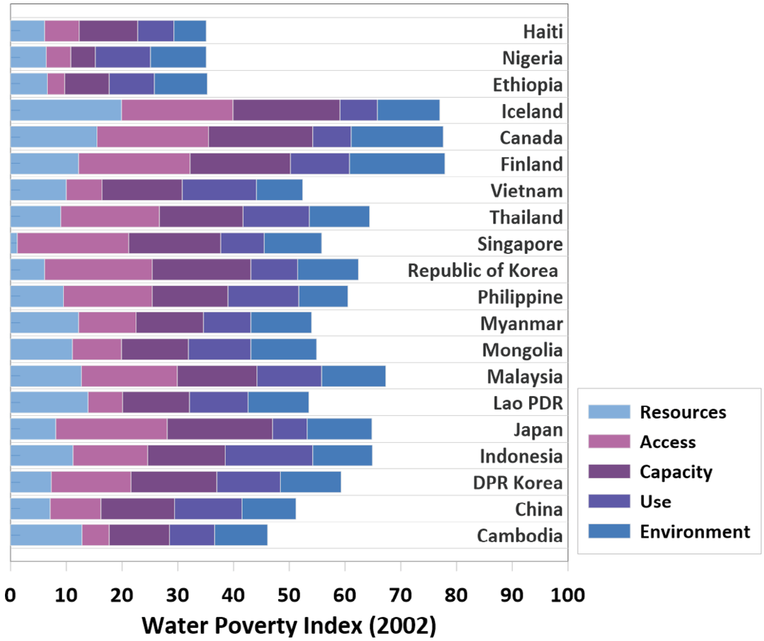

Fig. 2.5 Water poverty index of East and Southeast Asian countries and some selected economies. The index is comprised of five dimensions, the scores of which range from zero to 20. Data for Brunei Darussalam were unavailable

2.3.3 Progress on SDG 6: Water and Sanitation for All

The global community has long recognized the significance of water security for sustainable development. Water is considered a prerequisite to attain many other sustainable development goals (SDGs), and such a strategic importance of water is well captured by SDG 6 to ensure the availability and sustainable management of water and sanitation for all. The achievement of SDG 6, therefore, serves as an important indicator to provide insights into global, regional, and national water security.

Figure 2.6 shows the progress on several SDG 6 indicators, including SDG 6.1.1 (percent of the population using safely managed drinking water services), SDG 6.2.1 (percent of the population using safely managed sanitation services), SDG 6.4.1 (water use efficiency) and SDG 6.4.2 [freshwater withdrawal as a proportion of available freshwater resources (percent)]. Satisfactory progress has been made for most of the presented indicators except for water stress, which showed a continuously increasing trend for most countries. However, there are still several countries in the region that suffer from the lack of clean water and sanitation, particularly in the developing countries. For example, more than half of the population in Cambodia, Lao PDR, Mongolia, and Philippines still has insufficient access to clean water

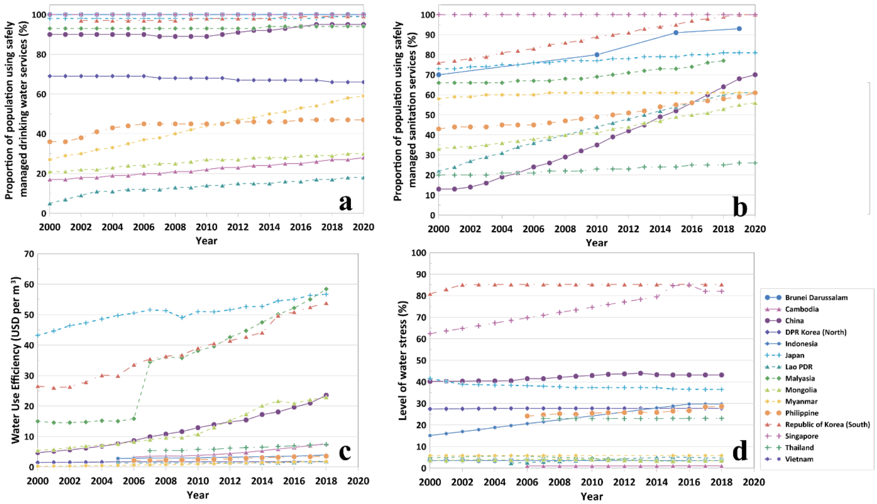

Fig. 2.6 Progress of SDG 6 indicators in East and Southeast Asia **a** SDG 6.1.1, **b** SDG 6.2.1, **c** SDG 6.4.1 and **d** SDG 6.4.2. *Note* SDG 6.1.1 for China only covers the urban population and SDG 6.1.2 for Brunei Darussalam was referred from UN (2021b); DPES (2020) adapted by the author

(SDG 6.1.1). Furthermore, the issue of sanitation was notable in countries such as Thailand, Mongolia, Lao PDR, and Philippines. Considering that the progress of these indicators is not on track in many countries, the situation gets more serious and even threatening in some countries. Water use efficiency (SDG 6.4.1) also showed fair or significant progress, but the absolute efficiency was still limited in developing countries such as DPR Korea, Lao PDR, and Myanmar (i.e., less than 2 USD per m^3). The water level stress (SDG 6.4.2) stood highest in Republic of Korea and Singapore, revealing the limited availability of freshwater resources.

In terms of progress on other SDG 6 indicators, the UNEP reported the implementation of IWRM (integrated water resource management; SDG 6.5.1) (UNEP-DHI 2021). The data showed that the average degree of IRWM implementation for 15 countries in East and Southeast Asia as of 2020 was medium–high (64 out of 100), which was higher than the global average (54). Table 2.4 shows that among the 15 East and Southeast Asian countries, Singapore and Japan had the highest scores, followed by China and the Republic of Korea. The IWRM scores for Mongolia and Myanmar were medium–low.

2.4 Regional Challenges

In this section, the major regional challenges impeding water security in East and Southeast Asia are summarized.

Table 2.4 Score threshold and interpretation for SDG 6.5.1 and the level of IWRM implementation of East and Southeast Asian countries (as of 2020)

Status category	Score range	IWRM score interpretation	Countries (UNEP-DHI 2021)
Very high	91–100	Vast majority of IWRM elements are fully implemented	Singapore, Japan
High	79–90	IRWM objectives are generally met, and geographic coverage and stakeholder engagement are generally good	China, Republic of Korea
Medium–high	51–70	Capacity to implement IWRM elements is generally adequate	Brunei Darussalam, DPR Korea, Indonesia, Malaysia, Lao DDR, Cambodia, Philippines, Thailand, Vietnam
Medium–low	31–50	IWRM elements are generally institutionalized, and implementation is under way	Mongolia, Myanmar
Low	11–30	Implementation of IWRM elements has generally begun	–
Very low	0–10	Development of IWRM elements has generally not begun or has stalled	–

Source GWP and UNEP-DHI (2021) adapted by the author

2.4.1 Universal Access to Clean Water and Sanitation

Access to clean water and sanitation is a human right. Everyone is entitled to sufficient, safe, acceptable, and physically accessible and affordable water for personal and domestic uses (UN General Assembly 2010). Everyone should also have access to sanitation services that provide privacy, ensure dignity and safety, and are physically accessible and affordable. The UN's 2030 Agenda, therefore, seeks to ensure availability and sustainable management of water and sanitation for all through the attainment of SDG 6 and its targets.

Despite the substantial progress that has been made in increasing access to clean drinking water and sanitation, billions of people worldwide still lack these basic services. One in three people worldwide do not have access to safe drinking water, and two in five people do not have basic hand washing facilities (UN 2021a). In Southeast Asia, as of 2020, more than 60% of rural people do not have access to safely managed drinking water, and more than half of the total population does not use safely managed sanitation despite the general progress on these indicators (Fig. 2.6a, b). Though the access to clean water and sanitation in urban areas is high in East Asia, people residing in rural areas are experiencing the contrary, due to the lack of basic facilities (i.e., only 45% of the rural population uses safely managed sanitation) (UN 2021c).

Achieving universal access to safe drinking water and sanitation is a great challenge for the region, but it is a prerequisite and a regional priority for sustainable development. Providing these public goods to all is closely linked to economic and social development as well. UNICEF and WHO (2020) estimated that the economic losses associated with inadequate sanitation accounted for 1–1.2% of the total GDP (as of 2012) in East and Southeast Asia. With the unexpected surge of the COVID-19 pandemic, the importance of sanitation and access to clean water has become even more critical. Without achieving these targets, the region will not be able to sustain its economic growth and the integrity of society.

2.4.2 Water Shortage

In the global context, it is generally considered that East and Southeast Asia receive annual rainfall exceeding the global average; thus, these regions do not have a serious physical scarcity of water. However, there is seasonal variability of precipitation in most of the region, resulting in periodic water shortages and flooding. Additionally, rapid expansion of socioeconomic activities together with explosive population growth has posed a serious threat for the provision of sufficient water resources to all. Table 1.5 compares the seasonal variability of East and Southeast Asia (FAO 2021). The index represents the variation in water supply between months of the year, the value of which ranges from zero to five, where zero and five indicate the lowest and highest variabilities, respectively. The results showed that, on average, East and Southeast Asia experience larger seasonal fluctuations in available water resources than the global average, and such seasonal water variability is particularly significant in Cambodia, DPR Korea, Lao PDR, Myanmar, Republic of Korea, Thailand, Vietnam, Mongolia, and China.

Socioeconomic concern with regard to severe droughts is one of the major issues on which the region has focused for a long time. Southeast Asia has regularly experienced severe droughts. The prolonged droughts between 2015 and 2018, the worst on record for two decades, affected more than 70% of the land area, with over 325 million people exposed (UNESCAP 2020). The cost of seasonal droughts hit the agricultural sector the hardest. Venkatappa et al. (2021) reported that that 20.6 million tons of crop production was lost between 2015 and 2019 due to droughts and floods in Southeast Asia. The water shortage and economic cost of seasonal droughts have seriously affected East Asia as well. China is one of the regions that suffers from drought disasters most frequently, with serious socioeconomic losses. As an example, approximately six million people in China suffered from a lack of public water due to the severe drought that hit the country from June to August 2013. The economic cost from the agricultural sector during the same period amounted to approximately 780 million USD (K-Water 2017). In the Republic of Korea, during 1994–1995, drought affected approximately 4.8% of the total population due to the limited domestic and agricultural water supply (K-Water 2017).

Table 2.5 Interannual and seasonal variability in water resources in East and Southeast Asia

Country	Seasonal variability index (–)	Country	Seasonal variability index (–)
Brunei Darussalam	1	Myanmar	3.7
Cambodia	3.1	Philippines	2.1
China	2.7	Republic of Korea	3.3
DPR Korea	3.8	Singapore	1
Indonesia	1.9	Thailand	3.5
Japan	1.7	Vietnam	3.2
Lao PDR	3.6	E & SE Asia	2.61
Malaysia	1.7	World	2.29
Mongolia	2.9		

Source FAO (2021) adapted by the author

In the case of China and Mongolia, these countries receive annual rainfall less than the global average, and physical water scarcity is a major national concern. The issue of water scarcity is further exacerbated by the uneven distribution of water resources that does not reflect socioeconomic needs. In China, the spatially varying distribution of water resources worsens the water shortage problem in some areas. North China, which comprises 45% of the total population and 65% of arable land of the country, has only 19% of the total water resources (Jiang 2015), resulting in serious water shortages, groundwater depletion, and potential loss of socioeconomic opportunities in the area. The risks of water scarcity are further exacerbated by seasonal cycles. In Mongolia, although the water availability per capita is high for the country as a whole, the regional differences in rainfall and the uneven distribution of population result in local hot spots of water insecurity, particularly in Ulaanbaatar (the capital of the country where more than half of the population lives) and the Gobi region, where the mining industry requires a water supply for operation (ADB 2020b).

As a response to combat water scarcity, the demand for groundwater has increased greatly in the region. According to a statistical analysis on global water usage (FAO 2021), the total groundwater withdrawal from 11 countries in the region (except Cambodia, DPR Korea, Lao PDR, Singapore) accounted for approximately 19.2% of global withdrawal as of 2018. The groundwater extraction rate in China has increased from 57×10^9 m^3/year in the 1970s to 111×10^9 m^3/year in the 2000s, causing serious groundwater depletion and land subsidence problems (UNESCO 2006). In particular, due to the lack of available surface water resources, the northern part of China (North China Plan) has extensively used groundwater, putting the aquifers in the region at serious risk of depletion and pollution. In Mongolia, groundwater is tapped as the main water source because of the high seasonal variability of river flow and the cold winter, which has resulted in extensive aquifer extraction and groundwater depletion problems (ADB 2020b). In Thailand, the heavy pumping of groundwater

Table 2.6 Major aquifers in East and Southeast Asia under severe groundwater stress

Aquifer name	Country
North China aquifer system (Huang Huai Hai Plain)	China
Yalu River Valley aquifer	China, DPR Korea
Yenisei upstream aquifer	Mongolia, Russia
Mekong River Delta aquifer	Cambodia, Vietnam
Hong River Basin aquifer	China, Vietnam
Downstream of Lancang River aquifer	China, Myanmar
Nu River Valley aquifer	China, Myanmar
Karst Aquifer of Upper Zuojiang Valley aquifer	China, Vietnam

Source UN-IGRAC (2021) adapted by the author

in Bangkok between 1955 and 1982 caused a decline of up to 50 m in groundwater levels, resulting in groundwater shortages and land subsidence problems (Gupta and Babel 2005; Phien-wej et al. 2006). Vietnam has also suffered from serious groundwater depletion, seawater intrusion, and land subsidence problems caused by the intensive consumption of groundwater for irrigation purposes, particularly in the Mekong Delta (Erban et al. 2014).

UN-IGRAC used the groundwater stress index (the ratio between groundwater withdrawal and groundwater recharge) and developed the global inventory of groundwater stress. Table 2.6 shows some major aquifers in East and Southeast Asia where an intensive level of groundwater depletion occurs, exceeding its natural recharges.

2.4.3 Wastewater and Water Quality

As the total water usage in the region grows, the quantity of wastewater and its pollutants discharged are continuously increasing. The estimated total amount of wastewater produced in East and Southeast Asia was approximately 100.9×10^9 m^3/year as of 2018, which was 1.46 times higher than that of 2007 (FAO 2021). However, the capacity of wastewater treatment facilities in the region could not keep up with such a rapidly increasing demand. Accordingly, the vast majority of wastewater produced in the region, particularly from developing economies, is released directly to the environment without adequate treatment, resulting in adverse influences on human health, water quality, ecosystems, and socioeconomic productivity.

The capacity of wastewater treatment varies depending on the subregion and country. According to Liao et al. (2021), the wastewater treatment rates in East and Southeast Asia are 57% and 38%, respectively. Figure 2.7 summarizes the wastewater treatment rates from some countries in the region. Although caution should be made when comparing national values considering that the data in the graph were referred from various sources, it is apparent that substantial gaps exist in the capacity of wastewater treatment depending on countries. The advanced economies in the region are equipped with infrastructures to properly manage wastewater. Singapore has achieved 100% wastewater treatment since 2015 (Government of Singapore 2021). In the Republic of Korea, the proportion of domestic and industrial wastewater effluents that were safely treated was 94.3% as of 2019 (ME 2020). China has also achieved remarkable progress in wastewater treatment infrastructure. From 1991 to 2018, the rate of wastewater treated in municipal wastewater treatment plants increased from 14.9 to 95.5% across the country (Xu et al. 2020). On the other hand, the infrastructure and basic services in several countries in Southeast Asia lag behind as compared to their rapid urbanisation and population growth. The dramatic increase in municipal wastewater compounded by accelerated urban growth is one of the greatest challenges for many governments in the region.

Consequently, the water quality in this region is under increasing threat. Among the various sources affecting water quality (agriculture, manufacturing, chemical overuse, etc.), untreated wastewater is one of the major pollution sources. Pathogens, organic matter, and nutrients from sewage and industrial processes highly pollute major rivers in the region, such as the Chao Phraya River (Thailand), Klang River (Malaysia), Citarum River (Indonesia), and Pasig River (Philippines) (UNESCAP and ADB 2000). For these countries, river pollution at times becomes unmanageable. For example, Marleni and Raspati (2020) reported that more than 75.2% of rivers in Indonesia were heavily polluted as of 2015.

The degradation of water environments increasingly threatens public health. Billions of people in the region face health risks caused by water pollution. In addition to municipal wastewater, agricultural inputs from fertilizers, pesticides, and animal

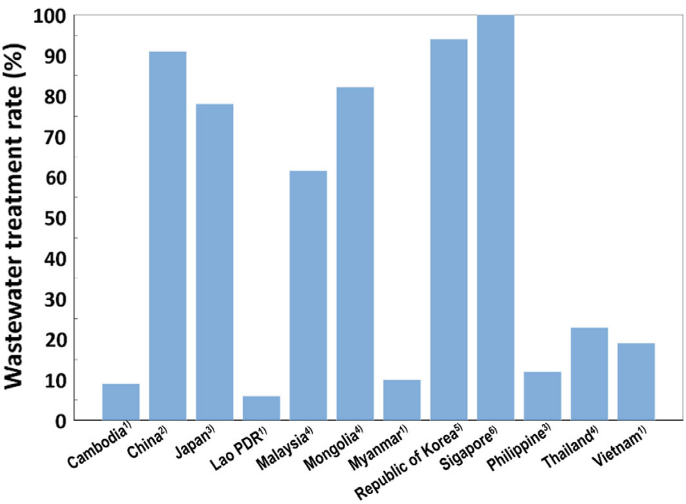

Fig. 2.7 Municipal wastewater treatment rate in East and Southeast Asian countries (*Source* (1) WWAP (2017), (2) Xu et al. (2020), (3) Liao et al. (2021), (4) FAO (2021), (5) ME (2020), (6) Government of Singapore (2021) adapted by the author

waste have been an environmental concern affecting water quality (Mateo-Sagasta et al. 2017). Toxic contaminants of industrial pollutants, even at low quantities, may cause chronic toxicity and endocrine disruption in humans and wildlife. Furthermore, growing concerns about emerging contaminants, such as pharmaceuticals, perfluorinated compounds, and water disinfection by-products, pose additional challenges in protecting public health (Sauvé and Desrosiers 2014).

In terms of groundwater quality, a high arsenic content is occasionally observed in the region. High levels of arsenic groundwater used for drinking could become a public health issue. In China, groundwater with a high arsenic level was found in Inner Mongolia (Rodríguez-Lado et al. 2013). In Southeast Asia, groundwater contamination by arsenic has been problematic, particularly in the southern part of Vietnam and Cambodia (Erban et al. 2013; Fendorf et al. 2010). In addition to arsenic contamination, groundwater quality deterioration frequently occurs in the region as a result of industrial, agricultural, and subsistence pollution. In agriculture, intensive application of fertilizers and other agrochemicals and disposal of animal waste into the ground could cause the long-term contamination of groundwater by nitrate and other pollutants (Zhang et al. 1996). Leakage of hazardous materials from septic tanks, gas stations and other man-made products could cause groundwater contamination (Hosono et al. 2011; Taniguchi et al. 2008). Extensive groundwater extraction in coastal aquifers has led to saltwater intrusion and an increase in groundwater salinity (Vu et al. 2018).

The region faces serious issues of water quality degradation. Water pollution in the region has exacerbated freshwater scarcity, ill health, and ecosystem degradation. The region needs to invest in wastewater sectors and reduce the pollution loads to tackle worsening water pollution. Despite the necessity to tackle water pollution, unfortunately, insufficient efforts are being made to monitor river quality (Evans et al. 2012).

2.4.4 Water and Ecosystem (Environmental Water Flow)

Freshwater systems play a pivotal role in sustaining ecosystems and providing a range of ecosystem services (Martin-Ortega et al. 2015). Healthy water-related ecosystems bring numerous benefits, including good water quality, basic flood protection, food security from agricultural products and healthy fisheries, and transportation. To preserve the benefits of natural water-related ecosystems, the maintenance of environmental flow regimes and the protection of water quality and habitats for biodiversity are vital. However, human interventions in the environment have frequently degraded the health of aquatic ecosystems. A decrease in environmental water flow by groundwater depletion or river controls (dams, etc.) has reduced the volume of water flows and sedimentation rates, thereby resulting in the loss of aquatic habitat. The degradation of water quality, temperature increase, and removal of riparian vegetation have negatively affected ecosystem health and biodiversity. Alarming rates of land use alteration and physical changes in landscapes have significantly reduced regional biodiversity. Effective assessment of aquatic ecosystems and understanding of environmental water security, therefore, are vital to preserving ecosystem health and the benefits of these ecosystems.

Table 2.7 shows the required environmental water flow, total water withdrawal, and amount of renewable water resources for East and Southeast Asian countries. In the table, the potential of additional water development indicates the amount of renewable water resources after deducting environmental flow requirements and current total water withdrawal. The results show that countries such as Brunei Darussalam, the Republic of Korea, and Singapore have the lowest potential for additional water development. The estimation of total water demand considering environmental flow for each country shows that China, Indonesia, the Republic of Korea, and Singapore have utilized more than 70% of their total renewable water resources. This result demonstrates that some advanced economies with nationwide water infrastructure benefit from a sufficient supply of water resources to people, but at the same time, such intensive water consumption could increase environmental water stress and decrease ecosystem diversity. Efforts need to be made to save renewable water consumption and protect water-related ecosystems and their biodiversity and health.

Table 2.7 Environmental flow requirements, total water withdrawal and potential of additional water development of East and Southeast Asia as of 2018

Country	Environmental flow requirements ($\times 10^9$ m^3/year)	Total water withdrawal ($\times 10^9$ m^3/year)	Total renewable water resources ($\times 10^9$ m^3/year)	Potential of additional water development ($\times 10^9$ m^3/year)
Brunei Darussalam	5.8	0.1	8.5	2.6
Cambodia	265.4	2.2	476.1	208.5
China	1471.0	598.1	2840.2	771.1
DPR Korea	45.9	8.7	77.15	22.6
Indonesia	1269.0	222.6	2018.7	527.1
Japan	212.5	79.3	430	138.2
Lao PDR	180.1	7.3	333.5	146.1
Malaysia	385.0	5.5	580	189.5
Mongolia	21.2	0.5	34.8	13.2
Myanmar	595.0	33.4	1167.8	539.4
Philippines	151.9	93.7	479	233.4
Republic of Korea	35.4	27.1	69.7	7.2
Singapore	–	0.7	0.6	−0.1
Thailand	189.6	57.3	438.6	191.7
Vietnam	432.6	82	884.1	369.5

Source FAO (2021) adapted by the author

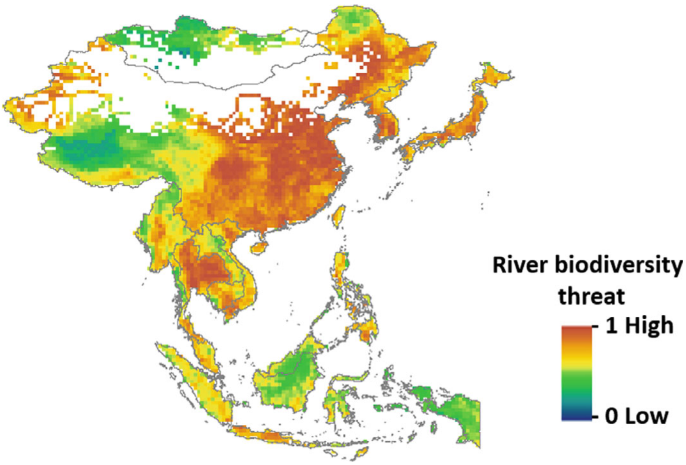

Fig. 2.8 Regional geography of incident threat to biodiversity (@Vörösmarty et al. 2010)

In addition to the potential decreases in environmental water flow, land use change, and quality degradation by human intervention, the potential risks of biodiversity loss have also escalated. As an example, lakes and wetlands in China have substantially decreased in size and number (An et al. 2007; Sun et al. 2015). Southeast Asia has lost its biodiversity by deforestation, urbanisation, mining, reservoir construction, wetland drainage, and pollution (Hughes 2017). In the Republic of Korea, losses of coastal and riverine diversity through land use change and weir construction have been raised as a cross-cutting environmental issue despite the country's general effort to restore its aquatic ecosystem (Hong et al. 2010; Im et al. 2020).

Vörösmarty et al. (2010) compiled a broad suite of individual stressors to produce cumulative incident threat indices for global river biodiversity (Fig. 2.8). The results showed that large parts of China, the Republic of Korea, Japan, and Thailand, as well as parts of Cambodia, Indonesia, Malaysia, the Philippines, Vietnam, and Myanmar were under serious river biodiversity threat.

2.4.5 Water-Related Disasters and Climate Change

East and Southeast Asia are global hotspots for water-related disasters. The region is vulnerable to varying types of hydrological, climatological, and meteorological disasters, including floods, droughts, and storms (UNESCAP 2021). A comparison with global statistics revealed that more people in East and Southeast Asia are affected by storms, extreme heats, floods, and droughts. In terms of economic loss, the impacts of extreme weather events, particularly floods, storms, and extreme heat, hit the region hardest with significant socioeconomic losses.

With the changing climate, the impacts of extreme weather events will further expose the population in the region to risk. ADB (2017) reported that the projected overall summer warming in Asia and the Pacific would reach 2–6 °C by 2100 depending on representative concentration pathway (RCP) scenarios. As a result, the region will suffer from intensive rainfall, extreme heat, and sea level rise. Lehmann et al. (2015) showed that during the period from 1981 to 2010, the number of record-breaking rainfalls notably increased globally, with the strongest increase found over Southeast Asia. Sea level rise due to global warming will result in coastal floods, inundation, and seawater intrusion into freshwater bodies. Coastal cities in this region are particularly vulnerable to sea level rise and floods, including Guangzhou (China), Shenzhen (China), Ho Chi Minh City (Vietnam), Jakarta (Indonesia), Bangkok (Thailand), and Nagoya (Japan) (ADB 2017). The Philippines and Indonesia will be extensively exposed to sea level rise and coastal flooding. The Mekong Delta, a global rice production area, will be seriously threatened by sea level rise due to its low elevation (Minderhoud et al. 2019).

Climate change will pose a direct threat to water security. The economic impact of climate change will be devastating unless substantial measures are taken. More people will be exposed to floods, droughts, storms, and extreme heat waves in the region. The developing economies in the region, which are not capable of coping with such disasters, will be the hardest hit by the consequences of climate change. Given the high vulnerability of the region to varying natural disasters, the region will not be able to maintain sustainable economic growth unless climate change and water security are addressed.

2.4.6 Transboundary Water

Transboundary waters pose challenges for achieving regional water security. Water systems shared by two or more countries closely link environmental, political, and socioeconomic aspects among neighbouring countries. Therefore, the management of transboundary water basins is compounded by the need to ensure coordination and dialogue between countries. With growing water demand and pressure from climate change, changes in water use from upstream areas threaten the water security of downstream regions, causing new conflicts between water-related sectors across the basin.

East and Southeast Asia are home to some of the world's largest rivers, including the Yangtze (China), Yellow (China), Mekong (mainland Southeast Asia), Salween (China, Myanmar, and Thailand), and Irrawaddy (China, Myanmar). Some of these rivers run though international borders, sharing benefits from waterways for socioeconomic development. Among them, the Mekong, which runs through the six countries of China, Myanmar, Lao PDR, Thailand, Cambodia, and Vietnam, is known as one of the world's largest transboundary rivers, with significant socioeconomic impacts. The cooperation and management of the Mekong River is of critical concern. Traditionally, rivers have provided a basis for livelihoods and food security for millions of people (MRC 2010), sustaining rice production, fisheries, and transportation. The rapid industrialization and development of hydropower along the river has opened a new dimension for river governance. Driven by its large hydropower potential, many countries, particularly in the upstream regions, have constructed and operated hydropower dams, raising concerns among downstream countries about the negative impacts of dam building. Dams also affect sediment and nutrient transport, fish migration, and river quality causing a decrease in aquaculture and river ecosystems (Binh et al. 2020; Campbell and Barlow 2020).

Transboundary aquifers (TBAs), like transboundary rivers and lakes, have been recognized as an important water resource. Despite their significance, however, TBAs have received less attention than transboundary rivers, mainly due to their hidden, diverse nature and the difficulty in conducting hydrological investigations across international borders (Lee et al. 2018). The international community has increasingly addressed the importance of proper management of TBAs because prioritizing the use of shared groundwater resources by one government may affect the groundwater availability in neighbouring countries, thereby raising tensions between the countries. In the case of TBAs, aquifers are generally prone to overexploitation due to their hidden nature. The consequences of TBA depletion and deterioration, therefore, negatively affect the aquifer system for a longer period of time. In East and Southeast Asia, several important transboundary aquifers are located within and across the region, including the Cambodia-Mekong River Delta Aquifer. Cooperative and effective management of TBAs is of particular importance to the region and requires increasing efforts from intergovernmental agencies, policymakers, scientists, and local communities to reach mutual acceptance of effective cooperation (Lee et al. 2018).

2.5 Regional Efforts Towards Water Security

To combat increasing risks of water insecurity, the region has made meaningful progress through advances in water governance, science and technology, public engagement, etc. In this section, the good practices and regional/national efforts towards regional water security in East and Southeast Asia are introduced.

2.5.1 Nonconventional Water Resources

Nonconventional water, such as reclaimed water and desalinated water, has been recognized as a valuable water resource (WWAP 2017; UN Water 2020). In the global context, there is a growing consensus that nonconventional water resources are a cornerstone to achieve a circular economy and sustainability (UN Water 2020). In East and Southeast Asia, the contribution of these nonconventional water resources to total water demand is still limited, mainly due to limited infrastructure, high cost of water reclamation facilities, lack of quality standards for reclaimed water, and relative abundance of natural water resources, such as rainfall. However, with an increasing risk of water scarcity and the need to develop alternative water sources, investments in nonconventional water infrastructures have continuously increased in the region.

With rising pressure on freshwater supplies, China has strived to develop alternative water resources, including wastewater reuse, seawater desalination and rainwater harvesting (Zhu et al. 2019). The utilization of reclaimed water in China has rapidly increased, from 1.3×10^9 m^3/year in 2011 to 6.2×10^9 m^3/year in 2015 (Lyu et al. 2016; Zhu and Dou 2018). Currently, the total water reclamation rate of China accounts for 11–15% of the total municipal wastewater produced (Xu et al. 2020). Together with the rapid development of seawater desalination technology, desalinated seawater is also playing an increasing role in addressing water shortages in China. As of 2019, the total production capacity of desalinated seawater in China was approximately 1.6×10^6 m^3/day (Ruan et al. 2021). Desalinated water was mainly used for industry (63.6% of total desalinated water) and domestic water supply (35.7%) (Zhu et al. 2019).

In the Republic of Korea, the government has strived to expand water reuse. As a consequence of the development of technology and a new law enacted to promote wastewater reuse, the use of wastewater in the country has been increased. The total amount of reclaimed water in the Republic of Korea was approximately 1.1×10^9 m^3/year, accounting for 15.5% of the total wastewater produced. Reclaimed water in the Republic of Korea is mostly used for the maintenance of river flow, industrial use, and agricultural use (K-Water 2017). The seawater desalination facilities in Korea are mainly used to provide water on small islands that are not equipped with centralized water supply systems and waterworks. Accordingly, small-scale seawater desalination facilities (less than 1000 m^3/day) are widely distributed on small islands, contributing to more than 70% of domestic seawater desalination demands (K-Water 2017). Medium-scale desalination plants have also been operated in some areas, including the Busan Gijang seawater desalination facility, with a desalination capacity of 45,000 m^3/day, and the Gwangyang desalination facility, which can process 30,000 m^3/day of seawater for desalination. As an alternative water source in Korea in addition to reclaimed water and desalinated water, riverbank filtration, groundwater dams, and rainwater harvesting have been implemented in some areas. In Nakgong-gang (River) of Korea, for example, major riverbank filtration facilities have been operated to supply domestic waters to local people (Lee et al. 2012). The water extraction capacity of riverbank filtration systems for public water supply in Korea is approximately 170,000 m^3/day (K-Water 2017).

Singapore lacks natural freshwater resources. As a city-state with scarce land, the government of Singapore has proactively used nonconventional water resources to meet the national water demand. With a holistic water management approach and the development of various water technologies, Singapore has become a global model for integrated water management. According to the Public Utilities Board of Singapore (PUB 2021), Singapore supplies water to its people from four water resources (known as the Four National Taps): water from the local catchment, imported water, reclaimed water (called NEWater), and desalinated water. Currently, the reclaimed water and desalinated water of the country can meet up to 40% and 30% of the water supply, respectively. The government of Singapore has also put forth significant effort to collect rainwater as much as possible through infrastructures, land use planning, environmental control, and rainwater protection from pollution.

The utilization of reclaimed water is still limited in Japan, mainly due to inadequate quality standards and the high energy consumption of water reclamation facilities (Takeuchi and Tanaka 2020). However, some major cities in the country, Fukuoka and Tokyo, for example, started to use reclaimed water for urban applications, such as toilet flushing. The amount of reused wastewater outside of water treatment plants was 210×10^6 million m^3/year in 2016, accounting for approximately 1.3% of the total wastewater produced in the country. Reclaimed water is mostly used for river flow maintenance (35%), landscape irrigation (21.6%), snow melting water (20.2%), agricultural irrigation (5.8%), toilet flushing (4.1%), recreational applications (2.1%), and industrial activities (1.2%) (Takeuchi and Tanaka 2020). Desalination technology is also rapidly growing in the country. As an example, one of Japan's largest sea-water desalination plants provides a fresh drinking water capacity of up to 50,000 m^3/day (Atkinson 2005).

Water reuse in many developing economies in the region is still in its infancy. Jones et al. (2021) estimated the wastewater reuse rate at the country level using a data-driven approach and suggested that the wastewater reuse rate for most Southeast Asian countries (except for Singapore) is below 5%. The wastewater reuse rate in Mongolia was estimated to be between 5 and 10% of the total wastewater. The relative water reclamation rate in these countries demonstrates that the promotion of water reclamation is greatly needed. Moreover, the vast amount of wastewater discharge indicates that wastewater reuse still has great potential in this region.

2.5.2 Science and Technology to Achieve Water Security

Water technologies play a crucial role in achieving a sustainable future. Improved understanding of the water cycle and innovative scientific/technological solutions are essential to support adequate supplies of clean water to people, to protect and restore watersheds and aquatic ecosystems and to strengthen the economy. Accordingly, to cope with the rising challenges of water security, countries in East and Southeast Asia have actively developed and adopted state-of-the-art technologies and innovative approaches.

The integration of modern information and communication technologies (ICTs) with wireless sensors and remote sensing technologies has led to the revolutionary progress of earth observation and environmental sciences. In the field of water science, the automatic collection and wireless transmission of various types of hydrological data (rainfall, storms, snow soil moisture, evapotranspiration, river stage, etc.) from sensors, gauges, and remote sensing allow the real-time monitoring of water resource distribution and water-related disasters. Furthermore, the development of remote sensing technology, such as satellite, airborne, and drones has provided tools to analyse high-resolution hydrological data at the global scale and supplement the sparse and uneven network of ground-based gauges (Yuan et al. 2020). These technologies are currently ubiquitously adopted and applied to remotely monitor and maintain various water infrastructures, such as water distribution networks, drinking water supply systems, reservoirs, wastewater treatment facilities, and storm water management systems.

With the surge of earth observation data and the increasing stream of "big data," various forms of machine learning have played a valuable role in forecasts and decision-making processes associated with water management and allocation processes. The increasing emergence of novel machine learning methods and data science techniques allows us to better extract complex patterns of nature, gain insights into the phenomenon, forecast upcoming events, and provide optimal management/allocation of limited water resources in an efficient and sustainable manner (Shen 2018). For example, the University of Arizona established a precipitation estimation from remotely sensed information using artificial neural networks (PERSIANN) to estimate rainfall rates with infrared satellite imagery, ground surface data and machine learning models (Hsu et al. 1997). Such a system considerably improved satellite-based rainfall estimation and could monitor floods and droughts even in remote areas. Smart water management, such as smart irrigation systems, can optimize water allocation and increase operational efficiencies. Forecasting and early warning systems could greatly reduce potential costs of water disasters (droughts, floods) and save millions of lives. Accordingly, smart water management systems combined with ICT, remote sensing, and machine learning are increasingly used in water management systems in many East and Southeast Asian countries, such as Singapore's smart water programme and smart city project in the Republic of Korea (MOLIT 2021).

The development of wastewater reclamation technologies lays a foundation for the successful utilization of water reuse. Current technologies applied in wastewater reuse include oxidants (sodium hypochlorite, ultraviolet radiation, and O_3), biological treatments (anaerobic, maturation ponds, and constructed wetlands), physical separation (medium filtration and membrane filtration), and electrochemical treatments (Lyu et al. 2016). Notably, countries with advanced wastewater treatment technology have advantages in the development of reclaimed water (Liao et al. 2021).

Recent studies on wastewater treatment and water reuse technology have mainly focused on improving the efficiency of the treatment system. In wastewater treatment, the main issues affecting the feasibility of wastewater reuse include the quality of treated water (effectiveness), as well as the economic and energy efficiency of the water reclamation system. New treatment technologies achieve highly effective and reliable treatment, thereby reducing the unit treatment cost of wastewater. Rapid advances are occurring in biological treatment, nanotechnology, and the development of new materials and offer further untapped possibilities (Daigger et al. 2019). In addition to advances in treatment technology, the use of underground aquifers as a natural filter of treated wastewater expands the areas of water reuse. These natural aquifer systems could easily reduce the pollutants and emerging contaminants in wastewater effluent (Foster et al. 2005). Autonomous control of the treatment system combined with continuous water quality monitoring enhances the feasibility of decentralized wastewater treatment systems. As an example of good practices of a circular economy, energy-efficient resource recovery from wastewater and sludge, and waste-to energy conversion have also received increasing attention (Bora et al. 2020). More risks of emerging contaminants and viruses highlight the monitoring, remediation, and treatment of emerging contaminants from wastewater to ensure that people can safely utilize reused water without health risks (Ahmed et al. 2021).

With the rapid development of seawater desalination technology, desalinated seawater is playing a more important role in addressing the water shortage issue. Generally, seawater desalination is an energy-intensive process; thus, many efforts are currently being made to reduce the production cost and energy consumption of the desalination process as well as to obtain proper water quality for various purposes. Seawater desalination technologies are generally divided into two categories: membrane separation and thermal distillation. Among them, reverse osmosis (RO) membranes have been extensively used in many other water treatment projects. Each desalination technology has a different desalination scale, energy consumption, and lifetime system, and the average cost of seawater desalination is determined by the scale of the facilities and the technologies adopted (Lin et al. 2021).

Nature-based solutions (NBSs) use or mimic natural processes to contribute to the improved management of water (WWAP 2018). NBS is a promising technology, providing an essential means to move beyond business-as-usual approaches to attain sustainable and resilient water management. Examples of NBSs include a range of approaches, including restoring and protecting forests, floodplains and wetlands, developing green infrastructure, nature-friendly urban drainage systems, and constructed wetlands. In East and Southeast Asia, green infrastructures, low-impact development (LID), and assessments of ecosystem services have improved the understanding of ecological processes and integrated water cycles (Shafique and Kim 2018). Faced with changing climate and water extremes, new approaches to improve water availability and water quality are proactively suggested and applied in the field, such as managed aquifer recharge (MAR) (Dillon et al. 2019).

2.5.3 Improved Water Governance

Good governance is a prerequisite to achieve water security. Water governance is an evolving process that requires continuous improvement to better respond to new challenges, information, experiences, and problems (UN Water 2013). Coping with various water challenges requires robust and coherent public policies, strong institutional capacity, effective instruments to enhance water security, financing, stakeholder engagement, and monitoring and evaluation (OECD 2021).

In East and Southeast Asia, poor governance and weak institutional capacity still keep many economies in a precarious situation in terms of water security. The OECD

(2021) established a synthesized water governance indicator framework and assessed the effectiveness, efficiency, and inclusiveness of water governance in 48 economies in the Asia–Pacific. The key indicators comprising the framework include institutional fragmentation, scale mismatch, policy coherence, capacity, data and information, funding, regulation, stakeholder engagement, integrity and transparency, and monitoring and evaluation. According to the OECD report (2021), most countries in East and Southeast Asia have successfully adopted dedicated water-related policies and coordination mechanisms, but the implementation of these policies is still limited due to a lack of human resources and funding, fragmented and complex institutional structures, and a lack of experience. The roles of water service regulatory bodies are not clear in some developing economies, and the limited functioning of water policy instruments further hampers the implementation and efficiency of water policies. For example, in many countries in the region, there are no policy instruments to allocate or monitor groundwater extraction. The absence of robust economic instruments (abstraction and pollution charges, etc.) could be a threat for water security. A lack of data and information, limited monitoring and evaluation, a capacity gap, a low level of adoption of tools, and limited stakeholder engagement cause significant challenges in the region (OECD 2021). In summary, water institutions and instruments are still complicated and fragmented, challenging the effective management of water resources.

Despite the slow pace, countries in this region have made important progress in water governance. More refined and deliberate planning, as well as careful implementation of water policies are held in place by adopting IWRM and innovative approaches. In Japan, the Basic Act on the Water Cycle, which was enacted in 2014, declares that water is a public good. The law aims to maintain and restore the water cycle of the country through promotion of comprehensive and integrated measures on water circulation, thereby maintaining or restoring healthy water circulation, sound economic development, and the lives of the people. Under the new Act, the Secretariat of Headquarters for Water Policy in Cabinet Secretariat as an interagency and a multisector coordinating body has IWRM responsibilities. Additionally, groundwater and spring water, which were not previously covered by national legislation, were designated management targets (Taniguchi et al. 2017).

In the Republic of Korea, the government reorganized the national water management system, which was shared between ministries, into an integrated structure under the Ministry of Environment as a single institution to maximize the administrative efficiency of water management and ensure the cost-effective, fair, and sustainable use of the limited water resources in the country (ME 2021). According to the New Framework Act on Water Management, which was enforced in 2019, four Basin Water Commissions established under Presidential Water Commissions can deliberate and decide on important matters concerning water management. In addition to integrated water management, systematic approaches, such as new water quality goals for managing the total water pollution load management system, expanded waterworks facilities, disaster prevention and conflict management to combat inequity, are taken to ensure national water security (ME 2021).

Developing economies in the region have also made considerable progress in water governance. For example, in Phnom Penh, the capital of Cambodia, unaccounted-for water routinely surpassed 70% in 1993. Through the dedicated reform between 1993 and 2008, however, the Phnom Penh Water Supply Authority (PPWSA) increased its water production and distribution network by 437 and 557%, respectively. As a result, unaccounted-for water was also significantly reduced to 6% during the same period. Programmes to ensure the financial self-sufficiency of the authority were introduced, such as an increase in the water tariff (Biswas and Tortajada 2010).

In the context of transboundary water management, preventive diplomacy and regional collaborative mechanisms are crucial. The Mekong River Commission (MRC), an intergovernmental organization established in 1995, provides an example of subregional water coordination mechanisms. According to the MRC Agreement, the organization serves as a cooperation platform in all fields of the development, utilization, management, and conservation of water and related resources. It is also responsible for formulating a basin development plan and ensuring protection of the environment, natural resources, aquatic life and conditions, and ecological balance of the Mekong River basin (MRC 2020). As a regional knowledge hub on water resource management and dialogue platform among governments, the private sector and civil society, the MRC serves as an implementation platform for subregional water governance supporting sustainability and averting water conflicts.

2.5.4 Public Awareness and Participation

Public recognition and participation are keys to achieving water security. Raising public awareness through proper campaigns and knowledge sharing could influence the attitude of the public toward water demand, supply, and protection. East and Southeast Asia have increasingly recognized that more frequent occurrences of water risks and water-related disasters directly affect people's livelihood; therefore, securing water is a critical issue to ensure safe and sustainable socioeconomic development and livelihoods. In addition, institutional and instrumental efforts to address critical water issues and promote public cooperation are in place in many economies, bringing positive changes in people's behaviour and attitudes towards dealing with water issues. In the case of Singapore, the water consumption per capita has significantly decreased over the last 10 years (Fig. 2.3), and this positive trend is partially attributed to a wide range of water conservation plans of the PUB (Mandatory Water Efficiency Labelling Scheme, Water Closet Replacement Programme, Water Efficiency Awards, etc.) to encourage water saving (PUB 2021). In Japan, a study by Takeuchi and Tanaka (2020) showed that with the explanation of the water reuse and reclaimed water quality, the public acceptance of the agricultural reuse of water has increased by 20%. To obtain more public acceptance, the local government has provided public education with various outreach activities.

Water education and capacity building at all levels could greatly support the realization of water security and a circular economy. Public participation and positive behavioural changes in water and sanitation require comprehensive education programs targeting different groups and stakeholders, examples of which include water education in school, tertiary education and professional development for water scientists and decision-makers, community participation through training and education, education for water technicians and media professionals, and regional and international dialogues (UNESCO 2012b). In East and Southeast Asia, multidisciplinary and interdisciplinary educational programmes are in place to empower learners, communities, and policymakers. Governments, intergovernmental organizations, communities, and civil society are putting more efforts towards enhancing climate resilience in the region and achieving a sustainable society.

Water remains pivotal for sustainable development and is linked to a number of global challenges. Addressing water security in this region requires interdisciplinary collaboration across sectors, communities, and political borders. In terms of the water, energy, and food (WEF) nexus perspective, it should be highlighted that water security lies at the centre of WEF nexus security and consequently sustainable socioeconomic development in these regions. Water security should be a top priority for all countries, and this can only be achieved through improved water governance, advances in science and technology, and interdisciplinary and integrated collaboration.

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Chapter 3
State of Energy Security in East and Southeast Asia

Zulfikar Yurnaidi, Tharinya Supasa, Nadhilah Shani, Iqlima Fuqoha, Suduk Kim, and Eunju Min

Abstract In this chapter, we review the state of energy security in East and Southeast Asia using three indicators: (1) energy supply security, (2) energy diversification, and (3) reliable energy infrastructure. The energy supply security of the region is presented using the energy self-sufficiency ratio and export–import status. The energy diversification state of the region is explored based on the primary energy supply mix, installed power capacity, and electricity generation mix. We also examine the state of energy infrastructure reliability of the region, especially of electricity, using the system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI). Finally, we discuss two key linkages of the water, energy, and food (WEF) nexus in the region: bioenergy and hydropower.

Keywords Energy · Nexus · East Asia · Southeast Asia

Z. Yurnaidi (✉) · T. Supasa · N. Shani · I. Fuqoha
ASEAN Centre for Energy (ACE), Jakarta, Indonesia
e-mail: zyurnaidi@aseanenergy.org

T. Supasa
e-mail: tsupasa@aseanenergy.org

N. Shani
e-mail: shani@aseanenergy.org

I. Fuqoha
e-mail: ifuqoha@aseanenergy.org

S. Kim · E. Min
Ajou University, Suwon, Republic of Korea
e-mail: suduk@ajou.ac.kr

E. Min
e-mail: can1357@ajou.ac.kr

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3.1 Introduction

East and Southeast Asia is an economically giant region in the world. Its prominent growth puts it in an important position in the world's politics and economy. Southeast Asia is home to 643.7 million people with a combined GDP, in purchasing power parity (PPP), 2011 constant prices, of USD 7.12 trillion in 2017. As reported by the 6th ASEAN Energy Outlook (ACE 2017), the region is expected to have 768.2 million people and USD 20 trillion in GDP by 2040, requiring approximately 2.5 times the primary energy from the 2017 value. Its 10 nations, under harmonic collaboration of the Association of Southeast Asia Nations (ASEAN), aim for a more integrated and resilient regional economy. As the propeller of economic growth, energy security is the region's priority.

The total final energy consumption (TFEC) of ASEAN countries, excluding nonenergy use countries, is 375.3 Mtoe (million tonnes of oil equivalent) in 2017. Among various sectors, industry and transportation are the two dominant sectors that have the highest share of TFEC, with percentages of 37.9% and 35.3%, respectively. In terms of energy mix sources, oil is still the most dominant fuel, with a share of 47.2%, followed by electricity (20.4%), natural gas (7.4%) and coal (9.1%). Indonesia consumes the most energy in the region (31%), followed by Thailand, Vietnam, Malaysia, and the Philippines (ACE 2017).

At the same time, the five East Asian countries, China, Japan, South Korea, North Korea, and Mongolia, have diverse conditions in terms of territory and population. China is the largest country in this region, fifth in size worldwide, including its land and water. All countries in this region have access to the ocean except Mongolia. Mongolia, however, has the largest per capita land area. For economic growth during 2005–2017, China had a GDP (PPP, 2011 constant USD) growth rate at the upper 6% level, while Japan and South Korea had GDP growth rates of 1.97% and 3.06%, respectively. The GDP growth rates of Mongolia and North Korea are rather volatile, ranging from −1.3% to 17.3% and −7.7% to 15%, respectively (UN Data 2021).

In East Asia, using the TFEC of Mongolia (3.53 Mtoe in 2017) as the basis, the TFECs of China, Japan, South Korea, and North Korea are 565, 83, 52, and 1.7 times larger, or 1995 Mtoe, 292.8 Mtoe, 183.1 Mtoe, and 6.0 Mtoe, respectively. Among all East Asian countries, South Korea has the largest percentage of nonenergy use as part of its TFEC (28.6%). At the same time, industry uses 51.7% and 54.9% of the energy in China and North Korea, respectively (IEA 2020a, b). Notably, 34.7% of North Korea's TFEC is an unidentified use, which may potentially be a military sector use. In terms of fuel mix, South Korea and Japan consume more than half of their TFEC in the form of oil products, while North Korea consumes 59.2% of its TFEC in the form of coal. Although the energy mixes of the TFEC in China and Mongolia seem relatively more diversified than those in other countries, coal consumption accounts for 33% and 20% of the TFEC in China and Mongolia, respectively, which does not appear sustainable (IEA 2020c).

There is no rigid definition of energy security; however, the International Energy Agency (IEA) defined it as "the uninterrupted availability of energy sources at an affordable price." Energy security includes a long-term aspect, which mainly relates to timely investment to supply energy that corresponds to economic developments and environmental needs, and a short-term aspect, which focuses on the ability of the energy system to react promptly to sudden changes in the supply–demand balance (IEA 2020a).

Considering the context of East and Southeast Asia, where there is variability in economyy size and resource availability as well as distinct geographical landscapes among member countries, minimizing the gap in energy security between nations and achieving regional energy security are prominentt issues that need collaborative efforts. Enhancing regional connectivity is crucial for enabling multilateral energy trade so that the region could have more reliable and secure energy. In the ASEAN context, there are two major ongoing interconnection efforts, the ASEAN power grid and trans-ASEAN gas pipeline.

Measuring regional energy security is a challenging task, as each country has its own interpretation when defining energy security. Hence, measuring energy security with harmonized indicators that consider the diversity of the definitions is important. As a consensus-based approach, three main components of energy security are analysed in this chapter: (1) energy supply security, (2) energy diversification, and (3) reliable energy infrastructure.

3.2 Security of Supply

The first category of energy security is the security of the supply, which can be measured by energy independency or self-sufficiency. Additionally, as an alternative indicator for supply security, the export and import of energy resources are discussed in this section.

3.2.1 Self-sufficiency

Energy self-sufficiency is an indicator that defines the ability of a country or region to supply its own energy needs. It is calculated as the ratio of production to total primary energy supply (TPES). If the ratio is greater than 100% or 1, then the country's energy supply is secure. Alternatively, self-sufficiency can be represented using energy dependency on foreign energy sources (EDFESs), which is defined as $1 - (\text{production/TPES})$.

Southeast Asia has ample conventional energy resources such as coal, gas, and oil as well as renewables such as hydropower, biomass, geothermal, solar, and wind resources. With substantial resources, fossil energy (in 2017) dominated the primary energy mix, with oil at 39% of the mix, natural gas at 22%, and coal at 21%. At the same time, renewable energy (RE) has been growing rapidly across the region, accounting for 14% of the primary energy supply in 2017. This scenario might have been spurred by the increasing awareness of each ASEAN Member State (AMS) to transform their energy policies to be aligned with global sustainable energy and climate goals. In addition, through the 2016–2025 ASEAN Plan of Action for Energy Cooperation (APAEC) as the regional energy cooperation blueprint, each AMS has agreed to put more effort into achieving the regional renewable target of 23% of the primary energy mix by 2025. In the future, RE should enable countries to respond to challenges in energy security, particularly in terms of fossil fuel dependency.

Figure 3.1 shows that Southeast Asia has the highest self-sufficiency for coal, among fossil fuels. As a large coal producer with a 9% compound annual growth rate (CAGR) during 2005–2017, the region's coal self-sufficiency continued to increase until reaching its peak in 2013 (3.42), and then, it slightly decreased. Indonesia is the largest coal producer across the region, with a production growth rate of 9.6% per year, and it accounted for approximately 88% of regional coal production in 2017.

Gas has the second highest self-sufficiency after coal; however, its self-sufficiency ratio fell from 1.77 in 2005 to 1.39 in 2017. This decrease follows the slower gas production rate, 0.7% per year, compared to the growth of gas supply, 2.6% per year. The three largest gas producers in the region are Indonesia (63.8 Mtoe), followed by Malaysia (58.1 Mtoe), and Thailand (32 Mtoe), accounting for 80% of the total gas production in the region in 2017.

In contrast, the region's crude oil self-sufficiency was less than 1. Most ASEAN countries are net oil importers, even though there are two OPEC (Organization of the Petroleum Exporting Countries) member countries in the region, Malaysia and Brunei Darussalam. Regional crude oil production has declined −1.6% per year in all ASEAN countries except Thailand.

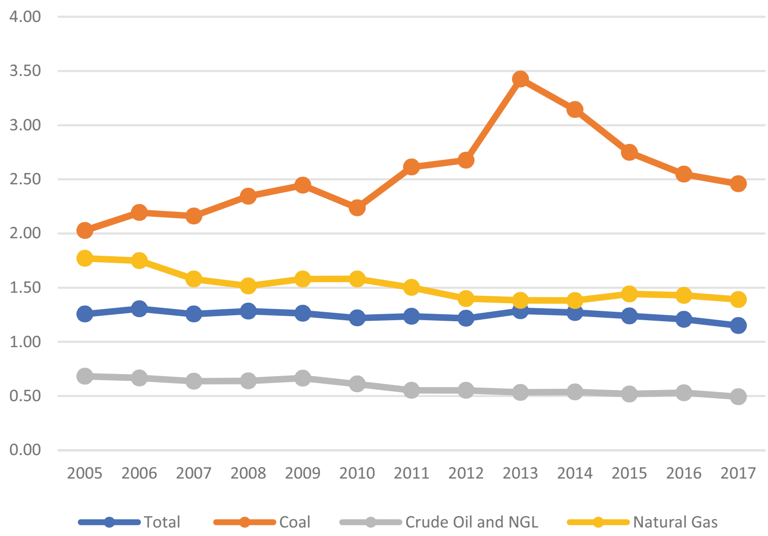

Fig. 3.1 Southeast Asia energy self-sufficiency (*Source* ACE 2020) adapted by the author

Overall total energy self-sufficiency has maintained a level slightly above 1. However, by observing the declining trend in fossil fuel self-sufficiency, especially oil and gas, energy self-sufficiency could be a challenging issue even in the short term if the region remains highly dependent on conventional energy.

Similar cases can be observed in East Asian region. Figure 3.2 shows the self-sufficiency indicators for East Asian countries. Since 1994, East Asia has imported an increasing amount of energy resources from abroad, gradually depending upon foreign oil, and with that, East Asia has played a large role in the international energy market. However, it should be noted that due to the difference in energy consumption scale, 1% of total self-sufficiency for China is equivalent to almost 30.6 Mtoe in value, which is more than 10% of the 2017 TPES of South Korea. Japan and South Korea have a high dependency on foreign energy sources, and only 10% and 20% of TPES are self-sufficient, respectively. For Japan, the dependency started to decrease after the first oil price shock of 1973, while for South Korea, a similar pattern of dependency started to decrease after the second oil price shock of 1979. Due to the oil shocks, these countries rushed to change their energy mixes by introducing nuclear power to cope with sudden energy sector shocks. Another interesting pattern in Japan is that their self-dependency suddenly dropped after the Fukushima accident in 2011. North Korea has high self-sufficiency in coal with zero self-sufficiency in oil, while Mongolia had a coal self-sufficiency of 6.8 and an oil self-sufficiency of 0.81 in 2017. North Korea has been generally energy self-sufficient, but its recent attempt to increase coal exports has been blocked due to economic sanctions. For example, the drop in the coal self-sufficiency index from 3.42 in 2016 to 1.09 in 2017 could have been caused by the reduced production of indigenous coal due to economic sanctions. Mongolia shows a similar pattern to that of North Korea except that it continues to increase its coal exports. Both countries do not produce natural gas.

3.2.2 Exports and Imports

Exports and imports of energy resources are another measure of supply security. A net exporter is a country with higher exports than imports, and vice versa for a net importing country. In Southeast Asia, the energy demand continuously rises and is driven by a fast-growing population and economic activities, yet primary production, particularly oil and gas production, shows the opposite trend. Moreover, export and import activities are market-driven; thus, oil and gas prices easily fluctuate. Hence, revisiting energy trading activity is necessary for developing energy policies or directives that support energy security in the long run.

As shown in Fig. 3.3, Southeast Asia is a net gas and coal exporting region but a net oil importing region. In 2017, the total energy exported from the region reached 442 Mtoe, which comprises 181.2 Mtoe (41%) of coal, 85 Mtoe of gas (19.2%), 171.9 Mtoe (38.9%) of crude oil and petroleum products combined, and 2.8 Mtoe (0.6%) of electricity and other sources. At the same time, for energy imports, primary

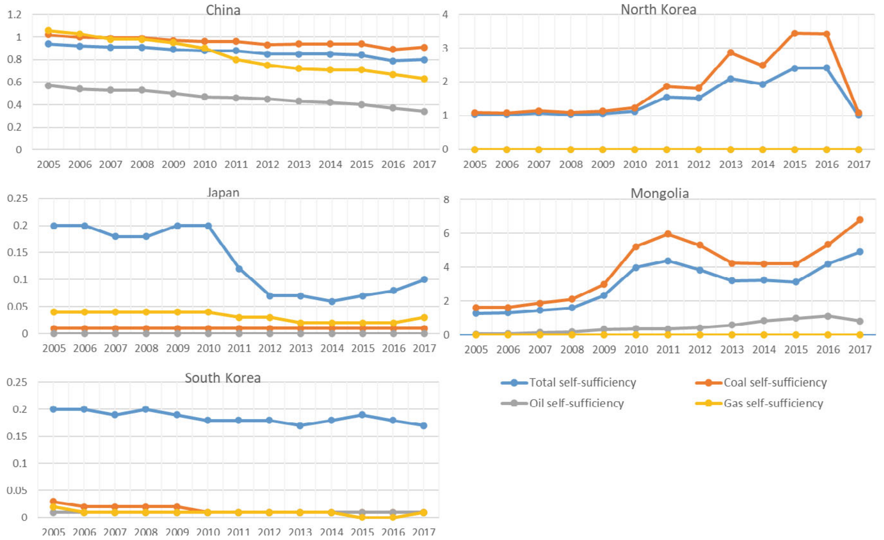

Fig. 3.2 East Asia energy self-sufficiency (*Source* IEA 2020b) adapted by the author

and secondary oil dominates the impacts at approximately 80.2% (354.9 Mtoe) of total imports (442.3 Mtoe), followed by coal and its products (55.2 Mtoe, 12.5%), gas (29.4 Mtoe, 6.6%), electricity and other sources (3.6 Mtoe, 0.8%).

In Fig. 3.4, the imports and exports of major fossil fuels in East Asia are presented. China and Korea have continuously increasing imports, while those of Japan show slightly different patterns. The sharp increase in natural gas imports since the 2011 Fukushima accident and sluggish oil imports since the mid-1990s are notable, while coal, peat, and oil shale imports have been continuously increasing. In terms of self-sufficiency and energy imports, North Korea and Mongolia are relatively better positioned than the other East Asian countries. Notably however, both countries are becoming more dependent on primary and secondary oil imports.

3.3 Energy Diversification

Well-diversified sources of energy can increase energy security, accessibility, and sustainability. Alternative energy should be injected into the energy supply system to alleviate fossil fuel import dependency. There are two energy diversification indicators presented in this section: (1) primary energy supply mix and (2) power installed capacity and generation mix.

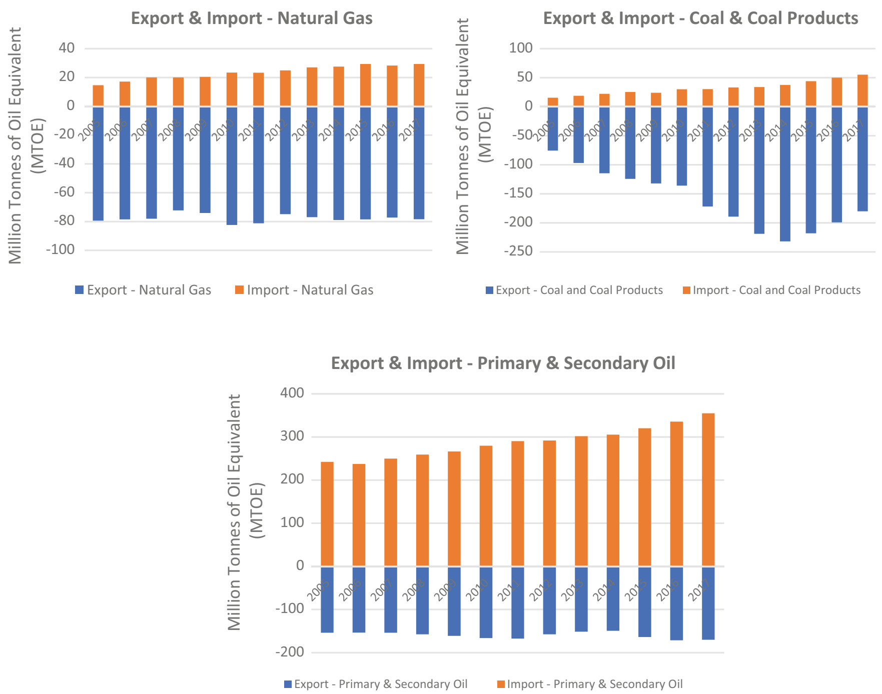

Fig. 3.3 Southeast Asia energy exports and imports (*Source* ACE 2020) adapted by the author

3.3.1 Primary Energy Supply Mix

In Southeast Asia, rapid growth of the economy drives the surging energy demand. From 2005 to 2017, the region's TPES increased 1.6 times from 407 to 625 Mtoe. The diversification of the energy supplies of Southeast Asia is shown in Fig. 3.6. Its TPES has been dominated by crude oil, natural gas, and coal.

Crude oil and natural gas liquids (NGLs) account for the largest share of the energy supply of Southeast Asia for in 2005 and 2017; however, their share of the total TPES significantly decreased from 48.1 to 35% from 2005 to 2017. Biomass supply decreased from 16.7% in 2005 to 12% in 2017 due to the energy transition of moving towards modern energy consumption in the household sector. In contrast, the share of coal in TPES expanded from 14.3% in 2005 to 21% in 2017.

The trend shown in Fig. 3.5 reflects the region's policy to reduce its dependence on imported energy. Although Southeast Asia has crude oil resources, particularly in Brunei, Indonesia, Malaysia, Thailand, and Vietnam, the domestic production capacity of these countries can meet approximately half of the oil demand. Hence, the other half must be fulfilled by imports. For example, in 2005, the region produced 133 Mtoe crude oil, while it imported 143 Mtoe crude oil. The ratio of domestic production versus imports of crude oil was relatively constant from 2005 to 2017.

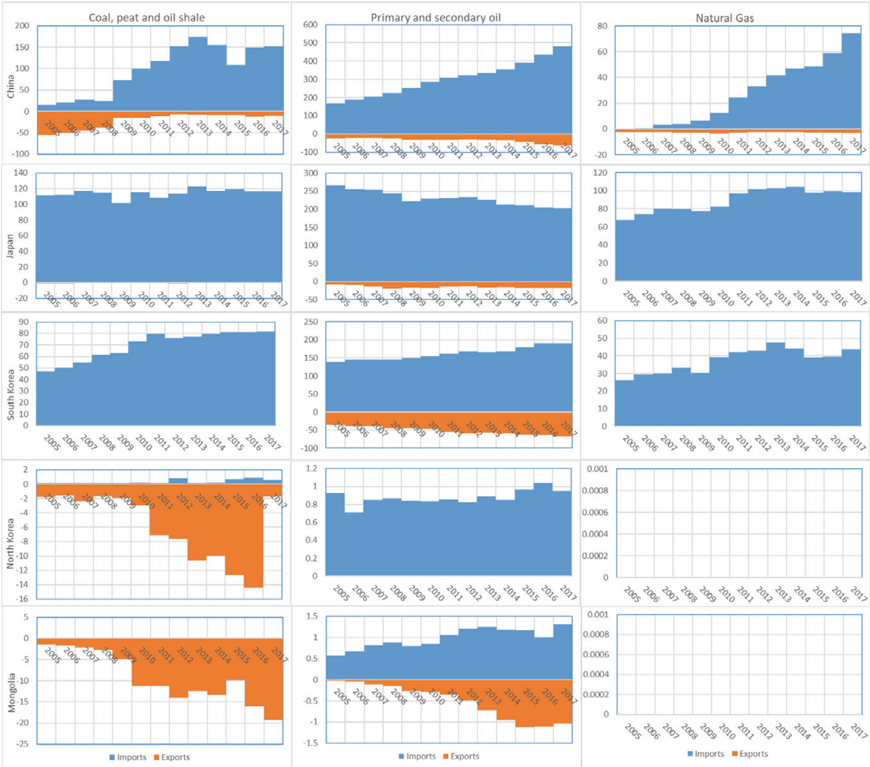

Fig. 3.4 East Asia energy exports and imports. Natural gas information for North Korea and Mongolia was not available (*Source* IEA 2020b) adapted by the author

On the other hand, abundant coal resources have been found in many Southeast Asian counties, particularly in Indonesia, the world's largest coal exporter, and Vietnam. Thus, utilizing local resources instead of imports had driven coal shares to increase. Figure 3.6 illustrates that the coal supply increased significantly in the Philippines, Indonesia, Vietnam, and Malaysia. In the Philippines and Vietnam, the supply of coal even surpassed crude oil in 2017.

The share of natural gas was relatively constant in both years (Fig. 3.5). However, the supply increased by 40% from 2005 to 2017. As natural gas is cleaner than coal, it is considered a main feedstock for the power sector. Remarkable growth of natural gas occurred in Thailand (Fig. 3.6). The expansion of natural gas exploration in Myanmar has driven the increase in natural gas supply in Thailand through pipeline systems. Finally, RE (hydropower, solar, wind, and geothermal) doubled from 19 Mtoe in 2005 to 36 Mtoe in 2017, accounting for 4.7–6% of TPES, respectively. This was a consequence of RE promotion in the region that aimed to increase the self-sufficiency ratio and electricity accessibility in rural areas and mitigate greenhouse gas emissions.

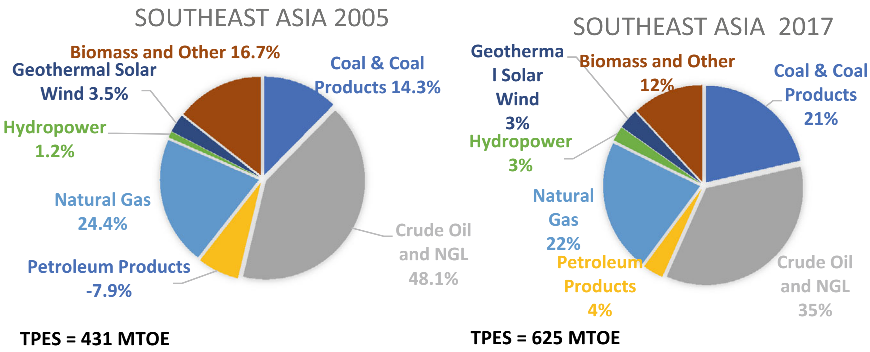

Fig. 3.5 Southeast Asia total primary energy supply (*Source* ACE 2020) adapted by the author

In Fig. 3.7, the TPES of East Asian countries are provided for 2005 and 2017. To properly understand each country's industrial structure, feedstocks used as nonenergy sources are also included. As indicated by the figure, China, Japan, and South Korea have large quantities of feedstocks, while Mongolia and North Korea do not have significant amounts. The stagnant economy with energy efficiency improvements drove Japan to reduce TPES during that period, while the reduction in TPES in North Korea could be associated with economic sanctions.

In terms of energy mix diversification in TPES, Japan and South Korea show a relatively diversified energy mix compared to the coal-intensive energy mix of North Korea, Mongolia, and China. The annual growth rates of TPES for China, Japan, South Korea, North Korea, and Mongolia are 4.5%, −1.6%, 2.5%, −2.8% and 4.5%, respectively.

3.3.2 *Power Installed Capacity and Generation Mix*

Electricity demand in Southeast Asia rapidly increased from 440 TWh in 2005 to 888 TWh in 2017. To meet the increasing peak-load demand, installed capacity had to be constructed. Accordingly, the power plant capacity doubled from 2005 to 2017, especially for coal and natural gas.

Southeast Asia benefits from abundant coal resources. Additionally, compared to natural gas and oil, coal has the most competitive power generation costs. These have accelerated the coal power capacity trebling from 22 GW in 2005 to 73 GW in 2017, accounting for 20% and 30% of the power capacity mix, respectively. Coal subcritical technology was the most popular technology used in new coal power plants. Growth was obvious in Indonesia and Vietnam. Although coal is a highly polluting feedstock, increasing the electrification ratio and ensuring a stable supply were still higher priorities during the period.

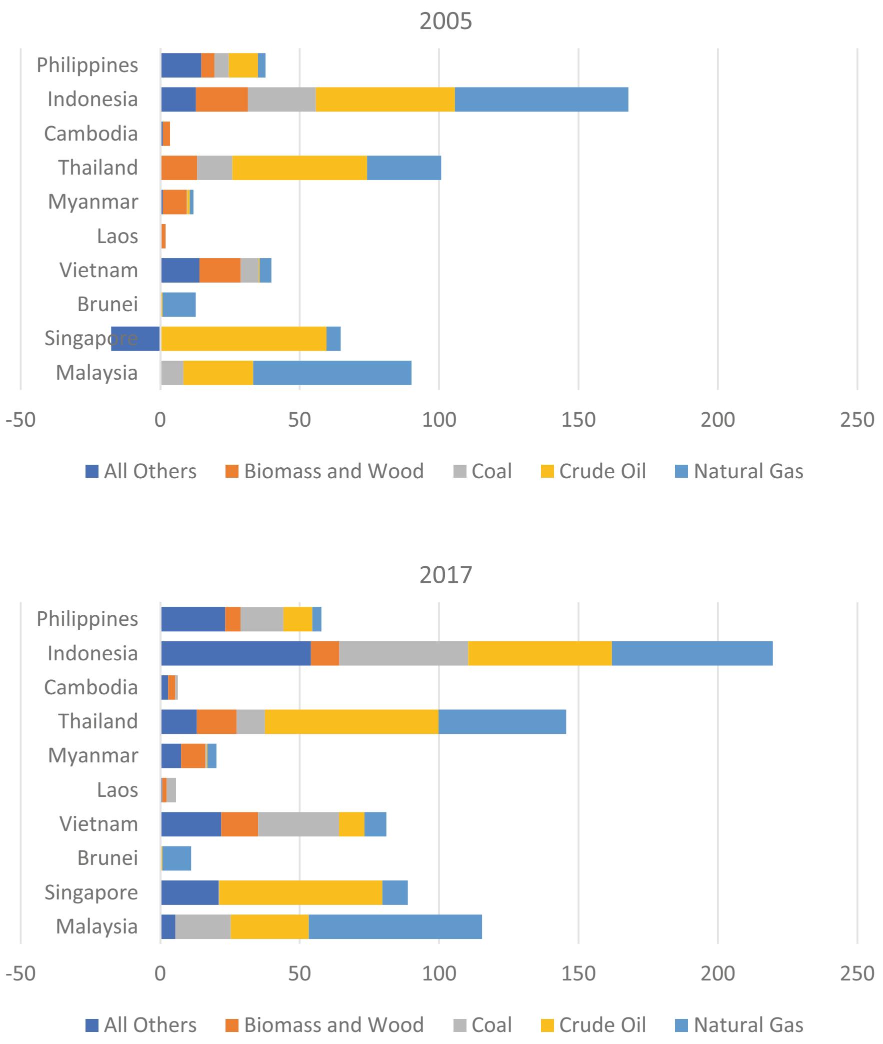

Fig. 3.6 Southeast Asia total primary energy supply by country (Mtoe) (*Source* ACE 2020) adapted by the author

Pressure from INDCs (intended nationally determined contributions) under the Paris Agreement is another key driver impacting power capacity diversification in Southeast Asia. Compared to coal, natural gas is considered a lower polluting feedstock. Among the power-plant technologies for natural gas, gas combined cycle turbines (GCCTs) have received more attention in Southeast Asia due to their higher efficiency than gas turbine technology. Gas power plant installation increased by 61% from 2005 to 2017 (from 52 GW in 2005 to 84 GW in 2017), mostly in Thailand, Singapore, and Indonesia. In addition, large-scale RE systems such as

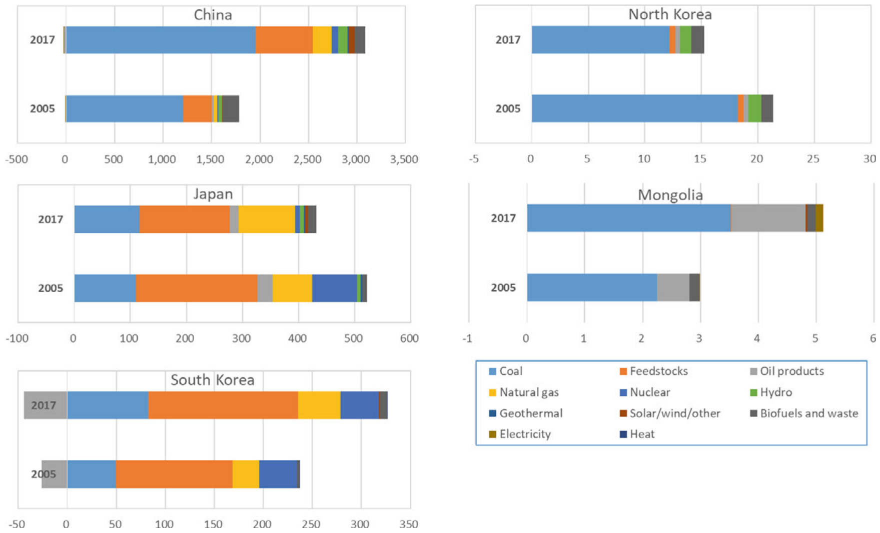

Fig. 3.7 Total primary energy supply in East Asia (Mtoe). Feedstocks indicate crude, NGLs and feedstocks. Electricity indicates net imports of electricity, and a positive number implies that imports are larger than exports, and vice versa (*Source* IEA 2020c) adapted by the author

hydropower have been constructed in emerging countries, including Vietnam, Lao PDR, Myanmar, and Cambodia.

Various clean-energy financial mechanisms have also funded a number of new small and medium renewable power producers from private sectors. Biomass and solar radiation are the most promising technologies in Southeast Asian countries. Examples of energy-related policies implemented in the region to stimulate RE capacity growth include adder, feed-in-tariff, carbon trade, bank guarantee, and low-interest loans for RE power plants. For example, Thailand started its Adder policy in 2007 and later changed to the FiT (feed in tariff) policy in 2012. The comprehensive rate principle in its FiT has driven a significant RE investment in Thailand. Consequently, the country has shown remarkable progress in biomass, solar PV (photovoltaic), wind and biogas power plants. At the same time, Singapore is the leader in waste energy.

Similar to the power capacity mix, electricity generation has been dominated by natural gas, coal, and hydropower plants (Fig. 3.9). Coal played more important roles in 2017 than in 2005, and one-third of the electricity in 2017 was generated by coal. Although natural gas has a slightly higher installed capacity than coal (Fig. 3.8), more electricity was generated by coal. The electricity generated from RE (hydropower, solar, wind, geothermal, biomass, other RE) has shown a progressively upward trend from 72.5 TWh in 2005 to 235 TWh in 2017.

Among the costs of RE types, the levelized cost of hydropower is competitive with that of gas and coal technology (IRENA 2020). In addition, the electricity generated from biomass power plants varies due to feedstock prices and fluctuating availability.

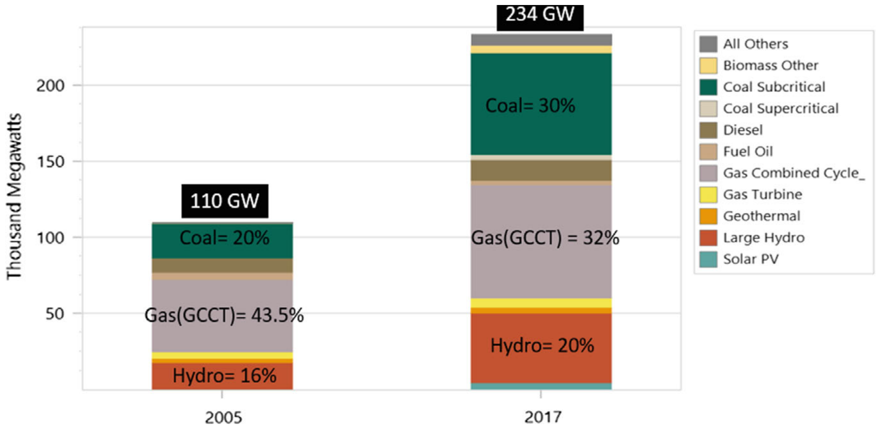

Fig. 3.8 Southeast Asia power installed capacity (*Source* ACE 2020) adapted by the author

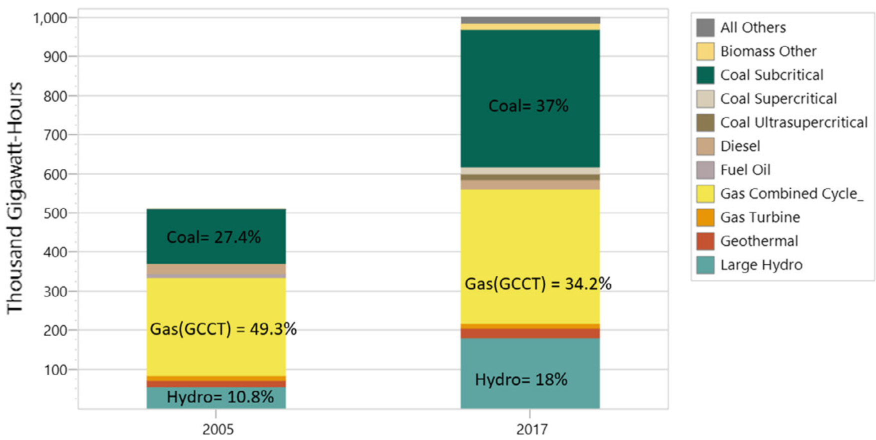

Fig. 3.9 Southeast Asia power generation mix (*Source* ACE 2020) adapted by the author

The downward trend in solar PV technology costs ensures more competitive electricity costs from solar energy in the near future. Relatedly, solar PV development in Vietnam has shown remarkable progress due to competitive feed-in tariffs. Such development has led Vietnam to become the largest solar country in Southeast Asia.

The installed capacities for East Asia are summarized in Fig. 3.10. According to WNA (2020), China has 45.40 GWe of nuclear power capacity currently operating, 2.24 GWe under construction, 50.9 GWe planned, and 106.9 GWe firmly proposed excluding other further proposals. For Japan, 31.7 GWe of nuclear capacity is currently operable, while 2.65 GWe and 17.12 GWe of operating capacity are under construction and shutdown, respectively. Korea currently has 23.2 GWe of operating capacity, while 5.6 GWe and 2.8 GWe of operating capacity are under construction and proposed, respectively. Considering the total reactors operable globally by April 2020, the total operable nuclear power in this region is over 25% of the world's nuclear energy.

The electricity generation in East Asian countries in 2017 is summarized in Fig. 3.11. The largest share of electricity generation was from coal in China, Mongolia, and South Korea. At the same time, Japan generated a large amount of electricity from gas followed by from coal. In South Korea, the role of nuclear energy has receded in recent years but is still quite dominant.

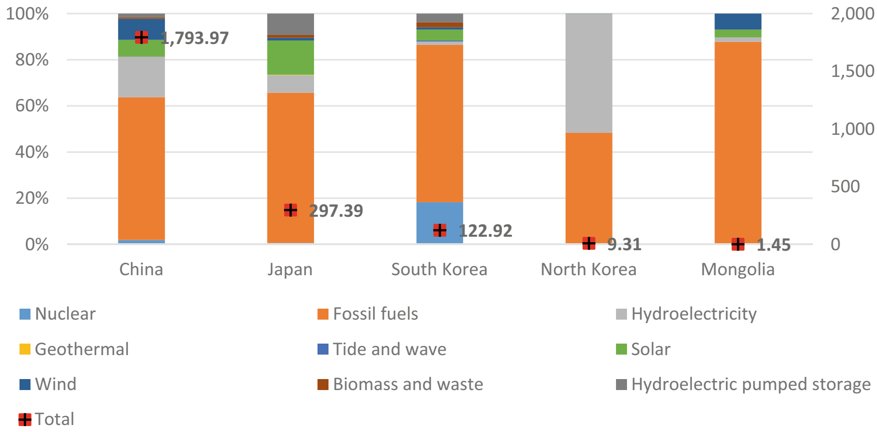

Fig. 3.10 Installed power capacity in East Asia (left axis: share, right axis: total [GWe])

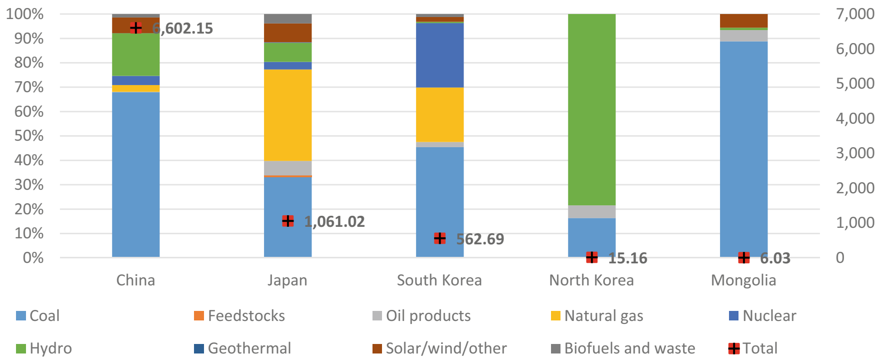

Fig. 3.11 Electricity generation in East Asia (2017) (left axis: share, right axis: total [TWh])

3.4 Security and Reliable Energy Infrastructure

Energy security requires secure, reliable, and resilient energy infrastructure. Energy infrastructure should be able to withstand disturbance and perform optimally. The infrastructure of an energy system encompasses a wide range of facilities, including:

- Primary Production: Coal mines and oil and gas rigs/wells
- Transformation: Refineries, power plants, and liquefaction terminals
- Distribution: Electric grids, substations, gas pipelines, and gas stations.

A reliable energy structure is important for ensuring energy security. In the production sector, any issues occurring during primary production could impact the energy price. In the transformation sector, for example, the nine hours of blackout in August 2019 seriously affected Jakarta and most of West Java, one of the largest cities in Southeast Asia. The case can be even worse in less developed regions of Southeast Asia, especially in noncapital cities suffering from a limited energy distribution system.

The economic damage from an unreliable energy infrastructure can be substantial. The loss of electricity impacts economic activity. The need to prepare a backup system could increase financial burdens for electricity distribution and, paradoxically, limit universal access to electricity due to the high electricity price attributed to these backup systems. Recent threats of rising sea levels and severe weather due to climate change would exacerbate this issue.

One of the main types of energy infrastructure associated with energy security is a power grid. Grid reliability can be measured by the system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI). SAIDI is the total duration of outages (in hours) experienced by a customer divided by the total number of customers served in a year, whereas SAIFI is the average number of service interruptions experienced by a customer in a year. SAIFI measures "how often" the electricity system is disturbed, while SAIDI measures "how long" the system is disturbed. As shown in Table 3.1, in Southeast Asia, Singapore has the best grid reliability as of 2020, followed by Brunei, Thailand, and Malaysia. Lao PDR, Cambodia, and Myanmar still need to improve the reliability of their power systems and reduce the SAIDI/SAIFI. In East Asia, Japan, and South Korea have similar patterns of high SAIDI and SAIFI performances. At the same time, China still has the potential for further improvement, although both indices have been improving. Mongolia has the highest SAIDI/SAIFI index in East Asia, implying that power sector outages and interruption problems are prevalent in the country. Data for North Korea were unavailable.

Other measures to determine grid reliability and resiliency are power transmission and distribution loss. Electric power transmission loss indicates the losses in transmission between sources of supply and points of distribution, whereas distribution loss includes the losses during the distribution of power to consumers, including pilfered energy. Figure 3.12 presents the electric power transmission and distribution losses in 10 Southeast Asian countries. Cambodia and Myanmar show losses of

Table 3.1 East and Southeast Asia power SAIDI and SAIFI

	2015	2016	2017	2018	2019	2020
SAIDI						
China	1.301	1.301	1.565	1.369	0.896	0.896
Japan	0.488	0.371	0.04	0.086	0.017	0.038
Korea, Rep.	0.04	0.04	0.1	0.09	0.09	0.04
Mongolia	75	93	81	54	73	62
Brunei Darussalam	2.7	1.8	0.6	0.54	0.52	0.37
Cambodia	130.9	34.22	24.79	22.84	27.25	20.78
Indonesia	3.678	3.549	2.551	4.498	3.953	2.819
Lao PDR			49.28	8.7	4.83	3.96
Malaysia	0.6	0.55	0.54	0.54	0.68	0.48
Myanmar					22	30.28
Philippines	6.6	5.8	4.23	4.59	3.91	3.57
Singapore	0.01	0.01	0.01	0	0	0.06
Thailand	0.78	0.79	0.6	0.45	0.47	0.38
Vietnam	32.9	21.41	12	8.57	3.87	2.07
SAIFI						
China	0.38	0.38	0.38	0.3	0.2	0.188
Japan	0.1	0.05	0.09	0.07	0.02	0.024
Korea, Rep.	0.08	0.05	0.08	0.06	0.04	0.05
Mongolia	11	11	10	8	8	15
Brunei Darussalam	1.1	0.8	0.4	0.43	0.38	0.33
Cambodia	101	24.5	19.9	18.7	18.8	15.35
Indonesia	2.93	2.44	1.65	2.89	3	2.178
Lao PDR			9.42	7.2	25.1	22.7
Malaysia	0.37	0.67	0.48	0.57	0.61	0.49
Myanmar					21.3	26.42
Philippines	3.41	3.2	3.96	3.96	3.15	2.23
Singapore	0.01	0.01	0.01	0.01	0.01	0.11
Thailand	1.66	1.61	1.37	0.97	0.95	0.72
Vietnam	16.1	10.8	6.72	5.11	3.02	1.57

Source World Bank (2020a) adapted by the author

more than 20%. Singapore shows approximately a 2% loss, which is the lowest in the subregion.

For the East Asian region, Fig. 3.13 presents their electric power transmission and distribution losses. Mongolia and North Korea show losses as high as 15%, while South Korea, Japan, and China show losses of approximately 5% or less.

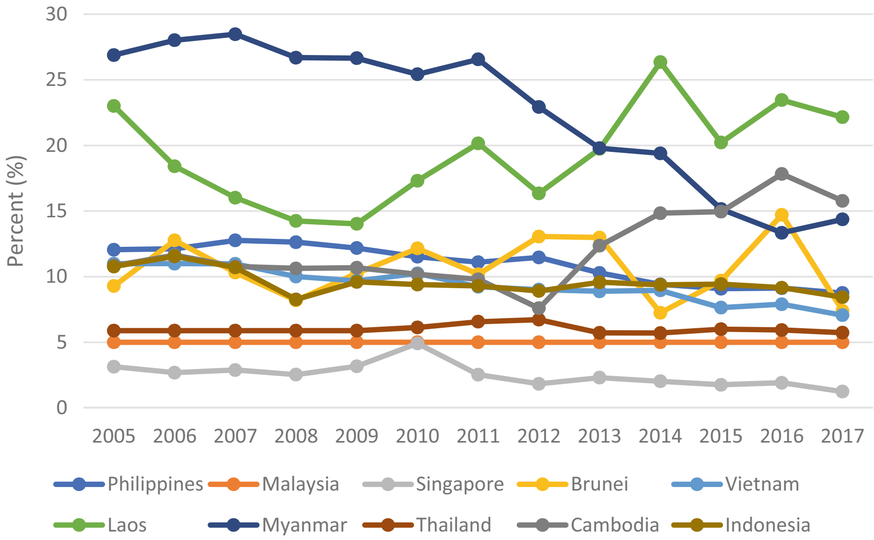

Fig. 3.12 Southeast Asia power transmission and distribution losses (%) (*Source* World Bank 2020b) adapted by the author

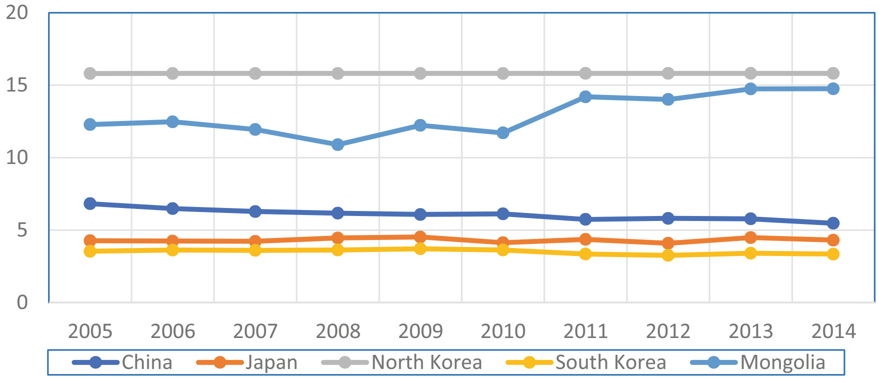

Fig. 3.13 East Asia power transmission and distribution losses (%) (*Source* World Bank 2020b) adapted by the author

3.5 Key Linkages in the Water–Energy–Food (WEF) Nexus in East and Southeast Asia

3.5.1 Intersectoral Linkage: Hydropower

One of the key linkages in the WEF nexus in East and Southeast Asia is hydropower. In Southeast Asia, hydropower has always played a significant role in the energy landscape, as the region has abundant water resources. By 2018, it was estimated that 52 GW of hydropower was installed across the region, which was approximately 20.3% of the total power capacity in ASEAN. In 2006, Vietnam had the largest share of hydropower capacity, followed by Indonesia, the Philippines, and Thailand. However, from 2007 to 2017, hydropower grew rapidly in the Mekong region, such as in Cambodia, Lao PDR, and Myanmar, due to significant increases in the energy demand of the countries.

Hydropower energy generation has also experienced considerable growth. Hydropower generation grew from 61.4 TWh in 2006 to 180.9 TWh in 2017, which was mostly because of Vietnam, Lao PDR, and Myanmar. As a clean energy source, hydropower also accounted for the second highest percentage of RE after geothermal treatment in 2017, accounting for 2.5% or approximately 15,901 Mtoe of the TPES in ASEAN (ACE 2017).

China generates the most hydroelectricity in East Asia. Its capacity reached 352.2 GW in 2018, and China houses some of the largest hydropower plants in the world, including the 22.5 GW Three Gorges hydroelectric power complex, 13.9 GW Xiluodu Dam hydropower plant, 6.4 GW Xiangjiaba hydropower plant, and 6.3 GW Longtan hydropower plant. After China, Japan is the second largest producer of hydroelectricity in East Asia. Japan had an installed power capacity of 50.1 GW in 2018. Among other large hydropower plants is the 2.8 GW pumped storage plant in Kanagawa and 1.6 GW Kazunogawa underground pumped storage plant.

Hydropower also broadens intra- and interregional connectivity. The surplus of electricity generation from hydropower sources has been one of the main drivers of bilateral power cooperation within ASEAN. Lao PDR, as the 'battery of ASEAN', has multiple bilateral power agreements with neighbouring countries such as Thailand, Cambodia, and Vietnam to sell its excess hydropower-generated electricity. During the 34th ASEAN Ministers on Energy Meeting (AMEM) in 2016, bilateral power cooperation evolved into multilateral power trade, with the initial phase of the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP), which aims to transfer energy from Lao PDR to Singapore using the existing interconnection between Thailand and Malaysia. This initiative marked an important step for the region's interconnectivity, of which hydropower is an integral part.

Some projects have further connected Asian countries, such as the Myanmar-Bangladesh-China Power Integration Project, with a transmission capacity plan of 3000 MW. Prior to that, cooperation between Myanmar and China under the Shweli River Cascade I Hydropower Station had been transmitting 300 MW of electricity between China and Myanmar since 2009 (ACE 2017).

Hydropower is a popular and reliable source of energy in the region due to its flexibility in both generating electricity and providing irrigation water. There are various modes of hydropower in the region, from large-dam hydropower plants, run-off from rivers, and pump storage hydropower. These modes generally have a wide range of capacity factors, an indication of the hydro-resources shared between generating electricity and irrigation systems. This interrelated function creates an underlying challenge for hydropower in the water–food–energy nexus, especially in the Mekong Delta region where the water resources from the river are shared and flow into different countries.

Despite its considerable benefits, hydropower, especially the large-dam type, creates complex environmental and financial challenges. Environmentalists oppose the construction of new, large hydropower plants, as they could impact the biodiversity in rivers and the livelihoods of riverine communities. The utilization of water resources in electricity generation (hydropower) could also impact agricultural activity due to changes in river flow quantities. As climate change impacts become more severe and cause prolonged dry seasons and drought, a water crisis around river areas is inevitable. In 2019, the Mekong River experienced its lowest water levels in more than 100 years, and the levels have not yet recovered (Fawthrop 2019). This water–energy crisis has led to complex water governance of the Mekong River, raising potential tensions around water allocation between different sectors, including dams and hydropower.

3.5.2 Intersectoral Linkage: Bioenergy

Bioenergy is another area of interlinkage of the WEF nexus. The production of biofuel requires agricultural feedstocks, e.g., oil palm, corn, and sugarcane, whose production requires water resources. Bioenergy production also competes with food production for land use. On the other hand, biomass resources can also be derived from agricultural waste.

With its large arable land and abundant resources, Southeast Asia has consumed a large amount of biomass and other bioenergy sources, accounting for approximately 12% of the primary energy supply in 2017. Bioenergy sources are widely popular as traditional cooking and heating fuels in the residential sector, accounting for 24 Mtoe out of 74 Mtoe in total biomass. "Modern" bioenergy, including biofuels, is utilized as feedstock in industry, which is the largest sector that uses bioenergy, followed by electricity generation, transportation, and commercial production.

In terms of power generation, bioenergy use grew extensively after 2010 as Thailand installed approximately 1987 MW of biomass power plants in 2011 and 344 MW of biogas in 2012. By 2017, ASEAN had installed a 5.4 GW of bioenergy-based power plant or a 2.3% power capacity mix. As the region aims to achieve a 23% RE share of TPES by 2025, bioenergy electricity is projected to double, from 21 TWh in 2017 to 42 TWh in 2025 or 3.1% of the power mix. Under the same scenario, a bioenergy-based power plant is likely to continue to increase its power generation to approximately 116 TWh by 2040 or 5.5% of the power mix.

The promising future of bioenergy electricity is also reflected in the national targets of ASEAN countries, which are aligned with their development of power plants. For example, Indonesia, the country with the largest share of the region's primary energy, aims to add installed capacity of 2200 MW of biomass power plants, 274 MW of waste-to-energy plants, and 128 MW of biogas by 2025. Thailand, with almost 4 GW of biomass plants, will focus more on building waste-to-energy plants. The country aims to increase the waste-to-energy plant capacity to 784 MW by 2022, which is 2.8% higher than the 2018 capacity. Vietnam has a very ambitious target for building more biomass power plants, from 55 MW in 2017 to 1820 MW in 2025. Myanmar, which plans to increase the country's electrification rate, will introduce a 20 MW biomass power plant in 2020 and increase its amount of biomass to seven times more by 2025. The country also plans to build 20 MW of waste-to-energy plants.

However, to sustain bioenergy-based power plant operation, countries need to consider feedstock availability. Resource assessment of potential bioenergy feedstock in each country will be the key to ensuring this approach is economically viable. Another issue is the environmental impacts caused by hazardous chemicals, such as dioxins, emitted from the combustion process.

In the transportation sector, biodiesel and bioethanol are aggressively promoted in some ASEAN countries, as countries plan to increase biofuel use to reduce oil import dependency. Thailand, Malaysia, Indonesia, and the Philippines have abundant biofuel feedstock resources, such as sugarcane, palm oil, and coconut oil. Looking at the historical trend, these four countries had made impressive progress in shifting to cleaner fuels in the transportation sector. ASEAN biodiesel consumption increased fivefold within seven years, from 824 Mtoe in 2010 to 4055 Mtoe in 2017, while ethanol consumption increased threefold, from 434 Mtoe in 2010 to 1280 Mtoe in 2017. In terms of biodiesel consumption, Indonesia accounts for the largest share at 56% of total production and the highest growth, from 197 to 2275 Mtoe within seven years or a 1.5-fold annual increase. In terms of ethanol demand, Thailand accounts for the largest share, with 73% of the total production in 2017, yet the Philippines has shown a higher growth rate, with approximately 35% of annual growth (ACE 2020).

Demand is increasing in addition to a higher blending policy and diesel/gasoline consumption. As the main feedstock for biodiesel production, palm oil production needs to increase through the extension of plantation areas. However, with limited arable land, promoting biodiesel would affect other important economic plant cultivation areas, such as those for rice and rubber.

Other sources of biodiesel feedstock, such as coconut oil, also face a food-energy challenge. As coconut oil and its products are in high demand from food, cosmetic, and other industries, the price of coconut oil can be higher than the price of diesel. The case of bioethanol, which can be produced from sugar cane, is similar. In the Philippines, the growing sugar demand, both domestic and international, coupled with rising ethanol demand due to increasing number of vehicles, has resulted in an inadequate domestic supply. Thus, the country has started to import ethanol to meet the fuel demand instead.

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Chapter 4
Status of Food Security in East and Southeast Asia

Shofwan Al Banna Choiruzzad

Abstract This chapter attempts to provide an overview of the food security status of East and Southeast Asia. While significant progress has been achieved during the last few decades, food security remains a challenge for many people in the region. This chapter starts by looking at different aspects of food security: (1) the availability of food, (2) access to food, (3) food utilization, and (4) the stability of food supplies. It also elaborates on the impact of the COVID-19 pandemic on food security in the region and regional cooperation to strengthen food security.

Keywords East and Southeast Asia · Food security · COVID-19 · Regional cooperation · Sustainability

4.1 Introduction

The economic growth enjoyed by most of the countries in east and southeast Asia regions, accompanied by the declining number of people living in poverty, has led to significant progress in the food security situation. Nevertheless, food security remains a challenge for many countries in the region. Based on the definition of food security of the United Nations Food and Agriculture Organization (FAO), which argued that "food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (World Food Summit 1996; FAO 2006), there are multiple situations in which many people in the region do not have physical or/and economic access to food.

This chapter is written to provide a concise but hopefully comprehensive picture of the food security status of East and Southeast Asia. It starts by looking at different aspects of food security: (1) the availability of food, (2) access to food, (3) food utilization, and (4) the stability of food supplies. In each section, this chapter aims

S. A. B. Choiruzzad (✉)
Department of International Relations, Universitas Indonesia, Depok City, Indonesia
e-mail: shofwan.albanna@ui.ac.id

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to capture the general picture of the region using available reliable data, mostly from the FAO but also from the World Bank, the International Monetary Fund (IMF), and other sources. These examinations are also complemented by some elaboration of important highlights of each aspect. Because the COVID-19 pandemic is undoubtedly an important disruption in food security, the second part of this chapter details the impact of the pandemic on food security in East and Southeast Asia. It also provides a reflection on how embedded food security is in ecological and social systems, calling for more attention to the challenge of climate change. The third section discusses regional cooperation in strengthening food security in the region. Finally, this chapter ends with a conclusion.

4.2 State of Food Security in East and Southeast Asia

While there are different understandings of which countries can be included in “East Asia” and/or “Southeast Asia,” 15 countries are included in this discussion: Japan, China, the Republic of Korea, the Democratic People’s Republic of Korea (DPRK), Mongolia, Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. For this chapter, “East and Southeast Asia” is treated as a single region that comprises the abovementioned countries.

The region has witnessed rapid economic growth since the 1960s, with fast-paced growth in East Asia. When China opened its market in the late 1970s, this trend was further boosted. Southeast Asia also followed suit and transformed from the poorest subregion in Asia in 1965 into one of its fastest-growing parts. Although disrupted temporarily by the 1997 Asian Crisis, East and Southeast Asian economies successfully recovered and are now among the few “global engines of growth.”

Together with economic growth, the region has also witnessed significant progress in poverty reduction. In this respect, China records the world’s most spectacular achievement, showing a decrease from 66.3% of the population living below 1.9 USD per day in 1990 (2011 PPP) to almost zero (0.5%) in 2016, the latest year for that indicator in the World Bank database (The World Bank 2021). Japan and the Republic of Korea even achieved this number earlier. Similar stories are also seen in other East and Southeast Asian countries. In Thailand, the population living below 1.9 USD (2011 PPP) per day was 19.3% in 1981, and in 2019, the number was 0.1%. In Indonesia, it was 54.9% in 1990 and 2.9% in 2019. In the Philippines, the number dropped from 13.7% in 2000 to 2.7% in 2018. Even late bloomers such as Lao PDR, which had more than half of its population living under 1.9 USD per day in 1997, successfully reduced it to 10% in 2018 (The World Bank 2021).

Economic growth, a reduction in the poverty rate, and strong agricultural productivity provide a strong foundation for strengthening food security. Thus, it is unsurprising that East and Southeast Asia recorded exemplary progress in food security. In the early 1990s, undernourishment in Southeast Asia accounted for 31% of the population, making it among the worst in the world. The undernourishment rate declined sharply in the 2000s, although conditions vary in different countries with different levels of development (OECD/Food and Agriculture Organization of the United Nations 2017). Nevertheless, several factors contributing to food insecurity continue to be a challenge in many parts of East and Southeast Asia. While its geographic features have made the region one of the most productive agricultural baskets in the world, they also make the region prone to various disasters, such as earthquakes, tsunamis, fires, droughts, and floods, which are exacerbated by the effect of climate change. Various social and political factors, from political instability to the absence of good governance to gender and economic inequalities, also contribute to food insecurity in some parts of the region. Furthermore, the COVID-19 pandemic has also created significant challenges to food security in East and Southeast Asia. This pandemic has not only affected public health but also disrupted logistics and economic activities, leading to rising unemployment and increasing food prices.

It is also important to note that East and Southeast Asia is a diverse region. It is not only the home of some of the world's richest and most advanced economies (Japan, the Republic of Korea, Singapore) but also the home of some of the least developed countries (Cambodia, Lao PDR, and Myanmar are officially still on the United Nations Conference on Trade and Development (UNCTAD) list of least developed countries (UNCTAD 2021)). This diversity influences the food security status of the region. Consequently, although this chapter aims to provide an overall picture of the food security status of East and Southeast Asia, one must approach the information here carefully since there are variations in the food security situation in each specific country in the region. Some countries in the region are ranked in the top 30 of the Global Food Security Index (Table 4.1) published by The Economist Intelligence Unit (i.e., Japan (ranked 9th), Singapore (19th), the Republic of Korea (29th)), but some of them are also in the bottom third of the 113 countries surveyed (Cambodia and Lao PDR), and some are not included on the list (The Economist Intelligence Unit 2020).

4.2.1 Food Availability

It is well known that East and Southeast Asia is one of the most productive agricultural baskets in the world. According to FAO Statistics, there are 789.50 million hectares of agricultural land in this region, composing 16.44% of the world's agricultural land in 2018 (FAO 2021a). The favourable climate, fertile lands, and diversity of geographic features allow East and Southeast Asia to consistently be among the main producers of various crops and food commodities in the world.

However, the large and growing population of East and Southeast Asia makes the task of ensuring food security in the region difficult. In 2000, the total population of East and Southeast Asia (Table 4.2) was estimated to be 2.04 billion people plus (more than 1.5 billion in East Asia and 524 million in Southeast Asia). In 2018, the number jumped to more than 2.3 billion people (1.66 billion in East Asia and 654 million in Southeast Asia).

Table 4.1 Rankings in the Global Food Security Index 2020

Country	Global rank
Japan	9
Singapore	19
Republic of Korea	29
China	39
Malaysia	43
Thailand	51
Vietnam	63
Indonesia	65
Myanmar	70
Philippines	73
Cambodia	81
Lao PDR	90

Note Total countries ranked: 113. Brunei, Mongolia, and the PDR Korea are not included on the list
Source The Economist Intelligence Unit (2020) adapted by the author

Table 4.2 Population of East and Southeast Asia

	2000	2018
East Asia	1,519,781,309	1,666,471,330
Southeast Asia	524,123,565	654,030,466
East and Southeast Asia	2,043,904,874	2,320,501,796

Source FAO (2021a) adapted by the author

Furthermore, the integration of East and Southeast Asia into the global economy also means that it is taking part in global commodity chains. The region is supplying crops and food not only for itself but also for the world. The globalizing economy also means that demands for more diverse food and commodities are increasing in East and Southeast Asian countries, creating the need for imports in those countries, either from within East and Southeast Asia or from other regions. Domestic food production and food trade are discussed in the following sections to understand the situation of food availability.

4.2.1.1 Domestic Food Production

East and Southeast Asia is the main producer of rice, which is also the staple food of the region. Producing more than 418 million tons of rice (paddy) in 2019, East and Southeast Asia contributed to more than half of the global production of rice (Fig. 4.1). From this number, more than 209 million tons are produced by China, while approximately 188 million tons are produced by Southeast Asia. Japan also has a strong agricultural sector that produced more than 10 million tons of rice in 2019. Vietnam (with more than 43 million tons of rice produced in 2019) and Thailand (with more than 28 million tons in 2019) are known as leading producers and exporters of rice in Southeast Asia. While producing more rice than Vietnam or Thailand (54 million tons of rice in 2019), the sheer size of Indonesia's population means that Indonesia needs to import rice from other countries.

Apart from rice, East and Southeast Asia produces other important cereal/grains, such as wheat and maize. In 2019, the region produced 135.2 million tons of wheat and 315.58 million tons of maize. The region also produced considerable amounts of other cereals, such as buckwheat, barley, sorghum, and rye (Table 4.3).

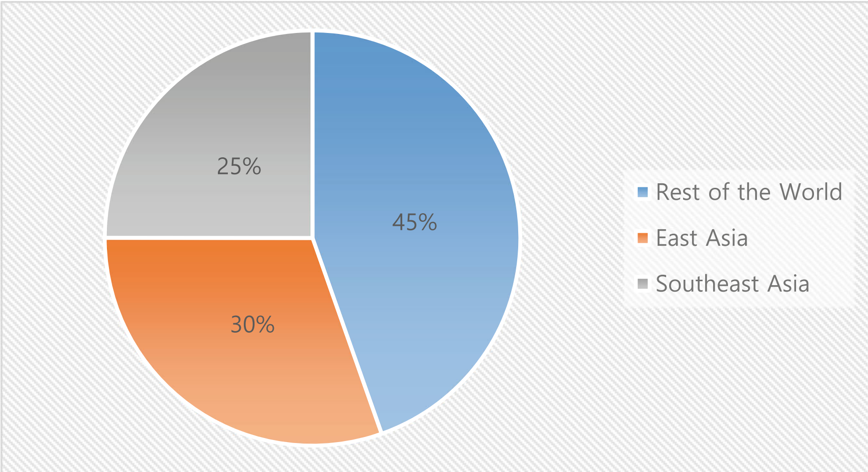

Fig. 4.1 Share of global rice production (*Source* FAO 2021a) adapted by the author

Table 4.3 Cereal production in East and Southeast Asia (million tons)

Commodity	Average 2005–2015	2016	2017	2018	2019
Cereals (total)	760.18	879.82	888.36	885.35	879.54
Rice	408.39	426.28	430.92	431.32	418.48
Wheat	117.55	134.71	135.60	132.83	135.20
Buckwheat	0.64	0.45	0.47	0.46	0.47
Barley	2.71	1.71	1.51	1.39	1.42
Maize	224.05	310.59	312.22	311.54	315.51
Sorghum	2.69	2.28	2.75	3.16	3.83
Rye	0.65	0.58	0.59	0.58	0.57
Cereals nes	0.25	0.32	0.33	0.34	0.35

Source FAO (2021a) adapted by the author

East and Southeast Asia also produces other food commodities that are significant in the global economy and in global food security. This is an important epicentre of oil crop production since the majority of the world's most widely used vegetable oil, palm oil, is produced in this region. The largest producers of this versatile commodity are Indonesia and Malaysia. The two countries produce approximately 84% of the global palm oil (United States Department of Agriculture 2021). Various kinds of vegetables and fruits are also abundant in this region, produced both for domestic consumption and for exports. East and Southeast Asia also produces a significant amount of sugar crops, 338.65 million tons in 2019. This region also produces a variety of root and tuber crops, such as cassava, yams, potatoes, and sweet potatoes. While a more detailed number of each crop can be seen in the FAOSTAT database, aggregate numbers for different categories can be seen in Table 4.4.

The production of food commodities in East and Southeast Asia also comes from livestock. Animal products, such as meat, eggs, and milk, are also produced domestically in East and Southeast Asian countries. The region produced 107.09 million tons of meat in 2019, including 35.09 million tons of poultry meat, 9.56 tons of beef and buffalo meat, and 5.5 million tons of sheep and goat meat. Apart from meat, countries in the region produce milk and eggs, which are also used extensively for daily consumption. The production of eggs increased from an annual average of 35.11 million tons during the 2005–2015 period to 45.93 million tons in 2019, while the production of milk was relatively stable at approximately 51–54 million tons per year (Table 4.5).

With vast inland waters and marine areas, East and Southeast Asia also have a strong fishery sector. In 2019, the region produced 26.69 million tons of freshwater fish in inland waters plus 0.29 million tons from the region's marine areas. East and Southeast Asia also produces marine fish in a significant amount: 29.07 million tons from its marine areas and an additional 0.02 million tons from its inland waters. Diadromous fishes, fishes that migrate between the sea and freshwater, are also produced in a good number. In 2019, 11.67 million tons of diadromous fish were produced from East and Southeast Asia's inland water, while 1.81 million tons were

Table 4.4 Production of food commodities in East and Southeast Asia (million tons)

Commodity	Average 2005–2015	2016	2017	2018	2019
Oil crops	338.75	393.95	463.76	467.63	479.58
Vegetables	515.07	613.83	629.67	645.78	661.36
Fruits	263.73	303.21	309.89	312.66	320.74
Tree nuts	3.81	5.18	5.25	5.49	5.68
Pulses	10.68	12.28	12.97	12.99	13.01
Roots and tubers	233.26	238.60	239.36	240.22	242.15
Sugar crops	286.28	291.70	301.69	346.62	338.65
Sugar raw centrifugal	28.15	25.95	28.25	33.51	N/A

Source FAO (2021a) adapted by the author

Table 4.5 Production of animal products in East and Southeast Asia (million tons)

Commodity	Average 2005–2015	2016	2017	2018	2019
Beef and buffalo meat	8.70	9.07	9.25	9.40	9.56
Eggs primary	35.11	40.88	43.35	43.90	45.93
Poultry meat	26.11	31.76	32.76	35.10	36.09
Milk	54.22	51.62	51.31	51.73	53.43
Sheep and goat meat	4.37	5.10	5.25	5.37	5.50
Meat (total)	101.44	113.76	115.15	117.62	107.05

Source FAO (2021a) adapted by the author

Table 4.6 Production of fishery products in East and Southeast Asia (million tons)

Commodity	Average 2005–2015	2016	2017	2018	2019
Inland waters					
Aquatic plants	0.07	0.07	0.08	0.07	0.05
Crustaceans	2.34	3.07	3.35	3.85	4.34
Freshwater fishes	21.37	26.68	26.86	26.72	26.69
Diadromous fishes	7.54	10.21	11.02	11.28	11.67
Marine fishes	0.01	0.02	0.02	0.02	0.02
Molluscs	0.63	0.56	0.54	0.48	0.46
Marine areas					
Aquatic plants	21.75	31.76	32.69	33.52	34.80
Crustaceans	5.82	6.79	7.20	7.14	7.27
Freshwater fishes	0.23	0.48	0.32	0.32	0.29
Diadromous fishes	1.23	1.48	1.43	1.62	1.81
Marine fishes	27.39	29.10	28.81	29.31	29.07
Molluscs	16.17	18.30	18.93	18.96	19.01

Source FAO (2021b) adapted by the author

produced from its marine areas. Apart from fishes, East and Southeast Asia produces various crustaceans, aquatic plants, and molluscs (Table 4.6).

4.2.1.2 Food Imports and Exports

Despite being a major producer of food commodities the growing population, participation in the global economy, and diversifying food preferences make domestic production in East and Southeast Asian countries insufficient to ensure that their people can at all times have access to "sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life." Consequently, East and Southeast Asian countries need to import some food commodities to bridge the gap. Even the relatively closed economy of the DPRK imports a significant amount of food commodities (including more than 1 million tons of cereals in 2019).

Cereals make up a significant portion of the food commodity imports of East and Southeast Asia. In 2019, the region imported a total of 115.11 million tons of cereals worth 30,247.82 million USD. This is a slight increase (approximately 0.51 million tons) from the previous year, although the total value slightly declined to 30,862.60 million USD, illustrating some fluctuation in the price of commodities. However, in terms of quantity, the general trend is a continuous increase in imports of cereals. Maize and wheat compose a majority of imports in this 'cereal' category. In 2019, East and Southeast Asia imported 54.42 tons of maize (with a value of 11,789.31 million USD) and 39.5 million tons of wheat (worth 10,433.60 million USD). While most East and Southeast Asian countries produce rice, some of them also import rice to fulfil the needs of their large population. East and Southeast Asia imported 7.68 million tons of rice (milled) in 2019, a slight decrease from the previous year.

Apart from cereals, the region imports a significant amount of sugars, fruits, roots, tubers, and vegetables. Imports in the 'sugar and honey' category amounted to 19.13 million tons in 2019, with a total value of 8738.68 million USD. In the same year, the import of different types of fruits amounted to 16.73 million tons (27,650.29 million USD), the import of roots and tubers amounted to 11.10 million tons (5041.36 million USD), and the import of vegetables amounted to 8.86 million tons (9905.98 million USD). Other significant categories of imported commodities are nuts and pulses (Table 4.7).

The growing consumption of meat and other animal products, which follows economic growth, also means that the demands for meat and other animal products are increasing. As shown in Table 4.8, bovine meat imports increased from 4.68 million tons in 2018 to 5.46 million tons in 2019. A similar increase in imports was also recorded in other categories of meat, such as pig meat (from 5.94 million tons in 2018 to 6.65 million tons in 2019) and poultry meat (3.93 million tons in 2018 and 4.25 million tons in 2019). In addition to meat, an increase in imports was recorded in the egg and dairy product category. Regarding fishery products, imports of fish, crustaceans, and other fishery products also show an upward trend (Table 4.8).

As producers of many food crops and commodities, the region is also actively involved in the global trade in crops and food commodities as exporters. Cereals compose a large chunk of exports from East and Southeast Asian countries, with a quantity of 21 million tons in 2019 valued at 10056.27 million USD. Among cereals, rice is a significant commodity. Rice exports from the region amounted to 14.27 million tons in 2019, with a value of 7396.95 million USD. Other significant exports are fruits, vegetables, roots, tubers, sugar and honey (Table 4.9).

Animal and fishery product exports are also quite significant in East and Southeast Asia. Fish exports reached 8.21 million tons in 2018, with a value of 28,000.90 million USD. Poultry meat is significant, with 2.34 million tons of poultry meat exported in 2019. The quantity and value of exports of animal and fishery products can be seen in Table 4.10.

Table 4.7 Imports of food crops and commodities in East and Southeast Asia (million tons)

Commodity	Average 2008–2017		2018		2019	
	Import quantity (million tons)	Import value (million USD)	Import quantity (million tons)	Import value (million USD)	Import quantity (million tons)	Import value (million USD)
Cereals	91.06	27,859.73	114.60	30,862.60	115.11	30,247.82
Rice (milled)	6.13	3604.21	8.38	4564.44	7.65	3867.53
Wheat	30.36	9432.85	39.54	10,608.78	39.50	10,433.60
Buckwheat	0.06	43.35	0.09	43.11	0.10	44.95
Barley	5.66	1537.55	8.44	2158.07	7.77	2073.50
Maize	40.73	10,610.05	49.44	10,763.26	54.42	11,789.30
Sorghum	4.26	1100.37	4.32	1023.75	1.38	325.03
Vegetables	7.46	7477.52	9.19	9925.77	8.86	9904.12
Fruits	11.79	15,566.67	15.26	24,718.91	16.72	27,646.39
Nuts	2.23	4387.15	2.84	7334.25	4.52	7812.58
Pulses	1.52	997.65	3.05	1421.83	2.94	1483.45
Roots and tubers	12.31	4338.47	12.85	5402.10	11.10	5040.39
Sugar and honey	16.30	8875.75	20.65	9677.09	19.10	8726.11

Source FAO (2021a) adapted by the author

Table 4.8 Imports of animal and fishery products in East and Southeast Asia (million tons)

Commodity	Average 2008–2017		2018		2019	
	Import quantity (million tons)	Import value (million USD)	Import quantity (million tons)	Import quantity (million tons)	Import value (million USD)	Import quantity (million tons)
Bovine meat	2.87	10,510.04	4.68	19,190.22	5.46	22,504.77
Poultry meat	3.63	7303.11	3.92	8295.26	4.24	9202.02
Pig meat	4.74	11,881.75	5.94	14,261.01	6.65	16,631.95
Other meat	0.38	1349.86	0.61	2582.16	0.66	3050.50
Eggs and dairy products	4.08	12,034.21	6.05	15,871.58	6.44	17,004.38
Crustaceans	0.86	7511.88	1.13	11,568.06	n/a	n/a
Fish	7.45	21,366.83	8.60	27,205.84	n/a	n/a
Molluscs, aquatic invertebrates	1.36	5655.08	1.49	7959.19	n/a	n/a

Source FAO (2021a, b) adapted by the author

Table 4.9 Export of food crops and commodities in East and Southeast Asia (million tons)

Commodity	Average 2008–2017		2018		2019	
	Export quantity (million tons)	Export value (million USD)	Export quantity (million tons)	Export value (million USD)	Export quantity (million tons)	Export value (million USD)
Cereals	19.87	9965.36	23.10	11,656.34	21.00	10,056.27
Rice (milled)	15.01	7904.94	16.94	8668.21	14.27	7396.95
Wheat	0.05	15.40	0.06	14.68	0.04	14.52
Buckwheat	0.05	29.42	0.03	16.27	0.03	13.48
Barley	0.01	3.07	0.004	1.24	0.001	0.70
Maize	1.25	424.72	1.04	549.30	1.27	402.84
Sorghum	0.05	16.56	0.05	23.89	0.04	15.69
Vegetables	9.78	12,072.53	11.54	16,261.13	11.78	16,202.09
Fruits	13.43	13,529.45	17.02	21,474.03	15.89	24,205.95
Nuts	2.28	5088.60	2.97	7682.98	3.08	7899.40
Pulses	2.12	2133.79	1.87	1389.59	1.81	1508.96
Roots and tubers	11.23	3389.66	10.91	4274.15	9.09	3897.64
Sugar and honey	10.67	6286.09	13.94	7715.29	14.95	7400.85

Source FAO (2021a) adapted by the author

Table 4.10 Exports of animal and fishery products in East and Southeast Asia (million tons)

Commodity	Average 2008–2017		2018		2019	
	Export quantity (million tons)	Export value (million USD)	Export quantity (million tons)	Export value (million USD)	Export quantity (million tons)	Export value (million USD)
Bovine meat	0.24	712.44	0.31	1036.94	0.35	1116.91
Poultry meat	2.07	4806.17	2.55	6400.81	2.34	6165.31
Pig meat	0.86	1956.29	0.67	2003.70	0.36	1074.38
Other meat	0.12	332.92	0.24	728.59	0.20	551.97
Eggs and dairy products	0.84	1708.48	0.91	2520.15	0.92	2554.62
Crustaceans	1.38	11,318.68	1.23	12,482.55	N.A	N.A
Fish	7.36	22,972.10	8.21	28,000.90	N.A	N.A
Molluscs, aquatic invertebrates	1.40	6865.85	1.50	9398.77	N.A	N.A

Source FAO (2021a, b) adapted by the author

Table 4.11 Availability of selected food products in East and Southeast Asia (million tons)

Commodity	2014	2015	2016	2017	2018
Wheat and products	113.16	115.35	118.74	119.65	120.91
Rice and products	305.60	308.27	308.41	309.05	313.73
Barley and products	0.59	0.81	1.09	1.27	0.61
Maize and products	24.30	24.95	25.85	25.92	26.74
Rye and products	0.10	0.25	0.18	0.26	0.20
Sorghum and products	4.53	7.24	4.54	4.28	3.30
Cassava and products	27.77	26.68	24.94	23.79	20.89
Potato and products	70.07	71.50	67.68	66.88	68.26
Sugar and sweetener	31.91	31.79	31.02	31.55	32.61
Nuts and products	4.85	5.41	5.50	6.52	6.72
Vegetable oils	19.66	20.13	20.21	21.23	21.88
Vegetables	552.65	576.07	587.20	591.62	602.57
Fruits (excluding wine)	186.32	192.55	192.34	195.56	201.21
Bovine meat	11.54	11.72	11.99	12.61	13.20
Mutton and goat meat	5.17	5.43	5.66	5.57	5.58
Pig meat	63.93	65.09	66.75	67.57	68.62
Poultry meat	30.72	31.29	31.60	32.21	32.86
Milk (excluding butter)	49.08	44.67	44.06	44.01	45.47
Eggs	33.53	35.00	36.29	36.15	36.71
Fish and seafood	82.43	85.85	87.18	89.65	89.65

Source FAO (2021a) adapted by the author

4.2.1.3 Food Available for Consumption

Through domestic production and international trade, as well as stocks from previous periods, the food availability in East and Southeast Asia is relatively secure. There is no significant shortage of commodities that threaten food security in the region. Even when the COVID-19 pandemic hit the region in 2020, the supply of food was relatively stable. In Table 4.11, we can see the availability of some selected food commodities in East and Southeast Asia until 2019. However, how this adequate food availability is accessed by people in different countries and with different levels of income is another important aspect of food security.

4.2.2 Food Access

While the availability of food is important, access to food is influenced by various factors that affect the demand side. 'Food access' is defined by the FAO as "access by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet" (FAO 2006). Conceptually, an increase in GDP per capita and a decline in poverty will consequently increase access to food and, thus, decrease the prevalence of undernourishment and food insecurity. However, different levels and paces of development have created different situations in access to food. For example, household surveys show that the share of food consumption in total income has changed differently in Vietnam and Cambodia. In Vietnam, the share declined from 57.96% in the 1992–1993 period to 34.21% in 2006. In Cambodia, the share declined slower: 77.42% in 2004 and 74.48% in 2009 (FAO 2021a). While those are separate surveys, they show that the different paces of development affect the capacity to obtain food at the household level.

In the early 1990s, undernourishment in Southeast Asia accounted for 31% of the population, making it among the worst in the world (OECD/Food and Agriculture Organization of the United Nations 2017). At the aggregate level, the undernourishment rate decreased significantly in the 2000s, mainly because of the sharp decline in China. In general, East and Southeast Asian countries experienced a decline in the number of undernourished people (nominal/absolute number of people) and in the prevalence of undernourishment (percentage to total population); however, some countries did not.

East Asian countries that developed earlier and countries such as Japan and the Republic of Korea already achieved a very low number of undernourished people before the 1990s and have continued to keep the number low into the present. China, which still had more than 50 million undernourished people in 2008, showed amazing progress and successfully reduced the number to almost zero in 2018. In contrast, the DPRK witnessed a significant increase in the number of undernourished people. Some countries, such as Indonesia, have experienced a significant decrease in the number of undernourished people, although the number is still significant (17.2 million people or approximately 6.4% of the population in 2018). More detailed information on the progress in reducing undernourishment can be seen in Table 4.12.

Another important indicator of food access is the number of severely food insecure people and the prevalence of severe food insecurity. In the FAO's database (FAO 2021a), a household is classified as severely food insecure when at least one adult in the household has been reported to have been exposed, at times during the year, to several of the most severe experiences described in the questions of the Food Insecurity Experience Scales (FIES), such as having been forced to reduce the quantity of food, having skipped meals, having gone hungry, or having to go a whole day without eating because of a lack of money or other resources. While country-level data are unavailable, the FAO provides interesting data on the number of severely food insecure people and the prevalence of severe food insecurity (Table 4.13). While the economy is generally growing positively and poverty is declining, the number of severely food insecure people is still increasing, both in absolute numbers and as a percentage of the total population, although it is still below the global average. This shows that food availability and economic growth do not always automatically translate into better access to food for everyone. There are complex factors that influence

Table 4.12 Number of undernourished people and the prevalence of undernourishment

Country	Number of undernourished people (million) (3-year average)		Prevalence of undernourishment (percentage) (3-year average)	
	2007–2009	2017–2019	2007–2009	2017–2019
Brunei Darussalam	n.a	n.a	< 2.5	< 2.5
Cambodia	2	1.1	14.5	6.8
China (mainland)	53.6	n.a	4	< 2.5
Democratic People's Republic of Korea	9.7	10.9	39.7	42.6
Indonesia	40.9	17.2	17.4	6.4
Japan	n.a	n.a	< 2.5	< 2.5
Lao People's Democratic Republic	1.1	0.4	18.3	5.4
Malaysia	1	1	3.6	3.2
Mongolia	0.6	0.2	22.3	5.5
Myanmar	9.2	4.2	18.4	7.8
Philippines	11.4	10.3	12.6	9.7
Republic of Korea	n.a	n.a	< 2.5	< 2.5
Singapore	n.a	n.a	0	0
Thailand	7.1	5.5	10.6	7.9
Viet Nam	11.1	6.5	12.9	6.8
World	693.7	632.9	10.2	8.3

Source FAO (2021a) adapted by the author

access to food, from inequality to infrastructure quality. Thus, measures to ensure food security must consider the specific contexts of different countries and regions, including their unique social, economic, and cultural characteristics.

Table 4.13 Number of severely food insecure people and the prevalence of severe food insecurity

	Number of severely food insecure people (million) (annual value)		Prevalence of severe food insecurity in the total population (percentage) (annual value)	
	2014	2019	2014	2019
East Asia	13.2	21.7	0.8	1.3
Southeast Asia	15.2	16.9	2.4	2.6
World	604.5	779.9	8.3	10.1

Source FAO (2021a) adapted by the author

4.2.3 Food Utilization

According to the FAO, 'food utilization' refers to the "utilization of food through adequate diet, clean water, sanitation, and health care to reach a state of nutritional well-being where all physiological needs are met" (FAO 2006). Utilization is also understood as "the way the body makes the most of various nutrients in the food" (FAO 2008). This means that not only the quantity of food but also the nutritional value of food and the way foods are consumed are important. Since East and Southeast Asia region is a major producer of many food crops and commodities, the number of nutritious foods is not a problem at the aggregate level. However, the problem of distribution, unequal access to food, and multiple social, economic, cultural, and political factors have contributed to problems in utilization.

The protein supply quantity (expressed in grams/capita/day) in East and Southeast Asia (Table 4.14) shows that, in general, the protein supply quantity is adequate. Nevertheless, it also reveals an interesting pattern of comparison. For example, people in Southeast Asia tend to consume more rice than their counterparts in East Asia, who also consume significantly more wheat than Southeast Asians. East Asians also consume significantly more vegetables than Southeast Asians.

Food security is not only about how people are able to consume food but also about how we can ensure various practices with regard to how we consume food, leading to the healthy nutritional status of individuals. Even when food is abundant, multiple socio-economic-political-cultural factors can lead to an unhealthy pattern of consumption, which in turn can lead to problems such as wasting or stunting among children and obesity among adults. For example, in many less developed areas in Southeast Asia (and in some parts of East Asia), there are still many children under five who suffer wasting. According to the World Health Organization (WHO), 'wasting' is defined as "low weight-for-height," which often indicates recent and severe weight loss, although it can also persist for a long time (World Health Organization 2021a). This condition often occurs when a person has extremely low energy intake or nutrient loss due to frequent or prolonged illnesses. If East Asia and Southeast Asia are combined into a single region, the percentage is lower than the global average. However, if we separate the two, Southeast Asia has a higher percentage of children under five years old affected by wasting. In 2019, 8.2% of children under five years old were affected by wasting in Southeast Asia, while globally, the number was 6.9%, and the number for East Asia was 1.7% (Fig. 4.2).

Another indicator that can be used to understand the quality of food utilization in the region is the percentage of children under five years of age who are stunted. Similar to wasting, stunting is also considered a condition of malnutrition. Stunting is defined as "low height-for-age" caused by chronic or recurrent undernutrition (World Health Organization 2021a). In general, the percentage of children under five years of age who are stunted has declined at the global level as well as in East and Southeast Asia. It is important to note that East Asia made very significant progress, with the percentage of stunting declining from 19.2% in 2000 to only 4.5% in 2019. In Southeast Asia, while progress was made, from 38.5% in 2000 to 24.7% in 2019, the number was still higher than the global average as of 2019 (21.3%) (Fig. 4.3).

Table 4.14 Protein supply quantity from different food items in East and Southeast Asia (gram/capita/day)

	2016			2018		
	East Asia	Southeast Asia	East and Southeast Asia	East Asia	Southeast Asia	East and Southeast Asia
Wheat and products	16.75	5.8	22.55	16.84	5.76	22.71
Rice and products	14.32	23.22	37.54	14.19	23.24	37.67
Barley and products	0.06	0.18	0.24	0.08	0.02	0.08
Maize and products	1.24	3.28	4.52	1.24	3.38	4.63
Rye and products	0.02	n/a	0.02	0.03	n/a	0.02
Sorghum and products	0.59	0.04	0.63	0.56	0.05	0.47
Cassava and products	0.04	0.58	0.62	0.04	0.46	0.5
Potato and products	1.8	0.2	2	1.77	0.19	1.99
Sugar and sweetener	0.02	0.05	0.07	0.02	0.05	0.07
Nuts and products	0.44	0.39	0.83	0.45	0.53	0.98
Vegetables	12.45	2.78	15.23	12.54	2.88	15.63
Fruits (excluding wine)	1.15	1.16	2.31	1.17	1.14	2.35
Bovine meat	2.05	1.77	3.82	2.15	1.75	4.05
Mutton and goat meat	1.23	0.17	1.4	1.19	0.17	1.36
Pig meat	10.74	3.71	14.45	10.84	3.76	14.71
Poultry meat	4.68	4.28	8.96	4.76	4.51	9.3
Milk	3.02	2.02	5.04	3	2.11	5.19
Eggs	6.09	2.09	8.18	6.01	2.21	8.26
Fish and seafood	9.69	11.54	21.23	9.75	12.02	21.73

Source FAO (2021a) adapted by the author

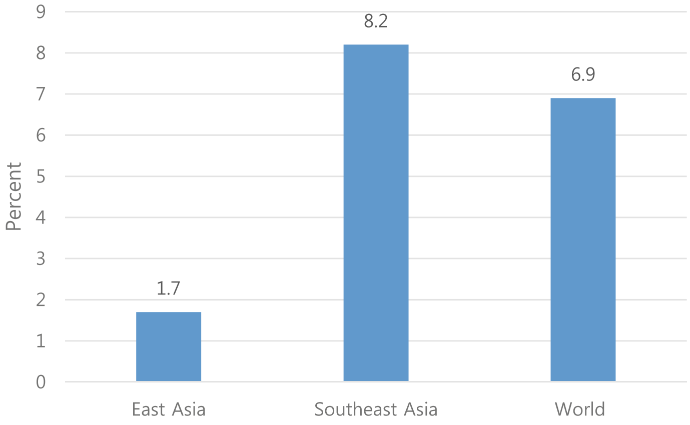

Fig. 4.2 Percentage of children under 5 years affected by wasting in East and Southeast Asia (percentage), 2019 (*Source* FAO 2021a) adapted by the author

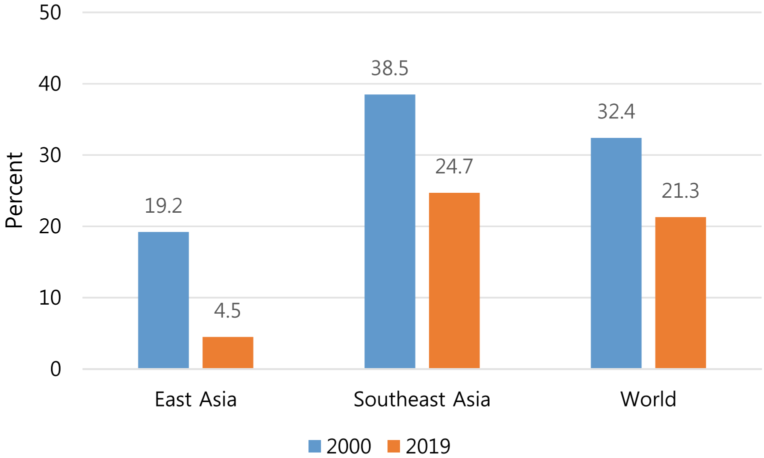

Fig. 4.3 Percentage of children under 5 years of age who are stunted in East and Southeast Asia (percentage), 2000 and 2019 (*Source* FAO 2021a) adapted by the author

While the percentage of children affected by wasting and stunting can be used to indicate a problem in food utilization in terms of malnutrition, which is associated with a low intake of nutrients and calories, there is another indicator that can be used to look at the food utilization problem in terms of the aspect of excessive consumption: obesity. The WHO defines obesity as "excessive fat accumulation that presents a risk to health," which is now considered "growing to epidemic proportions" (World Health Organization 2021b). The prevalence of obesity is increasing in both East and Southeast Asia, although it is still lower than the prevalence at the global level (Fig. 4.4).

Fig. 4.4 Prevalence of obesity in the adult population (18 years and older) (*Source* FAO 2021a) adapted by the author

4.2.4 Stability of Food Supplies

Stability is connected to food availability and access to food "at all times," which is potentially threatened by sudden shocks such as natural disasters and humanitarian crises or cyclical events (FAO 2006). In this context, many East and Southeast Asian countries are vulnerable to natural disasters due to their geographic location. Many of these countries are in the Pacific Ring of Fire, which makes them susceptible to earthquakes and volcanic eruptions, and many of them are also prone to extreme weather events such as cyclones and typhoons. In the Center for Research on the Epidemiology of Disasters (CRED) database, as shown in Fig. 4.5, five of the ten countries with the most natural disasters are in East and Southeast Asia (CRED 2019). Many parts of this region are also considered disaster hotspots by World Bank experts (Dilley et al. 2005).

To respond to such threats to the stability of food supplies, an adequate level of stocks is important to ensure that food is available and that the volatility of food prices is effectively managed. Fortunately, the size of such stocks is relatively sufficient in East and Southeast Asia (Table 4.15).

Another important indicator to look at is the cereal import dependency ratio, which provides a measure of the dependence of a country or region on cereal imports. It indicates how much of the available domestic food supply of cereals has been imported and how much comes from the country's own production. In this indicator, most East Asian countries, except for China (net exporter in 2005–2007, 4% at 2015–2017) and the DPRK (22.4% and 14.6% in 2005–2007 and 2015–2017, respectively), have a relatively high cereal import dependency ratio, showing that most of the available domestic supply of cereals comes from international trade. On the other hand, the cereal import dependency ratio of Southeast Asian countries is generally

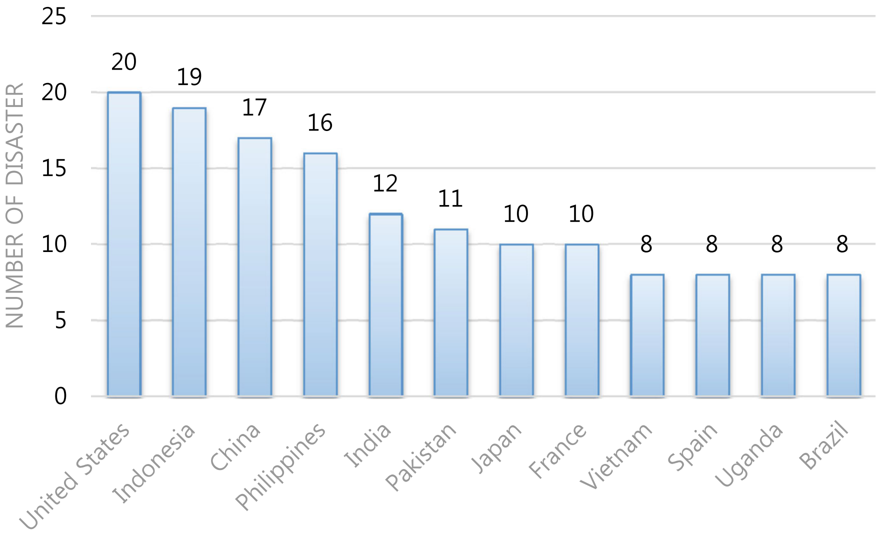

Fig. 4.5 Ten countries with the most natural disasters in 2019 (*Source* CRED 2019) adapted by the author

Table 4.15 Opening stocks of selected food commodities in East and Southeast Asia

Commodity	World	East and Southeast Asia		
		2016	2017	2018
Barley	45.08	1.20	1.20	0.84
Buckwheat	1.26	0.47	0.62	0.80
Cereals nes	6.70	0.05	0.05	0.04
Maize	432.69	230.71	242.50	242.29
Rice. Paddy	107.70	46.61	49.09	46.20
Rye	6.19	0.23	0.26	0.30
Sorghum	13.00	1.15	1.01	0.78
Wheat	403.66	103.97	122.43	138.80
Potato	53.49	4.66	1.75	1.86
Cassava	9.63	0.01	0.01	0.01

Source FAO (2021a) adapted by the author

low, except for Malaysia, Brunei, and Singapore. Some countries, such as Thailand and Cambodia, have recorded a negative cereal import dependency ratio, meaning that they were net exporters of cereals in the 2015–2017 period (Table 4.16).

Agriculture is an important sector in East and Southeast Asian economies. However, this region is also vulnerable to various climatic shocks and water stress, which often lead to crop failures. In this context, the expansion of irrigation, accompanied by improvements in water supply management, is an important measure for

Table 4.16 Cereal import dependency ratio in East and Southeast Asia (percentage)

Country	Cereal import dependency ratio (three years average)	
	2005–2007	2015–2017
Brunei Darussalam	91.1	n.a
Cambodia	1.2	−9.7
China	−1.6	4
Democratic People's Republic of Korea	22.4	14.6
Indonesia	12.2	10.7
Japan	77.7	69.8
Lao People's Democratic Republic	−0.6	−0.2
Malaysia	81.1	71.5
Mongolia	68	43.6
Myanmar	−1.5	−1.3
Philippines	22.2	20.4
Republic of Korea	75.4	75.9
Singapore	n.a	n.a
Thailand	−41.7	−68
Viet Nam	−12.5	6.1
World	−0.6	−1.8

Source FAO (2021a) adapted by the author

ensuring food security. The higher the percentage of arable land equipped for irrigation, the less vulnerable the agricultural sector is to shocks. In East and Southeast Asia, the percentage of arable land equipped for irrigation was relatively stagnant from 2009 to 2019. Some countries even recorded a noticeable decline, such as Brunei, Lao PDR, Vietnam, and Indonesia (Table 4.17).

4.3 COVID-19 Pandemic and the Sustainability of Food Security

Disruption to food security is often unpredictable, and the COVID-19 pandemic is an excellent example of this. While the pandemic has had a direct impact on public health, its repercussions on other dimensions of well-being, including food security, have been significant.

East and Southeast Asian countries' experiences with COVID-19 are quite diverse. Some experienced the pandemic early, while others experienced it slightly later. For example, Vietnam reacted quickly and strongly to COVID-19 and managed to control

Table 4.17 Percentage of arable land equipped for irrigation

Country	Percentage of arable land equipped for irrigation (three years average)	
	2008–2010	2018–2020
Brunei Darussalam	42.9	20
Cambodia	9.5	9.1
China	57	60.9
Democratic People's Republic of Korea	62.1	62.1
Indonesia	30.3	26.8
Japan	58.6	58.1
Lao People's Democratic Republic	25.9	19.2
Malaysia	42.3	52.7
Mongolia	12	14.8
Myanmar	21.4	20.9
Philippines	27.7	32.7
Republic of Korea	53	50.7
Singapore	n.a	n.a
Thailand	41.5	38.2
Viet Nam	72.5	65.7
World	23.1	24.1

Source FAO (2021a) adapted by the author

the public health impact relatively well, with fewer casualties. Thailand, Brunei, Cambodia, and Lao PDR also witnessed a low number of cases, at least until the early months of 2021. On the other hand, some countries have experienced a high number of cases and high fatality rates since the beginning, such as Indonesia and the Philippines. The timing, sequence, and casualties of the pandemic are different, as seen in Fig. 4.6.

While the number of cases and the number of fatalities directly due to COVID-19 are quite diverse, most countries have felt pressure in their food security situation. During the early days of the pandemic, some countries responded to the shock by restricting exports and impending imports. Such efforts led to rising short-term prices in importing countries and lower income prospects for exporters. APT (ASEAN Plus Three) leaders soon saw that those measures were counterproductive and started to coordinate their policies. In June 2020, APT leaders declared their commitment to keeping the markets open to ensure the resiliency and sustainability of regional supply chains and to refrain from taking policies that may hinder the flow of food, commodities, medicines, and medical supplies (ASEAN Plus Three 2020a). Such regional coordination eased the insecurity and allowed a stable supply of food and commodities during the pandemic. Despite the declines in the early stage of the

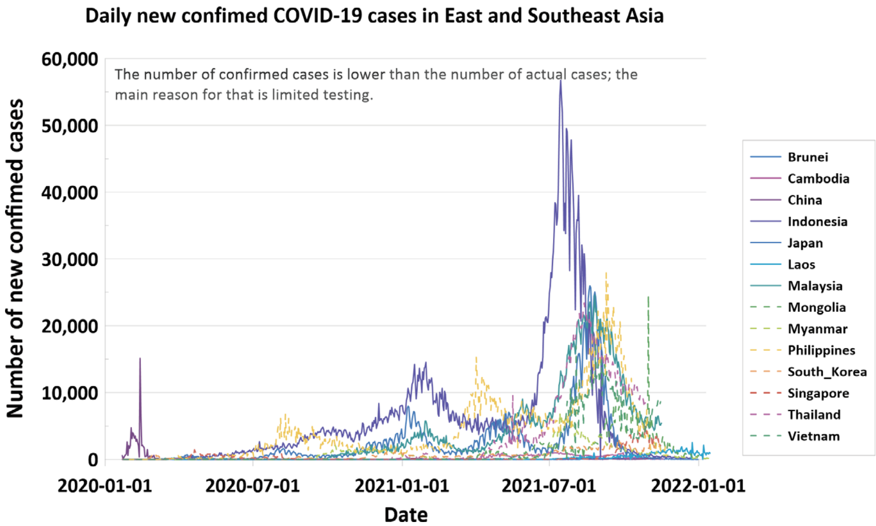

Fig. 4.6 Daily new confirmed COVID-19 cases (*Source* Our World in Data 2021) adapted by the author

pandemic, commodity production increased in 2020 compared to 2019. Nevertheless, continuous communication is still necessary to prevent panic on the supply side (Asia Pacific Foundation of Canada 2021).

While most countries can avoid the worst scenarios, the pressure on food security remains strong. Lockdowns and/or lesser mobility restrictions have created transport and border bottlenecks, affecting the quantity and quality of food available for consumption. Food production and availability are stable, but prices are rising (Table 4.18).

This situation has compromised the ability of people to access sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life. Before the pandemic, 144.5 million people in ASEAN member states could not afford a nutrient-adequate diet, and 61.3 million people struggled to afford an energy-sufficient diet. After the pandemic, the number of households unable to afford a nutrient-adequate diet rose to 179.8 million people, and those struggling to afford an energy-sufficient diet also increased to 68.9 million (Asia Pacific Foundation of Canada 2021). Studies on the food security situation in several countries have confirmed this situation. A study in Malaysia, which has handled the pandemic relatively well, found that 63.76% of respondents from families in the bottom 40% had to reduce their food intake (Ibrahim and Othman 2020). In the Philippines, the national hunger rate spiked from 8.8% in December 2019 to 21.1% in 2020 (Philstar 2020). A survey by the Indonesian Institute of Sciences (LIPI) found that 36% of surveyed households can be categorized as food insecure (LIPI 2020). It is estimated that households that struggle to afford a "calorie adequate" diet will rise from 6 to 8% due to the pandemic, and more than one-third of Indonesians

Table 4.18 Consumer price, food indices (base year 2015 = 100)

Country	Jan-19	Jul-19	Jan-20	Jul-20	Jan-21
Brunei	101.38	100.86	101.66	103.06	105.80
Cambodia	112.41	114.09	116.78	119.79	121.96
China (mainland)	107.76	110.24	126.76	121.58	123.21
Indonesia	116.11	115.33	120.92	121.61	123.35
Japan	104.90	104.41	105.66	106.17	105.57
Lao PDR	105.06	110.41	116.89	120.11	119.67
Malaysia	111.35	111.61	112.36	113.11	114.04
Mongolia	114.80	126.55	123.79	136.04	134.22
Myanmar	126.62	134.47	135.44	135.92	138.58
Philippines	114.47	113.84	117.01	116.55	124.15
Republic of Korea	108.80	106.68	110.81	111.28	118.04
Singapore	106.03	105.81	107.92	110.04	110.11
Thailand	98.64	100.80	100,043	101.35	101.01
Vietnam	107.15	107.38	118.86	120.15	119.86

Source FAO (2021a) adapted by the author

(approximately 90 million) will have difficulty accessing a "nutrition adequate" diet (Asia Pacific Foundation of Canada 2021). A similar result was found in Lao PDR, where a survey revealed that 30% of respondents consumed less nutritious food due to rising grocery prices and lower income (WFP and FAO 2020). Vietnam also faced similar conditions, with a study finding that 34.5% of respondents claimed that they experienced worsened food quality compared to the usual (UNICEF Viet Nam 2020). In Cambodia, the percentage of food-insecure households rose from approximately 18% to approximately 22% (and probably more) due to the pandemic (Asia Pacific Foundation of Canada 2021). In Myanmar, 24% of urban residents and 44% of pregnant mothers did not eat enough healthy food (Headey et al. 2020). Due to the continuing political crisis, it is expected that the situation will worsen.

The COVID-19 pandemic illustrates the embeddedness of food security in ecological and social systems. The sustainability of food security is strongly tied to the patterns of interaction between humans and nature, including in developing responsible patterns of production and consumption (Banerjee 2010). For example, the conservation of tropical peatlands, abundant in Southeast Asia, is crucial to preventing future outbreaks of potential zoonotic diseases. Expansions of human economic and social activities often create habitat disruptions in areas with high biodiversity, which includes the presence of many potential disease vectors and creates risks for future zoonotic disease pandemics (Harrison et al. 2020). Thus, measures to ensure food security must also be integrated into greater efforts to mitigate climate change and to prepare proper adaptation in vulnerable societies.

Table 4.19 Rankings and scores of East and Southeast Asia countries in the ND-GAIN Country Index 2019

Country	ND-GAIN ranking	Score
Brunei	42*	57.6
Cambodia	140	39.3
China	61	53.7
Indonesia	97	47.1
Japan	15	68.2
Korea (Republic of)	14	69.1
Korea (DPR of)	N/A	N/A
Lao PDR	142	38.9
Malaysia	42*	57.6
Mongolia	67	52
Myanmar	160	36.1
Philippines	114	43.6
Singapore	7	71.4
Thailand	62	52.8
Vietnam	98	47.0

Source Notre Dame Global Adaptation Initiative (2021) adapted by the author
*Its just to note that the score of Brunei and Malaysia is the same for that year

In this context, understanding the nexus between water, energy, and food security is crucial. Unsustainable patterns of energy consumption and production create pressures on the environment, including water, which in turn will affect food security in the region. On the other hand, food production also produces greenhouse gas emissions through various channels, from forest conversion to peatland burning to the use of energy, which will affect the environment. Understanding the entanglements between water, energy, and food security is important for climate change mitigation and adaptation, which is crucial for the sustainability of food security in the region.

This is a significant challenge for most East and Southeast Asian countries. In the Notre Dame-Global Adaptation Initiative (ND-GAIN) Country Index 2019, which attempts to summarize a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience, most countries in this region scored below 60. Only Singapore, the Republic of Korea, and Japan scored above 60 (Table 4.19).

4.4 Regional Cooperation to Strengthen Food Security

Among the 15 countries in East and Southeast Asia, 10 are ASEAN (Association of Southeast Asian Nations) members, and 13 of them are APT members. This shows

Table 4.20 Participation of East and Southeast Asian countries in ASEAN and/or APT

Country	Participation in ASEAN and/or APT
Brunei	ASEAN (1984), APT
Cambodia	ASEAN (1999), APT
China	APT
Indonesia	ASEAN (1967), APT
Japan	APT
Korea (Republic of)	APT
Korea (DPR of)	n/a
Lao PDR	ASEAN (1997), APT
Malaysia	ASEAN (1967), APT
Mongolia	n/a; SCO (observer)
Myanmar	ASEAN (1997), APT
Philippines	ASEAN (1967), APT
Singapore	ASEAN (1967), APT
Thailand	ASEAN (1967), APT
Vietnam	ASEAN (1995), APT

Source ASEAN (2021) adapted by the author

that regional cooperation plays an important role in managing multiple aspects of international relations in the region (Table 4.20).

In this context, food security has been an important agenda for East and Southeast Asian leaders since the establishment of these regional organizations. The ASEAN Declaration, signed in Bangkok in 1967 and, thus, also known as the Bangkok Declaration, mentioned that one of the aims and purposes of the establishment of ASEAN was "To collaborate more effectively for the greater utilization of their agriculture and industries and the raising of the living standards of their peoples" (ASEAN 1967). While not mentioning the term food security explicitly, the inclusion of such passages shows the importance of food security in regional cooperation. The concern for food security was also evident in the Declaration of ASEAN Concord, signed in Bali, February 24th, 1976. The elimination of poverty, hunger, disease, and illiteracy was mentioned as the "primary concern of the member states." Furthermore, "cooperation in basic commodities, particularly food and energy," was made the first programme of action in the economic cooperation segment (ASEAN 1976). In 1979, the term "food security" was explicitly mentioned in the Agreement on the ASEAN Food Security Reserve, signed in New York, October 4th, 1979, which established the ASEAN Emergency Rice Reserve (AERR) (ASEAN 1979). Under the AERR, each member promised to earmark a particular quantity of rice (50,000 tons in the beginning but then amended to 67,000 tons) to be available for other members in emergency situations. Nevertheless, the AERR was never utilized by ASEAN members, probably due to its limited size of stocks and complex requirements (Kim and Plaza 2018; Mujahid and Kornher 2016). To overcome this problem, there was a discussion to enlarge the cooperation to involve "Plus Three" countries, which have more financial capacity. The involvement of the Plus Three countries (Japan, China, Korea), as well as the modification of its mechanism, was expected to overcome the limitation of the AERR. In 2004, the East Asia Emergency Rice Reserve (EAERR) pilot project commenced.

Following another crisis in 2007/2008, ASEAN adopted the ASEAN Integrated Food Security (AIFS) Framework and the Strategic Plan of Action on Food Security in the ASEAN Region (SPA-FS) in March 2009 (ASEAN 2009). There are four components of the framework: (1) food security and emergency/shortage relief, (2) sustainable food trade development, (3) an integrated food security information system, and (4) agricultural innovation. Following the evolution of the concept of food security, the regional framework was further developed in 2015 with the publication of AIFS and SPA-FS 2015–2020, which included nutrition-enhancing agricultural development as the fifth component. It also developed more measurable outputs and more systematic monitoring and evaluation mechanisms (ASEAN 2016).

This framework has provided the basis for larger regional cooperation, which involves Plus Three countries (Japan, China, Republic of Korea) in the form of the ASEAN plus Three Emergency Rice Reserve (APTERR). The APTERR aims to strengthen food security through specific rice reserve mechanisms to prepare for large-scale disasters or other emergency cases. Learning from the non-utilization of the previous regional food reserve mechanism, the APTERR has two reserve mechanisms: (1) the "earmarked rice reserve," for which the member countries pledge to hold a certain quantity as an emergency international reserve and (2) the "stockpiled rice reserve," which is kept in the form of actual rice (or cash). The addition of the stockpiled reserve and/or cash fund aims to simplify the process since this fund is released as an immediate response to an emergency. If the emergency reserve has not been used or partly used during the reserve period, the remaining quantity is used for poverty reduction purposes. Regarding the earmarked reserve, the quantities that the countries have declared as the international emergency reserve are released. Other than the introduction of the stockpiled rice reserve, the APTERR has a much larger quantity in the earmarked rice reserve (787,000 tons) compared to the previous AERR (50,000 and then 67,000 tons). While the utilization of the APTERR is still very limited, observers have noted that it might have a calming effect on the market and thus help to tame the historically volatile international rice market (Mujahid and Kornher 2016).

Apart from the regional emergency reserve, another important initiative is the development of a food information and early warning system through the establishment of the ASEAN Food Security Information System (AFSIS). The AFSIS was first approved as a project by the Ministers of Agriculture and Forestry of the ASEAN member states plus the People's Republic of China, Japan, and the Republic of Korea during the APT Ministerial Meeting on Agriculture and Forestry (AMAF + 3), hosted by Lao PDR, in 2002. After the first phase (2003–2007) was completed, the project was extended into the second phase (2008–2012). At the end of the second phase, there was a joint endorsement among APT members to make the AFSIS a permanent mechanism rather than a project. However, disagreements over various issues led ASEAN leaders to cancel the plan, and in 2017, APT countries agreed to continue the AFSIS as a “Project led by Thailand with support from Plus Three Countries” (AFSIS 2021).

As already discussed, the COVID-19 pandemic has significantly affected the food security situation in the region. ASEAN and APT responded to the crisis by initiating several measures. During the early period of the pandemic, ASEAN anticipated the pandemic’s impact on food security by declaring a joint commitment to ensure food security, food safety, and nutrition by minimizing disruptions in the regional food supply chain (ASEAN 2020c). A similar commitment was declared by APT leaders during the Special ASEAN Plus Three (APT) Summit on Coronavirus Disease 2019 (COVID-19) on April 14th, 2020, which endorsed the utilization of the APTERR (ASEAN Plus Three 2020b). The commitment was further reiterated in the APT Economic Ministers Joint Statement on Mitigating the Economic Impact of the COVID-19 Pandemic on June 4th, 2020 (ASEAN Plus Three 2020a). While most APT countries tend to rely on national mechanisms to deal with COVID-19 and its consequences for food security, the regional mechanism has been utilized, although still in a limited manner (APTERR 2020). Beyond utilizing the emergency rice reserve, ASEAN published the ASEAN Declaration on Strengthening of Adaptation on Drought (ASEAN 2020a) and the ASEAN Guidelines on Disaster Responsive Social Protection to Increase Resilience (ASEAN 2020b).

East and Southeast Asia’s long experience with regional cooperation to ensure food security shows that while there are still limitations, regional cooperation is an important pathway to strengthen food security in East and Southeast Asia. The COVID-19 pandemic has provided a strong push for ASEAN and APT leaders to further develop regional mechanisms to anticipate the impacts of future pandemics or any other crises on food security. While most countries still rely on policies at the national level, regional cooperation mechanisms can help ease the burden of all member countries when such disruptions occur. Furthermore, since East and Southeast Asia is a major producer of food and agricultural commodities, strong regional cooperation will help to stabilize the volatile international market. Not only complementing national measures to ensure food security but also carrying out effective regional cooperation in East and Southeast Asia will help to strengthen food security in the region and beyond.

4.5 Conclusions

While East and Southeast Asia is a major producer of crops and food commodities, food security remains a challenge in many parts of the region. Significant progress in economic development and poverty reduction in the last few decades has contributed to a better food security situation, but multiple factors continuously threaten food availability, access to food, or the proper utilization of food among a substantial number of people in this region. East and Southeast Asian countries provide important lessons for global efforts to ensure food security, including both successes and failures.

Furthermore, the embeddedness of food security in social and ecological systems informs us that we should take a long-term view. Our current economic system, which has benefited East and Southeast Asian countries through high growth rates for decades, has also created unsustainable patterns of energy consumption and production, which will create pressures on environmental sustainability. In turn, these pressures on the environment will create pressures on the sustainability of food security in terms of food availability (e.g., climate change is related to changing weather patterns and extreme weather events that will affect food production), food access (e.g., the impacts of climate change are compounding the problem of inequality), food utilization (e.g., decreasing the quality of water, air, and the environment), and the stability of food supplies (e.g., more frequent disasters will create shocks). In this context, policies to ensure food security must be nested in a larger strategy to mitigate and adapt to climate change. Understanding the entanglements between water, energy, and food security is an important starting point.

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Chapter 5
Water-Food Nexus in East and Southeast Asia

Jin-Yong Choi, Pureun Yoon, Seung-Hwan Yoo, and Sang-Hyun Lee

Abstract Growing demands on natural resources such as water, energy, and food (WEF) have posed serious global challenges over the last decades. The concept of WEF nexus has emerged to address these challenges and provide a framework for sustainable resource allocation strategies. Among the varying interactions between the water, energy, and food sectors, this chapter reviews the water-food (WF) nexus relationship in East and Southeast Asia. Some indicators that are widely adopted for WF nexus analysis are introduced, including crop water estimation, water-food footprints, and virtual water trade. Furthermore, the regional relationships representing the WF nexus status in East and Southeast Asia are reviewed, and their implications for WF nexus security are discussed. Throughout this chapter, we demonstrate the importance of WF nexus analysis for ensuring sustainable food production and water security.

Keywords Water and food nexus · Water footprint · Virtual water flow

J.-Y. Choi (✉) · P. Yoon
Department of Rural Systems Engineering, College of Agriculture and Life Sciences, Seoul National University, Seoul, Republic of Korea
e-mail: iamchoi@snu.ac.kr

P. Yoon
e-mail: vnfms3259@snu.ac.kr

S.-H. Yoo
Department of Rural and Bio Systems Engineering, College of Agriculture and Life Sciences, Chonnam National University, Gwangju, Republic of Korea
e-mail: yoosh15@chonnam.ac.kr

S.-H. Lee
Department of Agricultural and Rural Engineering, Chungbuk National University, Cheongju, Republic of Korea
e-mail: sanghyun@chungbuk.ac.kr

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5.1 Introduction

Growing demands on natural resources such as water, energy, and food have posed serious global challenges over the last decades. The concept of the water-energy-food (WEF) nexus has emerged to address these challenges and provide a framework for sustainable resource allocation strategies. Abundant studies on the WEF nexus have shown various synergies and trade-off relationships among the nexus components and demonstrated that ensuring WEF security requires comprehensive analyses across different nexus components as an integrated system rather than single resource analysis (Hoff 2011).

Water is an essential resource for food production. Global statistics suggest that approximately 70% of available water is consumed for agriculture (FAO 2021). Accordingly, the water-food (WF) nexus has received significant attention in relation to securing sustainable food production. This is of particular importance in East and Southeast Asia, whose economy heavily relies on agricultural activities. Furthermore, rapid population growth and increasing standards of life in the region have accelerated the regional demands on food productivity, which has resulted in serious water shortages and management problems (Hoekstra and Mekonnen 2011; Porkka et al. 2016). In fact, water for the food nexus is one of the vital nexus components among the water-energy-food nexus in East and Southeast Asia.

Most Asian countries have challenges ensuring WEF security, which often interact positively or negatively. Sustainability in the agricultural sector is the main issue for resource management, particularly associated with water security. The water security conditions in East and Southeast Asian countries vary depending on geographical, political, and economic conditions. Even for Southeast Asian countries that have comparably abundant water resources, the strong seasonality in weather and increasing risks such as extreme heavy rains and droughts pose a new set of challenges.

Agriculture can be a main focus in the WEF nexus framework and water-food analysis. Many recent studies have been conducted to address WF nexus challenges and provide insights for sustainable resource allocation strategies (Dinesh Kumar et al. 2012; Biggs et al. 2015; Smidt et al. 2016; Zhang and Vesslinov 2017; Fabiani et al. 2020; Lee et al. 2020; Putra et al. 2020; Sadeghi et al. 2020). Sadeghi et al. (2020) presented the application of the WEF nexus approach to designate optimal agricultural management patterns at a watershed scale. Another agricultural application of the nexus approach was implemented by Fabiani et al. (2020), who conducted sustainability assessments at the farm level for intensive agricultural areas. They investigated the durum wheat production system in central Italy, with a focus on (1) the environmental sustainability of fertilization treatments through energy input/output analysis and the reduction of nitrate ($N–NO_3$) in the water cycle; (2) agricultural system agronomic and economic performance; and (3) regulatory and economic instruments to promote sustainable fertilization. Some studies have focused on providing a systematic framework to identify WEF sector interactions as an integrated system. For example, Putra et al. (2020) conducted a systematic analysis of the WEF security nexus in South Asia by using open data sources at the country scale and statistically analysed interactions between the WEF sectors, defining positive and negative correlations between the WEF security indicators as synergies and trade-offs, respectively.

In the context of East and Southeast Asia, the WF nexus has received increasing attention due to its strong linkage to human development and sustainability. ESCAP (2013) traced the discussions, analyses, and actions related to the WEF security nexus in the Asia and Pacific region and explained the nexus challenges, including an ageing irrigation system, agricultural productivity, environmental stress, land grabbing, and climate change. Some studies presented interesting WEF case studies from East and Southeast Asia, including a WEF nexus analysis conducted based on the water infrastructure projects in Lower Mekong Basin (Lebel et al. 2020), an assessment of irrigation water use status and trends in China (Han et al. 2020), a WEF security analysis in the Asia Pacific (Taniguchi et al. 2017), an analysis of the livelihood aspect of WEF nexus from a Philippines's case study (Spiegelberg et al. 2017), a virtual water export and crop trade analysis in Asia (Lee et al. 2017, 2018a), reviews of the WEF nexus approach for human environmental security in Asia–Pacific ring of fire (Endo and Oh 2018), and an analysis of the urban nexus approach for improved resource efficiency in Southeast Asian cities (Lehman 2018). Some studies on the WEF nexus in Asia have focused on the impact of climate change on WF sustainability and developed a nexus tool to understand relationships and trade-offs between essential resources—water-energy-food—and sustainability analysis (Lee et al. 2020). This study was a partial result of SNAK (Smart Nexus for Agriculture in Korea) conducted by a consortium of six institutes, including RDA (Rural Development Administration) and Seoul National University.

This chapter reviews the WF nexus relationship in East and Southeast Asia. We introduce a key concept for understanding WF relationships and explain indicators that can be used to analyse the WF nexus, including crop water estimations, food-water footprints, and virtual water trade. Examples showing the WF nexus status in East and Southeast Asia are also reviewed. Based on the regional analysis of the WF nexus, we demonstrate the importance of WF nexus analysis for ensuring sustainable food production and water security.

5.2 Conceptualization of the Water-Food Nexus

Figure 5.1 presents the conceptual framework of the WEF nexus and its interconnections with natural resource availability. In the figure, the WEF resource availability is represented using inner and outer ring structures. The outer ring, entitled the natural resource ring, includes available nexus resources that exist in nature. The inner ring, on the other hand, defines the resources that are secured for utilization through various infrastructure and human interventions, including pumps, irrigation, and cultivation. The complex synergy/trade-off relationships between the nexus components, which are triggered by various human activities, could affect resource security (i.e., secured

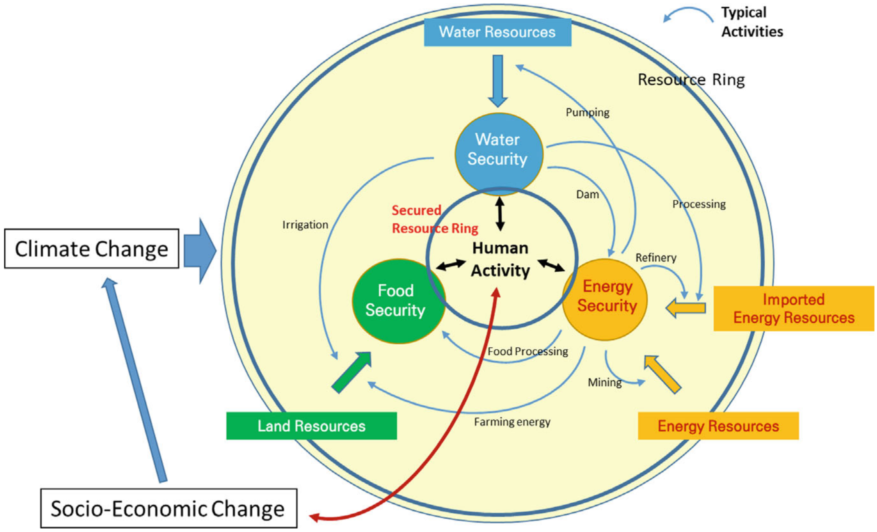

Fig. 5.1 Water-energy-food nexus with a two-ring conceptualization

resource ring). Furthermore, increasing variability in climate and socioeconomic changes further complicates the nexus relationships and the availability of the WEF resources (i.e., natural resource ring).

Typical activities that connect WEF components include irrigating, using dams, groundwater pumping, food processing, and producing farm energy. In the agricultural sectors, the WF relationships are considered to have the most significant effect on food production. Many studies have focused on better understanding the WF relationship and have suggested optimal water management for water and food security based on different approaches and investigations (Jalilov et al. 2016; Zayed and Elagib 2017; Lee et al. 2018b; Li et al. 2019a, b). In this chapter, we introduce some key concepts that are widely adopted for WF nexus analysis and review important WF nexus relationships in East and Southeast Asia.

Although in this chapter we mainly focus on the WF nexus, it should be noted that food production generally requires various inputs, including water, fertilizer, pesticides, machinery operations, labour, and input energy. Considering the various and complex interlinkages among different nexus elements, it is not possible to fully explain WF relationships separately from the WEF nexus (Hoff 2011). Additionally, for a more reliable analysis of the WF nexus, the broad spectrum of agricultural conditions including weather and topographical conditions and cultivation technology development (e.g., protection and cultivation with information and communications technology (ICT)) need to be reflected.

Figure 5.2 illustrates a water flow diagram, from its source to food production, and some important WF nexus relationships (crop water requirement, food water footprint, and virtual water trade). Rainfall is generally the first source of natural water resources as it provides moisture to crops directly as effective rainfall or is stored

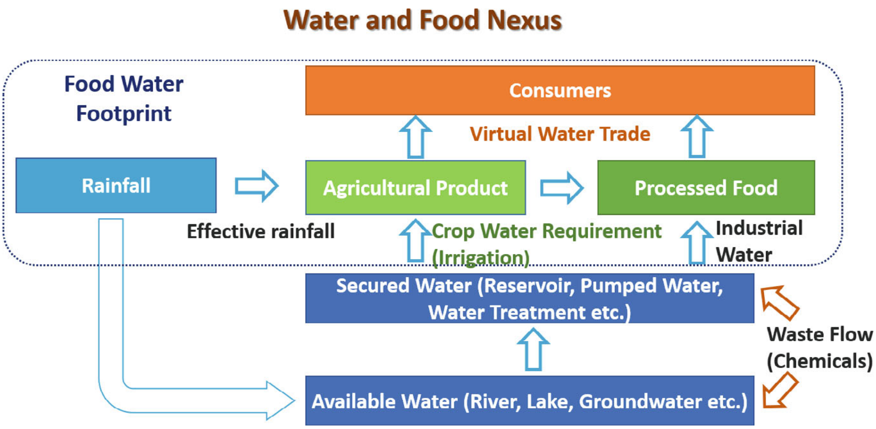

Fig. 5.2 Water needed for food components and water flows from rainfall to the food components and estimation items, including the water footprint and crop water requirement

in rivers, lakes, and groundwater as available water resources that are secured and eventually used for food production. Thus, effective rainfall, crop water requirements (irrigation) and industrial water are the major pathways through which water is consumed for food production. Among these pathways, irrigation is the largest water consumer. For example, irrigation in nine East and Southeast Asian countries (Brunei, Cambodia, Indonesia, Japan, Lao PDR, Malaysia, Mongolia, the Philippines, and the Republic of Korea) accounted for 95.3% of the total agricultural water withdrawals from 2013 to 2017 (FAO 2021). Consequently, estimation of crop water requirements for irrigation is an important starting point for a quantitative WF nexus analysis. In general, a crop water requirement assessment is based on the consumptive use of water calculated from potential evapotranspiration for different types of crops (Jensen et al. 1990).

The food-water footprint is defined as the total amount of water used for food production. In Fig. 5.2, major components of the food-water footprint are shown, including effective rainfall, irrigation, industrial water use, and the amount of waste flow caused by water contamination from fertilizers and chemicals. The food-water footprint can generally be broken down into three elements: blue, green, and grey water footprints. The blue and green water footprints for food indicate the water consumed for food production from the blue (surface and groundwater) and green water (soil water) resources, respectively, while the grey water footprint is the amount of polluted water produced during food production (pesticides, fertilizers, etc.). Food-water footprint analysis is a practical approach for quantitatively assessing water and food relations. This analysis also serves as the key indicator of both direct and indirect appropriation of freshwater resources for food production (Chapagain and Hoekstra 2010).

Virtual water describes the water consumed in the production of agricultural goods that are then traded in international markets (Allan 1996, 2002, 2003). The concept of the virtual water trade has received increasing attention in terms of potential water savings, as this trading could alleviate water stresses in water scarce regions by importing the products and the virtual water embodied in them. Under the rapid growth of international trade in both goods and services, the volume of global virtual water trade through the national, regional, and international food trade has also substantially increased. Some studies have attempted to reconstruct the historical evolution of the virtual water trade and concluded that the virtual water trade doubled between 1986 and 1997 (Dalin et al. 2012; Carr et al. 2013), and future predictions suggest that both virtual green and blue water exports will increase at least threefold by 2100 (Graham et al. 2020). Despite the intensive studies conducted over the last decades, however, the complexity of the virtual water trade at various scales and the varying spatial and temporal characteristics of the virtual water trade limit our understanding; thus, various elements in the virtual water trades remain unknown (Graham et al. 2020).

5.3 Analysis of the Water and Food Nexus Relationship

In this section, we introduce common approaches to analyse WF nexus relations (crop water irrigation, food-water footprint and virtual water trade) and the regional statistics of East and Southeast Asia.

5.3.1 Crop Water Requirement

Estimation of Crop Water Requirement

A net irrigation water requirement (NIWR) is defined as the depth of water required to compensate for water loss through crop evapotranspiration such that disease-free crops grow in large fields and achieve their full production potential for a given growing environment (Yoo et al. 2008). Considering that the NIWR is the dominant consumer of water for agricultural production, a reliable estimation of the water demand by the NIWR is crucial for establishing a sustainable water resource management strategy for food security and efficient water allocation. The NIWR is generally formulated using a water balance concept as described by Eq. (5.1) (Jensen et al. 1990):

$$\text{NIWR} = \text{ETc} + \text{DP} + \text{LR} + \text{MR} - \text{EFR} \tag{5.1}$$

where ETc is crop evapotranspiration (mm); DP is deep percolation (mm); LR is the leaching requirement (mm); MR is the miscellaneous water requirement (mm) for germination, frost protection, blossom delay, wind erosion, and plant cooling; and EFR is effective rainfall (mm) indicating the available rainfall for maintaining the ponding depth. In the case of paddy fields, the leaching and land preparation requirements in ponding rice fields are negligible. Therefore, Eq. (5.2) is a simpler and more commonly used equation for calculating the NIWR for a paddy field.

$$\mathrm{NIWR} = \mathrm{ETc} + \mathrm{DP} - \mathrm{EFR} \tag{5.2}$$

In Eq. (5.2), the estimation of consumptive use for irrigated crops is determined by crop coefficient-reference evapotranspiration. To produce an estimate of crop evapotranspiration (ETc), the reference crop evapotranspiration (ET_o) multiplied by an empirical crop coefficient (K_c) is usually used (Eq. (5.3)):

$$\mathrm{ETc} = K_c \times \mathrm{ETo} \tag{5.3}$$

ETo is usually calculated according to the FAO paper No. 56 methodology—the FAO Penman–Monteith equation (Allen et al. 1998):

$$\mathrm{ETo} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\, u_2)} \tag{5.4}$$

where Δ is the slope of the saturated vapour pressure/temperature curve (kPa/°C), γ is the psychrometric constant (kPa/°C), u_2 is the wind speed at a 2 m height (m/s), R_n is the total net radiation at the crop surface (MJ/m^2 day), G is the soil heat flux density (MJ/m^2 day), T is the mean daily air temperature at a 2 m height (°C), and e_s and e_a are the saturation vapour pressure (kPa) and the actual vapour pressure (kPa), respectively.

According to Eq. (5.2), deep percolation (DP) indicates the water outflow from the root zone underground, and this component can be estimated with the soil water balance. In addition, irrigation water is supplied to maintain an depth of ponding water for each growth stage and is calculated using a freeboard model (IRRI 1997) as Eq. (5.5):

$$\mathrm{PD_t} = \mathrm{PD_{t-1}} + \mathrm{IR_t} + \mathrm{RF_t} - \mathrm{ETc_t} - \mathrm{DP_t} - \mathrm{SR_t} \tag{5.5}$$

where t is the time (day), PD is ponding water depth (mm), SR is surface runoff in the paddy field outlet (mm), IR is irrigated water (mm) and RF is rainfall (mm) (Dastane 1978; Chung et al. 2006).

Crop Water Requirement of East and Southeast Asia

The estimation of irrigation water requirements can be conducted by a modelling approach that incorporates various factors, such as irrigated area, climate, and crops. FAO's AQUASAT provides a useful database to obtain insight into irrigation water withdrawals in East and Southeast Asia (FAO 2021). Table 5.1 summarizes the total renewable water resources, irrigation water requirements, and irrigation water withdrawal amounts of the 14 East and Southeast Asian countries (except for Singapore).

Statistical data reveal that the irrigation water requirements and amount of irrigation water withdrawals in the region account for approximately 30.82% and 28.32% of the global requirements, respectively. Compared to the actual amount of renewable freshwater resources (18.71% of the global amount), the shares of irrigation water requirements and irrigation water withdrawals in the region are high, mainly due to intensive agricultural production in the region. Irrigation water use is the largest in China, followed by that in Indonesia and Vietnam. The noticeable discrepancy between irrigation water requirements and irrigation water withdrawals suggests that improved water irrigation systems could substantially decrease the water requirements for agriculture. Although the dataset provides a basis for regional assessments, it should be noted that the quality of the data varies depending on country (data availability, classification, acquisition year, etc.); thus, caution should be taken when comparing countries.

5.3.2 Water for Food Analysis Using a Water Footprint

Estimation of Food-Water Footprint

The methodology to estimate a water footprint was suggested by Hoekstra and Chapagain (2008), Chapagain and Hoekstra (2010), Mekonnen and Hoekstra (2010a, b), and Hoekstra et al. (2011). The total water footprint of the process of growing crops or trees (WF_{proc}) is the sum of the green, blue, and grey components as follows:

$$WF_{proc} = WF_{proc,\,blue} + WF_{proc,\,green} + WF_{proc,\,grey} \quad \text{(unit : volume/mass)} \tag{5.6}$$

In Eq. (5.6), the blue water footprint ($WF_{proc,\,blue}$) refers to the consumption of blue water resources (surface and groundwater) throughout a product's supply chain. Consumption in this case means a loss of water from the available ground-surface water body in a catchment area, which occurs when water evaporates and returns to another catchment area or the sea, or is incorporated into a product. In agricultural production, blue water use refers to the volume of irrigation water (withdrawn from the surface or groundwater) evaporating from a crop field during the growing period. The green water footprint ($WF_{proc,\,green}$) refers to the consumption of green water resources (rainwater stored in the soil as soil moisture), and this component is mostly related to the rainwater volume that evaporates from a crop field during the growing period (Hoekstra et al. 2011). Each green and blue water footprint is calculated using the net irrigation water requirement and effective rainfall calculation method.

On the other hand, the grey water footprint ($WF_{proc,\,grey}$) is associated with the amount of water required to assimilate pollution to maintain the ambient water quality. Typical pollutants affecting the grey water footprints in food production include fertilizers (nitrogen, phosphorus, etc.), pesticides, and insecticides. The grey component in the water footprint of growing a crop or tree ($WF_{proc,\,grey}$, m^3/ton) is

Table 5.1 Water requirement ratio and comparison of water resources by country

	Total actual renewable freshwater resources (km^3/yr)	Year	Irrigation water requirement (km^3/yr)	Water requirement ratio (%)	Irrigation water withdrawal (km^3/yr)	Pressure on freshwater resources due to irrigation (%)
Brunei	8.5	1995	0.00	51	0.01	0.06
Cambodia	476.1	2006	0.92	48	1.93	0.40
China	2840.0	2006	256.87	72	358.00	12.61
Indonesia	2019.0	2005	47.42	51	92.76	4.59
Japan	430.0	2006	38.32	70	54.73	12.73
Lao PDR	333.5	2005	1.52	48	3.19	0.96
Malaysia	580.0	1994	1.27	51	2.51	0.43
Mongolia	34.8	1994	0.11	48	0.23	0.65
Myanmar	1168.0	2004	12.38	42	29.57	2.53
Philippines	479.0	2006	33.28	51	65.59	13.69
Korea, North	77.15	1995	3.02	70	4.31	5.58
Korea, South	69.7	2002	3.93	27	14.49	20.78
Thailand	438.6	2007	34.19	66	51.79	11.81
Vietnam	884.1	2005	29.24	38	77.75	8.79
East Asia	3451.65 (6.56%)		302.25 (20.14%)	70.01	431.75 (16.15%)	12.51
Southeast Asia	6386.80 (12.15%)		160.22 (10.68%)	49.28	325.09 (12.16%)	5.09
East and Southeast Asia	9838.45 (18.71%)		462.47 (30.82%)	61.11	756.84 (28.32%)	7.69
Global	52,579.47		1500.46	56.00	2672.64	5.07

Source FAO (2021) adapted by the author

calculated as the chemical application rate to the field per hectare (AR, kg/ha) times the leaching-run-off fraction (α) divided by the maximum acceptable concentration ($c_{\max}$, kg/m^3) minus the natural concentration for the pollutant considered (c_{nat}, kg/m^3) and then divided by the crop yield (Y, ton/ha) (Hoekstra et al. 2011).

$$WF_{proc,\,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y} \tag{5.7}$$

Food-Water Footprints in East and Southeast Asia

Globally, the agricultural sector is the largest consumer of freshwater, accounting for approximately 85% of global blue water consumption (Shikomanov 2000). Mekonnen and Hoekstra (2010a) analysed the contribution of different crops to the total water footprints at a global scale and showed that wheat, rice, and maize are the three primary crops accounting for the largest share of the total water volume. Among these three crops, rice is the primary crop grown in East and Southeast Asia that requires intensive water use for cultivation. Table 5.2 shows the water footprints of several rice-producing countries in East and Southeast Asia. The water footprint of rice production in each country is influenced by the climate, which controls rice growth and yield and the management of paddies. For example, large shares of the green water footprint in Southeast Asian countries such as Indonesia, Myanmar, the Philippines, and Thailand indicate that abundant rainwater in the region has provided water for rice production. The high dependence on green water in these countries implies that Southeast Asia has favourable natural conditions for rice production, but at the same time, the productivity of this region could be vulnerable to climate disasters such as droughts. On the other hand, the large proportion of the blue water footprint in China, Japan, and Korea indicates a high dependence on irrigation for rice paddy water supply.

Table 5.2 shows the contribution of the water footprint per ton of rice production, and Table 5.3 displays the water footprint of national rice production in East and Southeast Asia. In the region, the largest consumer of water for rice production is China, followed by Indonesia, Thailand, Myanmar, the Philippines, and Vietnam. The 12 countries in Table 5.3 (except Brunei, Mongolia, and Singapore) account for

Table 5.2 Comparison of rice WF for the major rice-producing countries

Country	Water footprint (m^3/ton) of paddy rice			
	Green	Blue	Grey	Total
China[a]	367	487	117	971
Indonesia[b]	583	487	118	1187
Japan[a]	341	401	61	802
Myanmar[b]	846	378	50	1274
Korea, Rep.[a]	356.3	388.6	84.5	829.4
Korea, Rep.[c]	294.5	501.6	48.4	844.5
Philippines[b]	844	423	78	1345
Thailand[a]	942	559	116	1617
USA[a]	227	835	101	1163
Global average[a]	618	720	112	1450

Source Chapagain and Hoekstra (2010); Chapagain and Hoekstra (2011); Yoo et al. (2011) adapted by the author

[a]Chapagain and Hoekstra (2010), [b]Chapagain and Hoekstra (2011), [c]Yoo et al. (2014)

Table 5.3 Water footprints of national rice production from 2000 to 2004

Country	Water footprint of national rice production (Mm^3/year)			
	Green	Blue	Grey	Total
Cambodia	2632	2432	455	5520
China	65,241	86,460	20,786	172,486
Indonesia	30,309	25,323	6113	61,744
Japan	3744	4408	665	8818
Lao PDR	1498	1385	259	3142
Malaysia	1384	1279	239	2903
Myanmar	19,111	8538	1125	28,774
Korea, Rep.	2423	2644	575	5641
Korea, DPR	1333	1232	231	2796
Philippines	11,246	5633	1034	17,914
Thailand	25,247	14,980	3112	43,339
Vietnam	10,455	6888	4319	21,663
East and Southeast Asia	174,623	161,202	38,913	374,740
Global	373,907	345,512	64,655	784,073

Source Chapagain and Hoekstra (2011) adapted by the author

46.70, 46.65 and 60.18% of the global green, blue and grey water footprints for rice production, respectively.

5.3.3 *Virtual Water and National Food Security*

Virtual Water Trade in East and Southeast Asia

The increasing globalization of commodities and trade has led to significant changes in the virtual water trade. D'Odourico et al. (2019) demonstrated that the virtual water trade has reshaped the patterns and distributions of global water resources and thus needs to be accounted for in the global hydrological cycle. Whereas the virtual water flow through commodities and services includes different elements, including industrial products, agricultural products, and energy production, agriculture is the largest water consumer and accounts for the largest volumes of the virtual water trade globally (D'Odourico et al. 2019).

The virtual water trade of a single crop depends on the water footprint of the crop and the trade amount. Analysis of global water footprints shows that wheat and rice have the largest blue water footprints, accounting for 35–69% of the global water footprint (Oki and Kanae 2004; Hoekstra and Hung 2005; Yang et al. 2006; Hanasaki et al. 2010). Rice is the main exporter of virtual water in East and Southeast Asia, and three countries in the region (Thailand, China, and Vietnam) accounted for 39.3%

of the global virtual water export through rice between 2000 and 2004 (Chapagain and Hoekstra 2011).

East and Southeast Asia are playing an emerging role in the virtual water trade. Global-scale analysis of virtual water flow by agricultural trade revealed some important virtual water flows in the region, including the increasing presence of China as a major food importer from North and South America, the increasing imports of soybean to Southeast Asia, and the increasing exports of palm oil from Indonesia and Malaysia to China and other regions (D'Odourico et al. 2019). In fact, the increasing pressure of China in global trade and the virtual water trade has received highlighted attention due to it having the largest contribution to the global economy (Fu et al. 2018). China's exported and imported virtual water embodied in agricultural products grew from 31.5 billion m^3/year to 145.0 m^3/year from 2003 to 2010, respectively, and the country imported more virtual water every year, which more than doubled from 2003 to 2010 (Fu et al. 2018). Although North and South America accounts for the largest percentage of the imported virtual water from China, the agricultural trade between China and Southeast Asia (Malaysia, Indonesia, Thailand, and Vietnam in particular) is also escalating, indicating that the agricultural economy of East and Southeast Asia heavily depends on the interregional food trade and virtual water flow. South Korea and Japan are known as net importers of virtual water.

Virtual Water Trade Analysis and National Food Security: Example from South Korea

Despite the notable progress in virtual water flow analysis, global-scale analysis and its impact on regional water resources have just started to be calculated and quantified (D'Odourico et al. 2019). The difficulty in conducting a virtual water trade analysis at the global scale is mainly due to the complexity of the virtual water trade at various scales and the varying spatial and temporal characteristics. Additionally, different levels and gaps in data among different countries and various external elements (e.g., pandemic) limit our understanding (Graham et al. 2020). To extend our current knowledge on the virtual water trade, an enhanced database at the country level is important. In this chapter, we present an example of a virtual water trade analysis using a case study of South Korea.

In the last few decades, the pattern of food consumption in South Korea has changed drastically, with a sharp increase in the consumption of imported food products (especially wheat and maize), while rice consumption has decreased. The amount of water from foreign sources embedded in the production of imported food is reflected in the virtual water trade (Table 5.4). Increasing reliance on imported crops with decreasing domestic production rates has led to a higher external water footprint and dependency on foreign water sources. The highest contributor to virtual water imports was wheat, which accounted for approximately 30% of the total imported virtual water between 2006 and 2010 (Lee et al. 2016).

An increasing amount of virtual water flow by crop trade indicates a decrease in national food security. National food security can be assessed with the food self-sufficiency ratio (SSR), which is the proportion of the total domestic food consumption met by domestic food production. According to Yoo et al. (2016), the SSR

Table 5.4 Total amount of virtual water flow by crop trade in South Korea from 2006 to 2010

Crops	Net imported water from 2006 to 2010			
	Crop (1000 ton)	Green water (Mm^3)	Blue water (Mm^3)	Total water (Mm^3)
Wheat	16,000	27,000	1430	28,400
Rice	1494	1438	888	2334
Barley	166	203	10	213
Rye and sorghum	168	255	8	263
Root and tuber	89	8	7	16
Maize	45,100	29,600	2710	32,300
Pulse crops	15,487	31,104	675	31,804
Vegetables	820	87	6	93
Fruits	3	−70	14	−56
Total	79,441	89,595	5754	95,389

Source Lee et al. (2016) adapted by the author

index of South Korea decreased from 56 to 27% from 1980 to 2010, showing that national food security in South Korea has decreased due to increased consumption of imported food, especially crops such as wheat, maize, and pulse crops (Table 5.5).

To improve national food security, the government of South Korea has set target SSRs for major food commodities, including crops, fruits, vegetables, meat, and dairy products (KREI and MIFAFF 2011). However, increasing food security requires stimulation of agricultural production within the country together with increased water resource appropriation, which will result in a trade-off between food security and water resources. The water footprint is useful in estimating the amount of

Table 5.5 Projected domestic consumption and production targets for the food self-sufficiency ratio (SSR) in 2020

Items	Consumption (1000 ton)	Production (1000 ton)	SSR (%)	Items	Consumption (1000 ton)	Production (1000 ton)	SSR (%)
Rice	4136.0	4053.0	98.0	Bovine meat	543.0	258.0	47.5
Wheat	1890.0	284.0	15.0	Pig meat	976.0	781.0	80.0
Barley	295.0	92.0	31.2	Poultry	701.0	561.0	80.0
Pulses	498.0	201.3	40.4	Milk	3142.0	2015.0	64.1
Starch roots	851.1	840.0	98.7	Eggs	656.0	649.0	98.9
Vege-tables	11,200.0	9300.0	83.0	Bulky feed	7931.0	7099.0	89.5
Fruits	3867.0	3020.0	78.1	Formula feed	18,035.0	4432.0	24.6

Source Yoo et al. (2016) adapted by the author

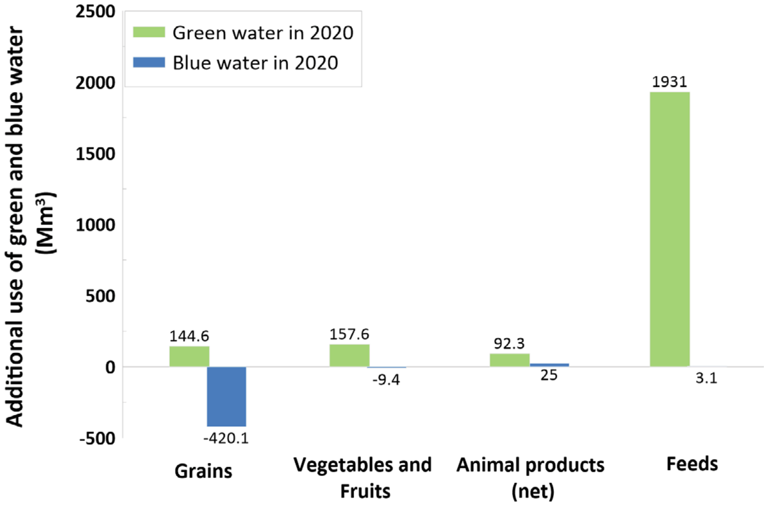

Fig. 5.3 Additional green and blue water usage for domestic production in 2020 (©Yoo et al. 2016)

water required to meet the higher SSR goals and securing water resources for proper agricultural production. During this step, a crop-type-based evaluation of the food-water footprint can be important for sustainable water management plans because the type of food commodity and the corresponding target SSR significantly affect green and blue water components. For example, in South Korea, blue water consumption is expected to decrease due to decreased rice consumption and production, where irrigation is most prevalent, but green water consumption is expected to increase to meet the water demand for the additional production of other crops and food products (Fig. 5.3).

5.4 Conclusions

In this chapter, we reviewed the WF nexus in East and Southeast Asia in terms of crop water irrigation, the water footprint, and virtual water trade. We focused on analysing the WF relationship between crop cultivation and water consumption because the water use for crop cultivation accounts for the largest portion of global water consumption. In East and Southeast Asia, for example, paddy rice cultivation is the leading agricultural activity for obtaining a staple food and driving the regional economy, but at the same time, it is the main consumer of freshwater resources in the region. Although the water-food relationship cannot be considered isolated from the WEF nexus, the WF nexus still needs to be highlighted because it acts as a primary consumer of water in the WEF nexus. Robust tools based on large databases and comprehensive system-dynamic tools can further our current understanding of various WEF nexus relations and assist resource sustainability.

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Chapter 6
Varying Interactions Among the Water, Energy and Food Nexus Across East and Southeast Asia

Muhammad Panji Islam Fajar Putra and Prajal Pradhan

Abstract The concept of the water, energy, and food (WEF) security nexus envisions the holistic development of WEF sectors, considering social, economic, and environmental aspects. Ensuring WEF security is challenging due to positive and negative interactions among the sectors. The nexus approach provides a framework to identify these interactions and to address this challenge. Despite its usefulness, however, only a limited number of nexus studies have discussed the quantitative interactions among the nexus elements. Furthermore, the varying nexus relationships across different countries have rarely been analysed and compared. To fill this gap, we systematically analysed WEF interactions for East and Southeast Asia by using open data sources at the country scale. We defined positive and negative correlations between the WEF security indicators as synergies and trade-offs, respectively. We identified the most positively and negatively influential indicators in the WEF networks using the results of our correlation analysis. Our results show that more trade-off relations than synergistic relations exist within and among the WEF sectors for East and Southeast Asia at the regional scale, e.g., interactions between energy-energy, energy-water, food-water, and water-water. The country-level analysis reveals that the percentages of synergies and trade-offs vary across countries. Some countries (e.g., China, Mongolia, and Myanmar) have more links in the synergy network. In contrast, others (e.g., Malaysia, the Republic of Korea, and Vietnam) have more links in the trade-off network. Our analysis highlights the strategies for promoting renewable and clean energy and discouraging fossil fuel consumption will leverage the WEF security nexus at both regional and country scales in the East and Southeast Asian regions.

M. P. I. F. Putra
CDP Europe, Berlin, Germany
e-mail: muhammad.panji-putra@cdp.net

P. Pradhan (✉)
Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, P.O. Box 60 12 03, 14412 Potsdam, Germany
e-mail: pradhan@pik-potsdam.de

Bauhaus Earth gGmbH, Berlin, Germany

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6.1 Introduction

The concept of the water, energy, and food (WEF) security nexus envisions the holistic development of WEF sectors, considering social, economic, and environmental aspects. This concept highlights complex interactions between the WEF sectors, which could be either synergies or trade-offs, depending on implemented management strategies. Integrated and sustainable resource management, therefore, could achieve the WEF security nexus instead of focusing on sectoral management. For example, maximizing water use for energy generation could undermine the water required for municipal supply, agricultural use, or natural flow. Thus, a shift from output maximization from a sector to the system would ensure the WEF security nexus is attained and Sustainable Development Goals (SDGs) are achieved (Cai et al. 2018).

The nexus concept can be applied to understand interactions between the WEF sectors and identify mutually beneficial strategies (Hoff 2011). These interactions can broadly be either *synergies* or *trade-offs*. When progress in one sector or security area is positively linked with another, it is called a synergy, whereas the negative relation among the sectors is called a trade-off. Strategies generating synergies can leverage the WEF security nexus. In contrast, trade-offs can exacerbate resource insecurity (Cai et al. 2018). Therefore, understanding WEF interactions is crucial for developing integrated strategies and sound policies to ensure the success of the WEF security nexus (Biggs et al. 2015). Although many studies have conducted qualitative analyses of the WEF nexus (Hoff et al. 2019; Mohtar 2016; Rasul 2014, 2016), only limited nexus studies have discussed the interactions quantitatively (Putra et al. 2020).

East and Southeast Asia is one of the world's regions where complex, conflicting, and competing interactions among the WEF sectors exist. Despite their socioeconomic and environmental significance, a systematic qualification of WEF interactions is still missing for the region. We filled this gap by systematically investigating WEF interactions for East and Southeast Asia based on correlation analysis and open data sources at the country scale. Furthermore, we identified the most positively and negatively influential indicators in the WEF networks using the results of our correlation analysis.

6.2 Data and Methods

Our study followed the approach proposed by Putra et al. (2020) to analyse WEF interactions systematically. We briefly describe the data and methods used for this chapter. Please see Putra et al. (2020) for a detailed description.

6.2.1 Data

Putra et al. (2020) conducted a statistical analysis of WEF interactions using time-series data of 36 WEF indicators selected based on the literature and data availability. Following the same approach, we chose these 36 indicators, consisting of four SDG indicators and eight indicators from different sources (Flammini et al. 2014; Rasul 2014) for each sector. These indicators reflect the availability, access, utilization, and stability aspects of WEF security. We collected time-series data for these indicators for the period between 1990 and 2020 (Table A6.1 in Annex; supplementary materials of this chapter are presented and discussed in Annex in the volume) from various sources, including the AQUASTAT (FAO 2021a), World Bank (World Bank 2021), FAOSTAT (FAO 2021b), and SDG databases (United Nations 2021).

We conducted our analysis at the country level for 15 East and Southeast Asian countries: Brunei Darussalam (BRN), China (CHN), Indonesia (IDN), Japan (JPN), Cambodia (KHM), Republic of Korea (KOR), Lao People's Democratic Republic (LAO), Malaysia (MYS), Mongolia (MNG), Myanmar (MMR), Philippines (PHL), Democratic People's Republic of Korea (PRK), Singapore (SGP), Thailand (THA), and Vietnam (VNM).

6.2.2 Statistical Analysis

We applied statistical analysis to understand interactions among WEF sectors, where positive correlations depict synergies and negative correlations show trade-offs, based on recent studies (Anderson et al. 2021; Kroll et al. 2019; Pradhan et al. 2017; Putra et al. 2020; Warchold et al. 2020). Before correlation analysis, we coded all indicators consistently towards achieving WEF security to avoid false results. We gave a positive sign to indicators with values that need to increase to enable WEF security and applied a negative sign in the opposite case (Table A6.1). For example, we assigned a positive sign to indicator E_1 (access to electricity) that needs to be at 100% to achieve energy security for all. However, indicator F_1 (undernourishment) needs to be zero to ensure food security for all. Thus, we assigned a negative sign to this indicator.

We conducted correlation analysis to capture the interaction between pairs of indicators for all 15 countries based on Spearman's rank correlation (ρ). Unlike

Pearson's correlation, which evaluates the linear relationship between two variables, Spearman's correlation is based on ranked values and can capture nonlinear relations. The correlation coefficient (ρ) estimates the strength and direction of an interaction between two variables (Spearman 1904). We interpreted positive and negative correlations between the indicators as synergies and trade-offs, respectively. A correlation with a *p value* of less than 0.05 was considered statistically significant. We limited our observations to indicator pairs having more than three data points to reduce false correlations in the sparse dataset.

We grouped interactions between indicators into synergies and trade-offs according to the correlation coefficient (ρ). A significant correlation with a ρ value greater than 0.6 was grouped as a *synergy* (positive interaction), and a ρ value less than -0.6 was considered a *trade-off* (negative interaction). In addition, a ρ value between -0.6 and 0.6 was considered *unclassified* to avoid over interpretation of the results.

We evaluated WEF interactions for all 15 countries at the sectoral scale: energy–energy (*E–E*), energy–food (*E–F*), energy–water (*E–W*), food–food (*F–F*), food–water (*F–W*), and water–water (*W–W*). For this approach, we aggregated the results of the correlation analysis between the indicator pairs and calculated the number of synergies, trade-offs, and unclassified synergies within and among the WEF sectors. At the regional scale, we assessed the interaction between two indicators based on the majority of interactions between the indicators for the 15 countries. Thus, an indicator pair was considered to have synergies, trade-offs, or unclassified at the regional scale if most countries had the same interaction patterns. When both synergies and trade-offs were observed at similar frequencies depending on the country, we considered the interaction to be unclassified.

6.2.3 Network Analysis

Following recent studies, we applied network analyses to identify the most influential indicators behind the observed interactions among the WEF sectors (Baffoe et al. 2021; Hirwa et al. 2021; Putra et al. 2020; Weitz et al. 2018). A network structure generally consists of nodes (also called vertices) and edges (also called links). A node is a set of objects connected by an edge, the size of which represents a degree of positive or negative interaction with different nodes. The edge represents the positive or negative interaction between the connected nodes. Our networks consisted of the 36 indicators (represented as nodes), and the edges through the interactions between the indicator pairs were represented. We considered synergistic indicator pairs as positive edges and trade-off pairs as negative edges.

We created WEF networks (i.e., synergy and trade-off networks) for all 15 countries and the region to identify the most influential indicators. At the country scale, node size was determined by the number of linked indicators. An edge is created based on the type of interaction between indicator pairs, mainly synergies and trade-offs. Unlike the country-scale network, the regional networks were designed to model the major interactions in the 15 countries. Here, we created edges and nodes by selecting indicator pairs with synergies or trade-offs of more than 30% across 15 countries to better capture the significant interactions. For example, we observed synergies in 7 countries (47%), trade-offs in 3 countries (20%), and unclassified synergies in 5 countries (33%) between indicators E_3 (renewable energy consumption) and E_{11} (emissions from the energy sector). Thus, we assigned a synergistic relation between E_3 and E_{11} for the regional networks based on our criteria.

6.3 Results

Our results highlight the variation in WEF interactions across East and Southeast Asian countries. This section first describes the observed WEF interactions and networks at the regional scale. Then, a short description of highlights for each country is presented, focusing on critical interactions and the indicators behind them.

6.3.1 East and Southeast Asia

In Fig. 6.1, we present the number data points available for different indicator pairs. We found more data points for indicator pairs across the different WEF sectors (i.e., *F*–*W*, *E*–*W*, and *E*–*F*) than within the same sector (*W*–*W*, *E*–*E*, and *F*–*F*) for most countries. This variation was mainly due to limited data availability within sectoral pairs (see Table A6.2 in Annex). In Cambodia, China, Indonesia, the Philippines, and Vietnam, the energy and food sectors have all necessary data points for all indicator pairs (Fig. 6.1). The high-income countries Brunei Darussalam and Singapore have fewer data points available for all sectoral pairs than those for the other high-income countries. In the lower-middle-income countries, poor data availability also occurred in Democratic People's Republic (DPR) of Korea and Lao PDR.

WEF interactions vary across the countries (Fig. 6.1). First, we observe a large percentage of unclassified relations in most sectoral pairs. Second, we see that there are more trade-offs than synergies among the WEF sectors at the regional scale. *E*–*E*, *E*–*W*, *F*–*W*, and *W*–*W* interactions show these phenomena for ten countries. Trade-offs and synergies range from 8 to 57% and from 5 to 43% in these WEF interactions, respectively. In some countries, however, there are more synergies than trade-offs for a few interactions among the sectors. Mainly, *F*–*F* interactions have more synergies for nine countries, and *E*–*E*, *E*–*W*, *F*–*W*, and *W*–*W* have more synergistic relations than trade-offs for five countries. Synergies range from 4 to 100% and trade-offs from 0 to 39% in these WEF interactions.

We observe complex WEF networks for synergies and trade-offs at the regional scale, reflecting the existing positive and negative linkages among WEF sectors across the countries (Fig. 6.2). Since these networks aggregate the results from the country-scale analysis, the same indicator can influence WEF networks for both

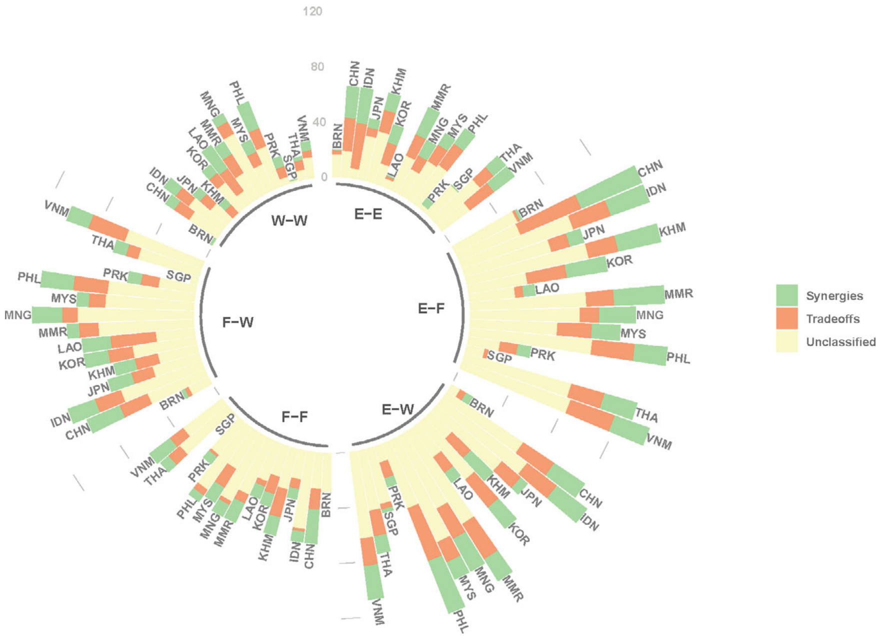

Fig. 6.1 Number of available data points for indicator pairs varies across the water, energy, and food (WEF) sectors and countries. WEF interactions vary across East and Southeast Asian countries at the sectoral scale. Each stacked bar represents the country's data analysed for the WEF sectors with the total number of data points of observed interactions. A long-stacked bar shows the greater availability of data pairs for a specific country in the respective sector pairs. The colour code shows different interactions. The countries are indicated by ISO codes on the top of each bar. Six pairs of the WEF sectors are presented in the inner polar region

synergies and trade-offs. For example, indicator W_1 (safe drinking water service) has 12 positive and 14 negative links in the regional networks. This dominance of some indicators in both networks is because of varying influences (positive or negative) of these indicators across the countries. This means that one indicator that is positively linked with other indicators in one country could have negative correlations with other indicators in the same country or a different country. Our results also identify several indicators that have more synergistic relations than trade-offs across countries, e.g., between W_3 and E_2, W_3 and E_9, and F_2 and some water indicators—W_4, W_5, W_6, W_7, and W_{12}. However, there are many negatively influenced indicators in the WEF networks across the countries as well, e.g., between F_2 and W_{11}, F_3 and W_{10}, F_3 and W_5, F_3 and W_{12}, F_4 and W_6, F_4 and W_7, W_5 and E_1, W_5 and W_2, and W_5 and W_3.

At the regional scale, indicators such as E_1 (access to electricity), E_{10} (energy use per capita), and W_3 (basic handwashing facilities) have the largest influence in the WEF network for synergies. They are synergistically linked with 17 other indicators. Four, five, and five indicators in the water, energy, and food sectors synergize with at least ten other indicators, respectively. The positive influences of these indicators in

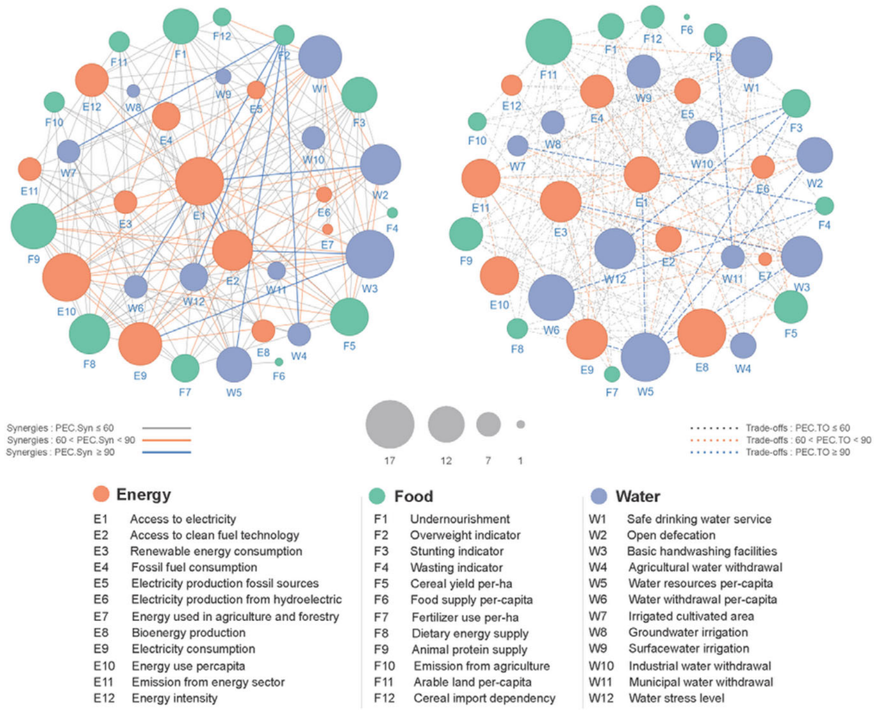

Fig. 6.2 We generated synergy (left side) and trade-off (right side) networks at the regional scale based on interactions among the water, energy, and food (WEF) sectors for the 15 analysed countries. In comparison to the smaller nodes, the larger nodes have more edges and larger influences in the networks. Edge colours represent the strength of the connections across countries based on the percentage (PEC) of synergies (Syn) or trade-offs (TO)

the WEF networks could be leveraged to achieve the regional WEF security nexus. However, these indicators can also substantially influence the trade-off network, i.e., having negative linkages with other indicators. Thus, a detailed investigation at the country scale is needed before promoting them.

Indicators including E_8 (bioenergy production) and W_5 (water resources per capita) negatively influence the WEF network with trade-off relations with 17 other indicators. This result highlights underlying challenges in promoting bioenergy production and ensuring water security in the region. However, these challenges might not be applied to all countries because E_8 and W_5 are also positively linked with seven and twelve other indicators, respectively. Eight, seven, and three indicators associated with the water, energy, and food sectors negatively influence at least ten other indicators, respectively. These findings highlight that there are more negative linkages or trade-offs for the water and energy sectors than positive linkages or synergies in the region. These trade-offs need to be addressed or should be transformed into nonobstructive relations to achieve WEF security in the region.

6.3.2 Brunei Darussalam (BRN)

We did not observe many WEF interactions for Brunei Darussalam (Figs. A6.1 and A6.2). Although more than 75% of the indicators have sufficient data (Table A6.3), minimal changes in these indicators during the analysis period resulted in nonsignificant correlations and isolated nodes in our WEF networks. For example, as a high-income country, Brunei Darussalam has provided electricity access to the entire population for the last few decades, and Brunei Darussalam's electricity was 100% based on fossil sources (E_5) by 2011. Then, a small portion of electricity was provided using renewable energy (E_3), which resulted in a positive linkage between E_3 and E_5 in our analysis.

Despite there being very minimal changes in many indicators, we capture a few interesting WEF interactions. For example, in the synergy network, we observe interactions of five energy indicators (E_3, E_5, E_{10}, E_{11}, and E_{12}), two food indicators (F_6 and F_{11}), and three water indicators (W_5, W_6, and W_7). Each of these indicators positively influence one to five other indicators. Indicator W_6 (water withdrawal per capita) has the largest influence among all indicators due to its synergistic relations with five others, e.g., per capita water resources (W_5) and irrigated cultivated area (W_7).

We observe that in comparison to the water and food indicators, more energy indicators are linked with other indicators in the trade-off network. This finding indicates that sustainable energy is crucial for addressing the existing trade-offs in the WEF network and ensuring the WEF security of the country. For example, due to the high percentage of electricity production based on fossil sources (E_5), reducing emissions from the energy sector (E_{11}) would be a challenge without promoting renewable energy (E_3).

6.3.3 China (CHN)

We observe more synergies and trade-offs than unclassified relations across WEF interactions for China (Figs. 6.3 and 6.4). Some indicators, however, do not have links either in the synergy network (e.g., F_2, W_1, W_3, and W_8) or in the trade-off network (e.g., W_1 and W_3).

The most influential indicators are in the energy and food sectors in the synergy network. For example, energy indicators E_1, E_9, and E_{10} positively influence the other 16 indicators. These synergistic relations indicate that increasing access to electricity (E_1), electricity consumption (E_9), and energy use per capita (E_{10}) have leveraged the WEF security nexus in China. It should be noted that the positive relations between these indicators partially reflect the impact of advanced infrastructure and governance; thus, external factors could have played an important role in this network. Furthermore, renewable sources should play a crucial role in ensuring energy security for limiting global warming well below 2 °C. Similarly, 60% of food indicators

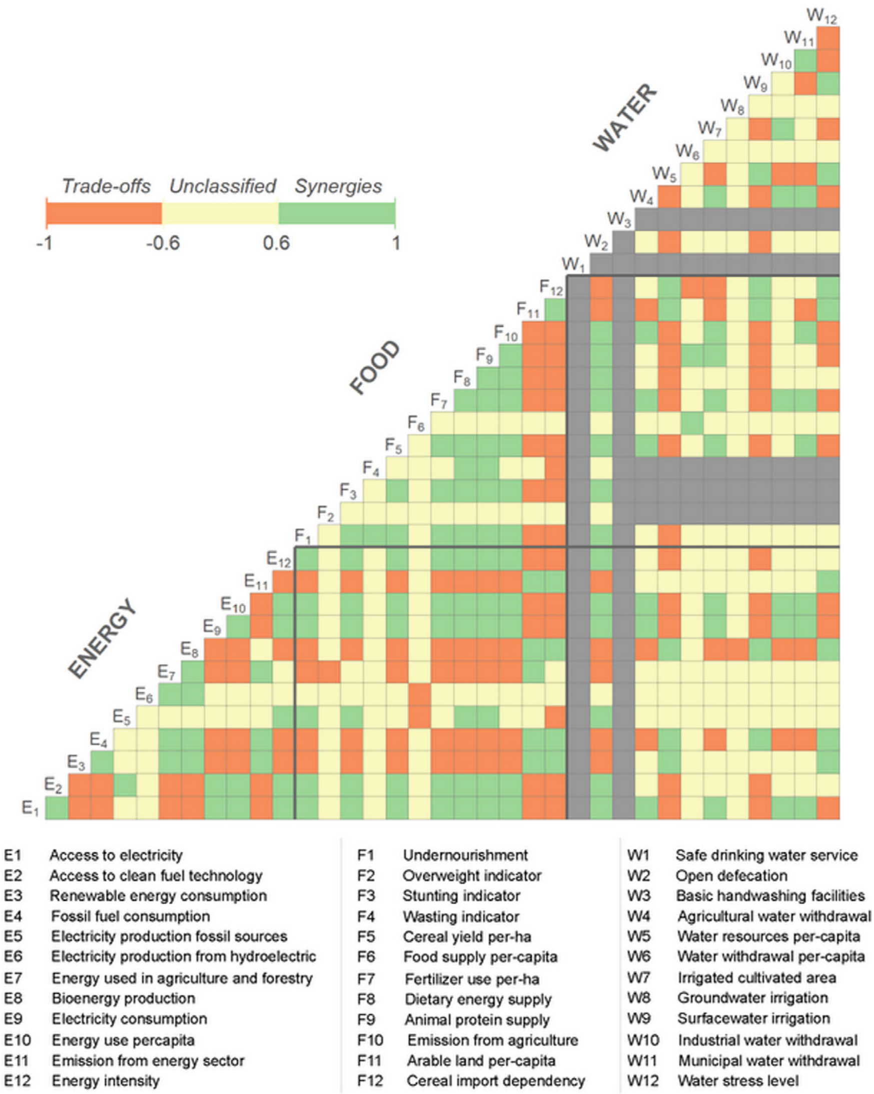

Fig. 6.3 Observed interactions between the water, energy, and food (WEF) sectors in China—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes in the diagonal represent the indicators

positively influence 13–16 other indicators in the network. F_7 (fertilizer use per ha) and F_9 (animal protein supply) have synergistic relations with 16 different indicators. These relations show how China's agricultural intensification and diet shifts are linked with progress in other WEF indicators. These positive linkages can leverage the WEF security nexus. However, too many fertilizer applications, diet shifts towards

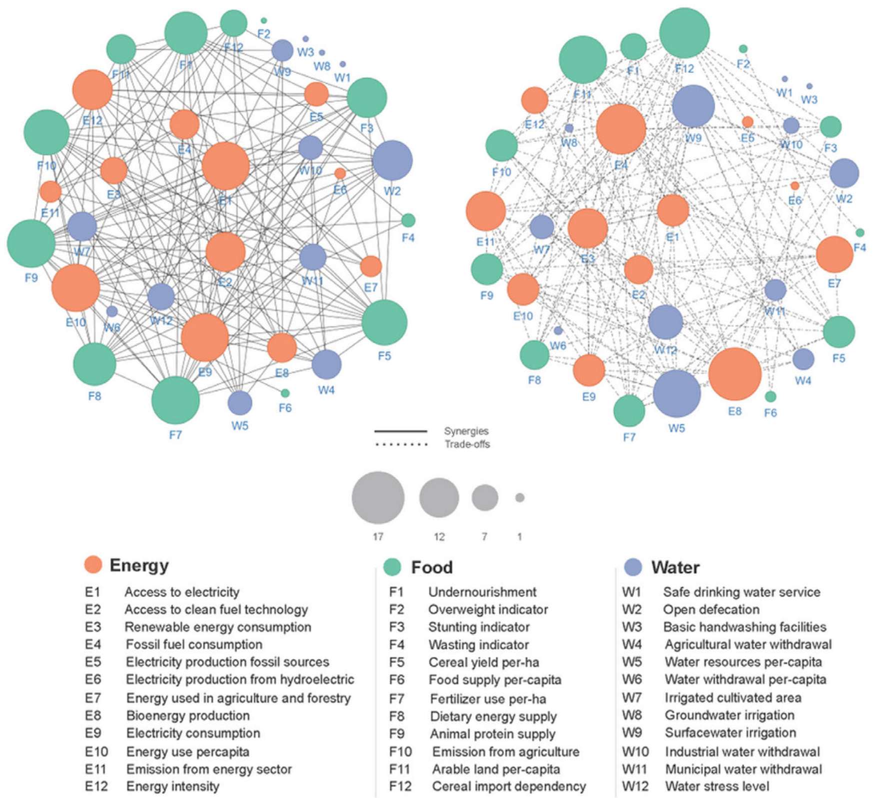

Fig. 6.4 Networks of the synergies (left side) and trade-offs (right side) were generated for China based on interactions among the water, energy, and food sectors. In comparison to the smaller nodes, the larger nodes have more edges and greater influences in the networks

a larger percentage of animal food sources, and increased food waste could threaten environmental sustainability, and food waste is increasingly recognized as a burning issue in China (Bodirsky et al. 2020; Hic et al. 2016; Ladha et al. 2020; Pradhan and Kropp 2020).

In the trade-off network, the most influential indicators are E_4, E_8, and F_{12}. This result shows that increased fossil energy consumption (E_4), growing bioenergy production (E_8), and dependency on cereal imports (F_{12}) would contradict China's achievement of the WEF security nexus. China should proactively promote a shift from traditional fossil fuels to renewable fuels, not only to ensure WEF security but also to limit global temperature and ensure sustainable development (Zhang et al. 2022). Globally, greenhouse gas emissions need to be rapidly reduced worldwide to limit global warming well below 2 °C (Rockström et al. 2017). Despite the significance of renewable energy, however, the negative relation between E_8 and other indicators shows that bioenergy needs to be promoted cautiously because of its adverse impacts on food and water security at a high level (IPCC 2019).

6.3.4 Indonesia (IDN)

Approximately 40% of the indicators are positively linked to 11–14 other indicators in Indonesia's synergy network (Fig. 6.5). These indicators are distributed across the WEF sectors. For example, the most influential water sector indicators, W_2 (open defecation) and W_3 (basic handwashing facilities), synergize with 12 and 14 other indicators, respectively. These indicators are positively linked to basic needs across the sectors, e.g., electricity access, undernourishment, access to clean fuel technology, and dietary and animal protein supply. Clean sanitation systems and proper nutrition supply are essential for stopping stunted growth (Aguayo and Menon 2016). Similarly, food sector indicator F_5 (cereal yield) has positive influences on reducing undernourishment (F_1), improving dietary energy (F_8), and increasing animal protein supply (F_9). These findings show the country's progress in the last few decades in meeting people's basic needs that align with achieving WEF security.

In contrast, our analysis also shows that increased cereal yield (F_5) negatively influences 30% of the other indicators, hindering the achievement of WEF security (Figs. 6.5 and A6.3). For example, this negative influence puts more pressure on water resources (W_5, W_8, W_9, and W_{12}). It may also increase the use of fossil fuels (E_4 and E_5), leading to greenhouse gas emissions (E_{11}). Some of these linkages are direct and can be explained. However, others might be because of spurious relationships due to either coincidence or a third factor. For example, F_5 is negatively linked to bioenergy (E_8), hydroelectric energy (E_6), and renewable energy progress (E_3). Agricultural intensification and expansion are two general strategies used to meet growing crop demands. However, they could have externalities, including land-use change, greenhouse gas emissions, and negative impacts on biodiversity and ecosystem services. Thus, there is a need to explore sustainable practices beyond traditional agricultural intensification and expansion (Pradhan et al. 2015).

Looking more specifically at the trade-off network, bioenergy (E_8) appears to be the most influential indicator. It is negatively linked with 16 other indicators, including five food-related indicators (F_1, F_5, F_8, F_9, and F_{12}). In Indonesia, the palm oil sector plays an essential role in the bioenergy sector. Subsequently, our results reflect extensive resource use for bioenergy production. It is negatively linked to the energy and water resource indicators (E_7, E_9, E_{10}, E_{12}, W_4, W_6, and W_{10}). Palm oil is the most traded vegetable oil globally, and the rapid growth and future expansion of palm oil plantations could threaten biodiversity and forests and increase greenhouse gas emissions (Vijay et al. 2016).

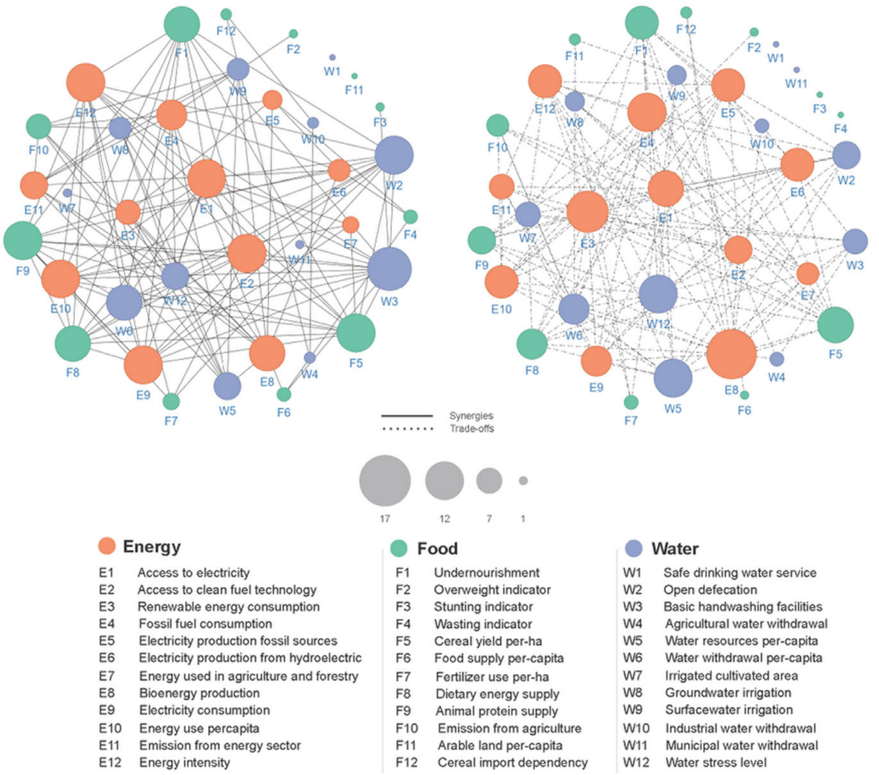

Fig. 6.5 Networks of the synergies (left side) and trade-offs (right side) were generated for Indonesia based on interactions among the water, energy, and food sectors. In comparison to the smaller nodes, the larger nodes have more edges and greater influences in the networks

6.3.5 Japan (JPN)

Japan is another high-income country in our analysis. Considering data availability, we observe five indicators with insufficient data (F_2, F_3, F_4, W_3, and W_8, Table A6.3). Our results show that 25% of the indicators have no link in the synergy and trade-off networks (Figs. A6.4 and A6.5). The main reason for the dissociated indicators is that they changed minimally within the analysis period. Mainly, the basic need indicators are relatively consistent, e.g., electricity access (E_1), clean fuel technology (E_2), undernourishment (F_1), and hygiene (W_2). Japan has been providing electricity access to 100% of its population since 1990, and 95% of the population has access to clean fuel technologies. Similarly, the proportion of the population that is without basic sanitation facilities and is undernourished is unchanged and very low.

Furthermore, we observe F_9 (animal protein supply) as the most influential indicator with positive links to 25% of the other indicators, including E_5, F_8, and W_6. In the last decade, the animal protein supply per capita has decreased to 47 g/cap/day in

Japan, within the healthy diet recommendation (Willett et al. 2019). These linkages highlight that healthy diets can leverage overall sustainability, including the WEF nexus. In the trade-off network, the most influential indicator is W_1 (safe drinking water services), with negative links to 30% WEF indicators, including fossil energy consumption (E_4), food supply (F_9), and water consumption (W_9). These links are hard to explain and might be due to spurious relationships.

6.3.6 Cambodia (KHM)

Approximately 50% of the water indicators have no links in Cambodia's synergy and trade-off networks due to a lack of progress in the water sector (Figs. A6.6 and A6.7). For example, we observe that the agriculture sector is responsible for most of the water withdrawals (94%), leaving only a small share of water for the industrial and municipal sectors during our analysis period. According to the database, irrigation water mostly comes from surface water, which is very vulnerable and directly affected by climate change (Jyrkama and Sykes 2007). Integrated water resource management, including the integrated use of surface water and groundwater, is crucial in reducing the vulnerabilities of water supply systems and adapting to water stress in response to climate change (Zhang 2015).

In the synergy network, seven indicators positively influence 12–14 other indicators, indicating their influential role in leveraging the WEF security nexus. These indicators include basic energy and water needs (E_1, E_2, E_9, W_1, and W_2) and food supply indicators (F_5 and F_{12}). The most influential indicator, E_9 (electricity consumption), has links with 40% of the WEF indicators. This indicator is correlated with increased cereal yield (F_5) and reduced cereal import dependency (F_{12}). Interestingly, electricity consumption is increasingly based on hydroelectricity (E_6). This result indicates a changing pattern of energy sources where hydroelectricity plays an essential role in Cambodia's energy mix with decreased electricity from fossil sources (E_5). Cambodia's plans for electricity production centre on hydropower with a 10,000 MW potential electricity supply (Eyler and Weatherby 2019).

In the trade-off network, we observe seven indicators with negative links to 10–14 other indicators. The most influential indicator, F_{11} (per capita arable land), has trade-offs with 40% of the WEF indicators. The negative links between F_5 and F_{11} can be connected to improved agricultural systems that have resulted in higher yields with reduced arable land.

As a country within the Mekong River Basin, some parts of Cambodia receive seasonal floods from monsoon rains. Although a change in flood regime can potentially be very destructive, it can also lead to modest increases in agricultural areas in the upper floodplain. This change may increase food production (Keskinen et al. 2015). However, agricultural systems still rely on fossil sources and are linked to increased greenhouse gas emissions (E_{11}). In addition, we also observe that improving water usage (W_5, W_6, and W_7) has negative links with basic energy (E_1 and E_2) and food indicators (F_5). These negative links could be related to hydropower development in Cambodia, which is technically challenging due to seasonal variability in water flows (Eyler and Weatherby 2019).

6.3.7 Republic of Korea (KOR)

Approximately 19 and 14% of the WEF indicators have no links in the synergy and trade-off networks for the Republic of Korea (Figs. 6.6 and A6.8). All disconnected indicators in the networks are mainly related to basic needs, which showed minor variations within our analysis period. These indicators include access to electricity (E_1), clean fuel technology (E_2), undernourishment (F_1), stunted growth (F_3), and sanitation (W_2). The Republic of Korea has been providing access to electricity and basic sanitation facilities to 100% of its population. Approximately 95% of its population has access to clean fuel technologies and a relatively low malnutrition rate (2.5%).

The most influential indicators, E_{10} and F_{10}, are linked to 30% of the WEF indicators in the synergy network. Interestingly, our results indicate that progress in reducing emissions from the agricultural sector is positively correlated with dietary energy (F_8), animal protein supply (F_9), and increased cereal yield (F_5). In the Republic of Korea, agricultural intensification based on advanced technology and improved governance might reduce emission intensity, increase productivity, and improve the food supply, resulting in synergies. Increased energy use (E_{10}) is also positively related to progress in renewable energy (E_3) and reduced fossil source consumption (E_4), which could be the result of improved energy management. Furthermore, our results show improved water governance within the country. The Republic of Korea has recognized the interdependencies among water users (cities, industry, agriculture, and ecosystems). These interdependencies can be addressed by a combination of water supply augmentation, water use efficiency, and water conservation (OECD 2018). Reducing water use in agriculture (W_4) is positively linked to improving irrigation coverage (W_7) and water use in the industrial sector (W_{10}).

In the trade-off network, seven energy and food sector indicators have negative links with 10–12 others. The most influential indicators, E_{11} (emissions from the energy sector) and F_{11} (arable land per capita), have trade-offs with 30% of the WEF indicators. Despite progress in renewable energy consumption, the share of renewables in the energy mix in the Republic of Korea remains low. The increased energy demand (E_9, E_{10}, and E_{12}) is negatively linked with greenhouse gas emissions because of a high dependency on fossil energy (E_4). Furthermore, the negative links between the energy and water sector indicators show conflicts between water consumption for energy production and other purposes, such as agriculture (W_7) and industrial usage (W_{10}). Additionally, the negative links of the food sector with the energy and water sectors indicate a resource-intensive farming model, reflecting growing consumer nutrient and protein demand (OECD 2018).

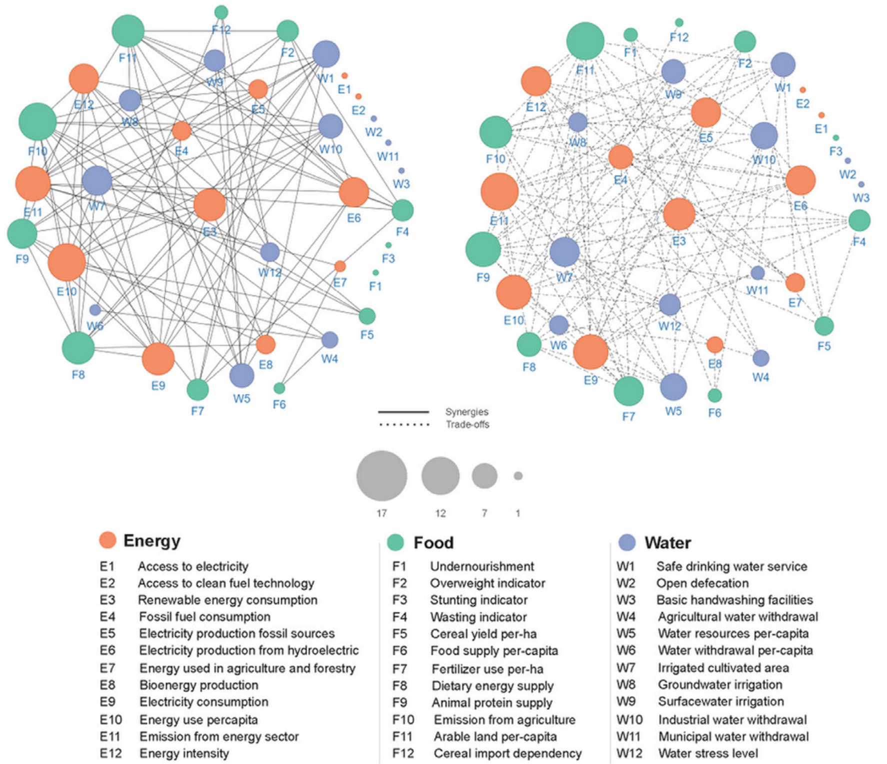

Fig. 6.6 Networks of the synergies (left side) and trade-offs (right side) were generated for the Republic of Korea based on interactions among the water, energy, and food sectors. In comparison to the smaller nodes, the larger nodes have more edges and greater influences in the networks

6.3.8 Lao People's Democratic Republic (Lao PDR)

We observe more trade-offs than synergies, particularly for *E*–*E*, *E*–*W*, *F*–*W*, and *W*–*W* interactions, ranging from 22 to 40% for Lao People's Democratic Republic (PDR) (Figs. A6.9 and A6.10). However, *E*–*F* and *F*–*F* interactions comprise a larger share of synergies (19% and 23%, respectively) than trade-offs. Approximately 25% of the WEF indicators have insufficient data for our analysis, including seven indicators in the energy sector and two indicators in the food sector (Table A6.3). Consequently, our results show more interactions in the water and food sectors for the synergy and trade-off networks. Three and two indicators are isolated in the synergy (E_{12}, F_2, and F_4) and trade-off (E_{12} and F_{10}) networks, respectively.

In the synergy network, four indicators (E_1, F_8, F_9, and W_1) are most influential, linked to 10–11 other indicators. This result indicates that progress related to these four indicators can leverage the WEF security nexus by influencing other indicators.

For example, our results suggest that improvement in electricity access (E_1) is positively linked to nutrient and protein supply (F_6, F_8, and F_9) and water access (W_1 and W_6). In Lao PDR, electricity accounts for approximately 30% of the total export value in the country. Thus, electricity generation can catalyse economic development, increase gross domestic product, and reduce poverty (McCartney and Brunner 2021). Similarly, progress in the food sector is depicted by the positive connection of the food indicators with energy and water progress, including increased yields (F_5), arable land (F_{11}), and nutrient and protein supply (F_6, F_8, and F_9). Although Lao PDR remains one of the poorest countries in the region (McCartney and Brunner 2021), there is progress in agricultural production, which accounts for the country's economic growth.

In the trade-off network, indicator W_5 (water resources per capita) has links to 11 other indicators. In addition, four water indicators (W_4, W_9, W_{11}, and W_{12}) are negatively connected with ten other indicators. This result represents conflicting progress in the water sector in comparison to the energy and food sectors. For example, increased water stress (W_{12}) negatively influences food supply and production (F_6, F_8, and F_9) and basic energy indicators (E_1 and E_2). As the primary water source, the Mekong River provides abundant water during the wet season, often causing floods. However, increased extreme weather leads to drought during the dry season. In the past, floods and drought damaged infrastructure, reduced food production, and hindered economic development. Moreover, the increased amount of hydropower in the country has led to significant environmental and social impacts and increased competition between water users (McCartney and Brunner 2021). Therefore, detailed technical and socioeconomic feasibility studies are needed to identify potential hydropower areas and vulnerable zones and, accordingly, to leverage the WEF security nexus of the country (Rasul 2014).

6.3.9 Myanmar (MMR)

More synergies than trade-offs are observed for Myanmar, particularly in *E–E*, *E–F*, and *F–F* interactions (Figs. A6.11 and A6.12). However, trade-offs dominate *E–W*, *F–W*, and *W–W* interactions. A large share of synergies accounts for 33% and 26% of the *E–E* and *E–F* interactions, respectively (Fig. 6.1). In Myanmar, only indicator W_1 (safe drinking water service) has insufficient data (Table A6.3), which could be the reason that we observe more interactions in the synergy and trade-off networks. We also found that in comparison to the other indicators, the energy indicators have more links in both networks. At the same time, the food sector has more links in only the synergy network, while the water sector is more connected in the trade-off network.

The most influential indicators, E_1 and F_9, are linked to 36% and 38% of the other WEF indicators in the synergy network, respectively. Electricity access (E_1) and animal protein supply (F_9) are the two most rapidly progressing indicators in Myanmar. Access to electricity reached 68% in 2019 and was positively linked to

13 other indicators, including access to clean fuel technology (E_2), hydroelectricity (E_6), supply of nutrients and food (F_6, F_8, and F_9), and water supply (W_4, W_8, and W_{10}). Biofuels and waste mainly related to the energy supply and electricity is increasingly dominated by hydroelectric power (IEA 2018b; Thant 2020). The animal protein supply (F_9) has quadrupled in the last two decades, reaching 40 g/cap/day in 2016. Progress in this indicator is positively correlated with 14 other indicators, mainly in the food and energy sectors.

Interestingly, in the trade-off network, we observe the dominant influence of the energy indicators, such as electricity access, bioenergy, fossil consumption, emission, and energy used in agriculture. These trade-offs indicate that the increased energy demand has been fulfilled based on fossil sources, resulting in a reduction in the bioenergy share and growing greenhouse gas emissions. The conflict within the energy sector also propagates to the food and water sectors. For example, the most negatively influential indicator E_1 has a negative correlation with progress in the water sector, e.g., surface irrigation (W_9), water withdrawal (W_6), water resources (W_5), and water stress (W_{12}). Similarly, a few energy indicators (E_1, E_8, E_{10}) negatively influence some food indicators, e.g., agricultural emissions, import dependency, arable land, crop yield, and food supply. Additionally, Myanmar's hydropower development also interferes with providing WEF security across borders (Dombrowsky and Hensengerth 2018). Despite the recent progress and development in the WEF sectors, Myanmar remains one of the least developed countries. It has many issues, including food insecurity, complex political and socioeconomic challenges, conflict, political instability, and the current fragile situation due to the COVID-19 pandemic (World Food Programme 2021). Myanmar may utilize the transformation opportunity generated by the pandemic to ensure WEF security, which may be short-lived and narrow (Pradhan et al. 2021).

6.3.10 Mongolia (MNG)

Mongolia has more synergies than trade-offs, particularly for *E–E*, *E–F*, *E–W*, *F–F*, and *F–W* interactions, with synergies ranging from 15 to 30% (Fig. 6.1, Figs. A6.13 and A6.14). The *E–E* interactions account for the largest synergies of 30%. The trade-offs are mostly observed within the *W–W* interactions. Despite the completeness of the country's data, four and seven indicators are isolated in the synergy and trade-off networks, respectively.

In the synergy network, we observe that 25% of the WEF indicators are linked to 11–15 other indicators. The most influential indicators are distributed across the sectors, including four energy, three food, and two water indicators. Influenced by positive progress in the energy sector, access to clean fuel technology has gradually increased within the last two decades, reaching 52% of the population in 2019. The two most influential indicators, E_2 and W_3, have links with 42% of the WEF indicators, representing leveraging effects of meeting people's basic needs for clean energy and sanitation. For example, these indicators are positively correlated with electricity access (E_1), water sanitation (W_2), food supply (F_8 and F_9), and food security (F_1 and F_3). Despite the progress, poverty and food insecurity remain a significant problem in Mongolia, with 20% of the population being undernourished in 2018. Poor infrastructure, climatic shocks, natural disasters, and extreme weather have exacerbated food insecurity with negative impacts on the agriculture sector. Most Mongolians rely mainly on traditional animal herding and food-processing practices, with a low level of modern food processing, raising food safety concerns (Park et al. 2017).

The energy and water indicators are the most influential indicators in the trade-off network: E_3, E_{11}, and W_{11} are linked to 11–14 other WEF indicators. In Mongolia, there has been a long-term conflict between the energy and water sectors. This conflict is mainly due to mining activities and uneven population distributions that are concentrated only in a few urban areas (Asian Development Bank 2014, 2020; McIntyre et al. 2016; Schoderer et al. 2021). The energy and electricity supplies highly depend on fossil fuel sources, mainly oil and coal. Rapid mining development has caused land-use changes and impacted water resources and the traditional animal herding lifestyles. Therefore, there is a need for effective governance mechanisms to support Mongolia's transition to a mining economy in addition to maintaining the sustainability of herder lifestyles to ensure WEF nexus security is attained (McIntyre et al. 2016).

6.3.11 Malaysia (MYS)

We observe trade-offs across the WEF sectors in Malaysia, ranging from 14 to 27%, mainly for *F–W*, *E–W*, *E–F*, *E–E*, and *F–F* interactions (Fig. 6.1, Figs. A6.15 and A6.16). In the *W–W* interactions, each synergy and trade-off accounts for 25% of the nexus interaction. The basic hygiene indicator (W_3) has insufficient data for Malaysia; thus, analysis of the nexus interaction between W_3 and other indicators is unavailable (Table A6.3). In addition, the network result depicts two (E_2 and W_{12}) and three (E_2, W_{10}, and W_{11}) isolated indicators in the synergy and trade-off networks, respectively.

The most influential indicators in the synergy network, E_1 and W_2, are linked to 28% and 25% of the other WEF indicators, representing their leveraging effects. In Malaysia, 100% of its population has had access to electricity (E_1) since 2011. The country reduced the size of its population without access to sanitation facilities (W_2) to 0.3% in 2016. Our results indicate that this progress is positively correlated with electricity consumption (E_9), energy intensity (E_{12}), cereal yields (F_5), animal protein supply (F_9), and basic water service (W_1). In addition, there is a positive correlation between progress in emissions (E_{11}) and fossil fuel consumption (F_4). Energy consumption is one of the main drivers behind increasing the greenhouse gas emissions of the country (Chong et al. 2019). In the food sector, Malaysia is a food-secure nation. It ranked 43rd in the 2020 global food security index and 8th in the regional Asia Pacific (Global Food Security Index 2020).

Interestingly, we also observe that E_1 is one of the most influential indicators in the trade-off network for Malaysia. It is linked to 28% of the other WEF indicators. Other influential indicators (E_9, E_{10}, F_3, and F_{11}) have links to 10–12 other WEF indicators. The negative correlations between electricity access (E_1) and increased energy demand, including electricity and energy usage (E_9 and E_{10}), indicate unsustainable energy sources in Malaysia.

Fossil fuel sources have powered Malaysia's economic development, and they represent more than 90% of its electricity production in the last two decades (Ahmad and Abdul-Ghani 2011; IEA 2018a; Sahid et al. 2013). Its fossil fuel dependency has threatened the achievement of sustainable development in the country. To achieve sustainable energy development, Malaysia needs to implement strategic options. These options include diversifying the sources of its energy supply, developing centralized renewable energy, enhancing energy efficiency, and facilitating low-carbon industry transition (Sahid et al. 2013). In addition, Malaysia needs to explore the potential of zero-carbon alternative fuels such as green hydrogen and green ammonia (Rahman and Wahid 2021).

6.3.12 The Philippines (PHL)

We observe more trade-offs than synergies in the Philippines, particularly in the *E–E*, *E–F*, and *F–W* interactions, ranging from 22 to 29% (Figs. 6.1, 6.7, and 6.8). Most trade-offs occurs in *F–F* and *W–W* interactions, whereas the *E–W* interactions have an equal share of synergies and trade-offs. The Philippines is the only country in our analysis with significant correlations between indicators, representing relatively good data availability (Table A6.2).

In the synergy network, 31% of the WEF indicators are linked to 10–13 other indicators. These indicators include 58% of the water indicators, representing leveraging effects of the sector in the WEF security nexus. Such leveraging effects are also observed for the energy and food sectors, mainly for improved electricity access (E_1), electricity consumption (E_9), energy intensity (E_{12}), and cereal yield (F_5). As a result of energy reform in early 2000, electricity access in the Philippines reached 96% in 2019. Progress in the water sector includes safe drinking water services for 47% of its population and hygiene facilities for 78%, and the proportion of the population without sanitation facilities decreased to 5% in 2017. In addition, we further observe a positive interlinkage between different water usages towards a larger share of industrial (W_{10}) and municipal (W_{11}) usage due to a decrease in water use in agriculture (W_4) from 82% in 2007 to 73% in 2017.

In the trade-off network, 33% of the WEF indicators are linked to 11–14 other indicators, including six energy indicators, five water indicators, and one food indicator. Although the production of renewable energy has increased, the share of renewable energy in the total energy supply has declined due to the increase in energy demand (Brahim 2014; IEA 2018c). Electricity demand is mainly supplied from fossil sources (E_4 and E_5); consequently, renewable energy consumption (E_3) and hydroelectric

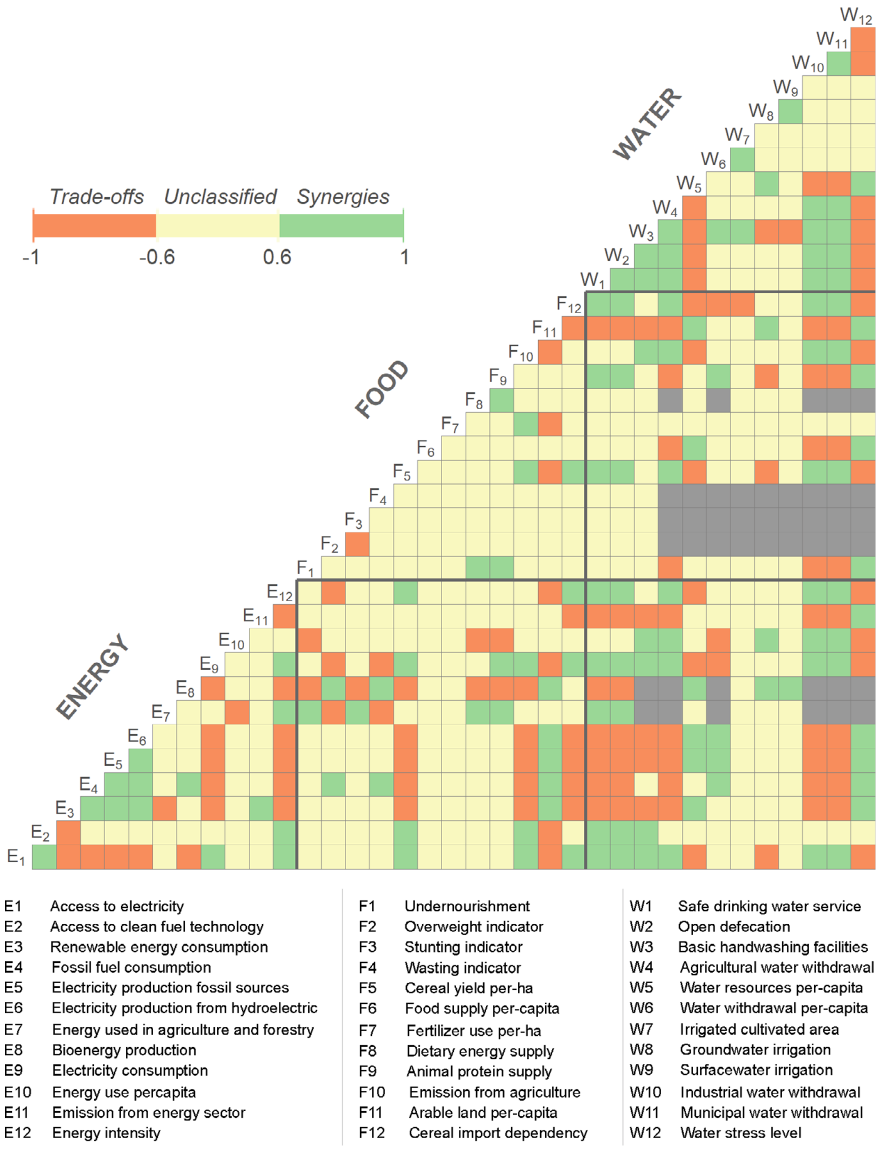

Fig. 6.7 Observed interactions between the water, energy, and food (WEF) sectors in the Philippines—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

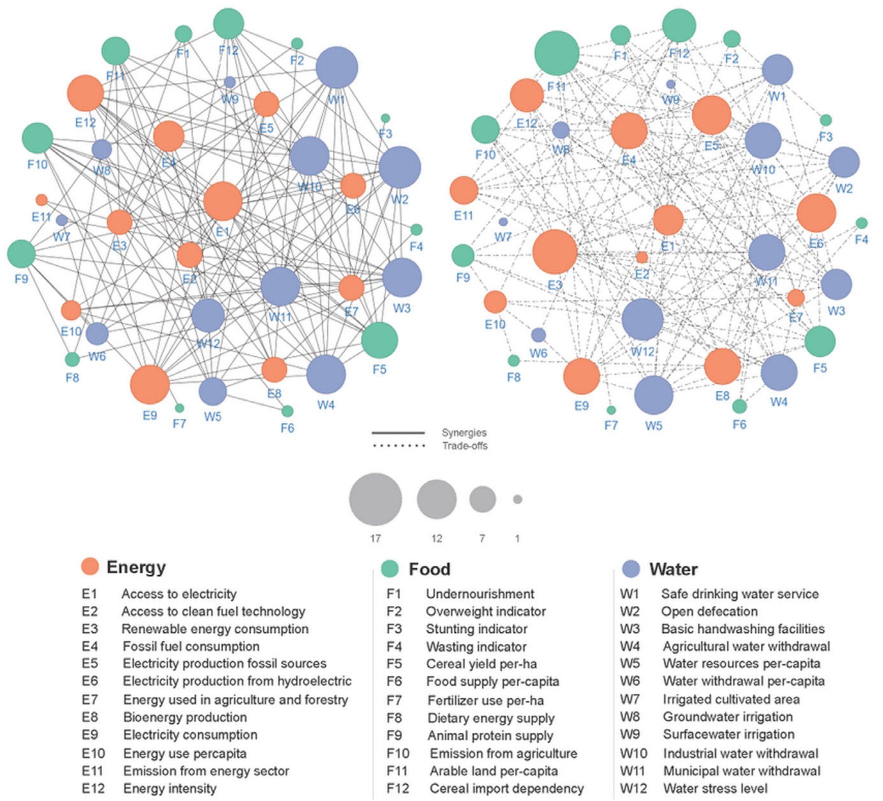

Fig. 6.8 Networks of the synergies (left side) and trade-offs (right side) were generated for the Philippines based on interactions among the water, energy, and food sectors. In comparison to the smaller nodes, the larger nodes have more edges and greater influences in the networks

energy consumption (E_6) have an anticorrelation with electricity consumption (E_9). In general, the energy mix in the Philippines is diverse. It consists of fossil sources (69%), wind and solar (15%), biofuels and waste (14%), and hydroelectric (1%) (IEA 2018c). A widely available agricultural residue from sugarcane, paddy rice, coconut, and maize can serve as substitutes for fossil fuels in the Philippines (Go et al. 2019). However, the growth of alternative renewables is much slower than the fossil fuel consumption rate, resulting in trade-offs in the *E*–*F* interactions. For example, bioenergy production (E_8) is negatively correlated with a few food indicators, i.e., F_8, F_9, and F_{10}. These trade-offs can further hinder attaining the WEF security nexus. In addition, the Philippines has been classified as a country with high food security risks; i.e., 64% of its population is chronically food insecure (Asian Development Bank 2013; IPC 2021). Interestingly, W_4, W_{10}, and W_{11} are the most negatively influential water indicators and are linked to 11 other WEF indicators. Various factors exacerbate the rising water demand (e.g., population growth, economic development, climate change, groundwater overuse, pollution, forest destruction, and overlapping institutional or legal water responsibility), resulting in water scarcity in the country (Alikpala and Ilagan 2018).

6.3.13 Democratic People's Republic of Korea (PRK)

We observe more synergies than trade-offs, particularly for *E–E*, *F–F*, and *W–W* interactions, ranging from 18 to 67%, for the DPR Korea (Figs. 6.1, A6.17 and A6.18). *E–E* interactions comprise a larger share of the synergies at 67%. This relation accounts for approximately 50% of the energy indicators due to data insufficiency. Seven energy indicators, two food indicators, and one water indicator have insufficient data for our analysis (Table A6.3). For this reason, our results show more interactions in the water and food sectors. Additionally, three other indicators (W_2, W_9, and W_{12}) are isolated in the synergy and trade-off networks.

The most influential indicators, E_1, E_{11}, and F_3, are linked to eight other WEF indicators in the synergy network. Access to electricity was at 50% in 2019 throughout the country. Although this value is considerably low compared to that in other countries, it doubled within a decade. Interestingly, access to electricity (E_1) is positively correlated with renewable consumption (E_3) and reduced energy emissions (E_{11}). Due to international sanctions, oil trade and exports to DPR Korea are prohibited. Thus, 76% of electricity was obtained from hydropower in 2015. Additionally, renewable sources such as biomass, waste, and solar panels play an essential role in the energy supply, particularly in the residential sector (Hippel and Hayes 2007; US Energy Information Administration 2018).

In the trade-off network, indicators F_1 and W_1 are the most negatively influential indicators linked to eight and seven other WEF indicators. This result may indicate resource conflict in reducing malnutrition and providing water services. Food insecurity, undernutrition, and access to health and sanitation services remain the main challenges in DPR Korea. A recent report estimated that more than 10 million people are in urgent need of nutrition support in the country. Similarly, more than 8 million people lack access to health services, clean water, and sanitation systems (OCHA 2020).

6.3.14 Singapore (SGP)

We have limited results for Singapore due to poor data availability for 40% of the WEF indicators, mainly in the food and water sectors (Tables A6.2 and A6.3, Figs. A6.19 and A6.20). Additionally, many indicators in Singapore show little change during our analysis period, particularly the basic need indicators, such as electricity access (E_1), clean fuel technologies (E_2), nutrient adequacy (F_1, F_2, and F_3), and water indicators (W_1, W_2, and W_3), and these disconnected indicators have nonsignificant or unclassified relationships. Consequently, we could capture few WEF interactions (Table A6.3).

As shown in Fig. A6.19, three energy (E_9, E_{10}, and E_{12}) and four water (W_6, W_{10}, W_{11}, and W_{12}) indicators create the synergy network. E_{10} (energy use per capita) shows synergies with three water indicators, mainly due to increased energy use and growing water demand in the municipal (W_{11}) and industrial sectors (W_{10}). Unlike many other countries where the agricultural sector (W_4) consumes the most water, the industrial sector is the largest water consumer in Singapore (Taniguchi et al. 2017).

In the trade-off network, three energy indicators (E_4, E_9, and E_{11}) are linked to a food indicator (F_{11}) and two water indicators (W_5 and W_{10}). Singapore has a high diversity of food sources despite low food self-sufficiency (Taniguchi et al. 2017). The country needs a substantial amount of energy to maintain diverse food sources in the limited available space to cultivate food. Despite its decreasing trend, the share of fossil sources (E_4) in the energy mix in Singapore is relatively high, resulting in a large share of greenhouse gas emissions originating from the energy sectors (E_{11}). Similarly, our result also highlights the negative links between the energy and water indicators, representing conflicts between the two sectors. For example, water and wastewater treatment processes account for 2.0% of the Singaporean electricity demand (Vincent et al. 2014). This indicates that although the wastewater treatment process is considered a robust, diversified, and sustainable system (Singapore's National Water Agency 2021), this high amount of energy consumption could limit its contributions to the sustainable development of the country.

6.3.15 Thailand (THA)

Thailand has more trade-off relations than synergies, particularly for *E–E*, *E–W*, *F–F*, and *W–W* interactions, ranging from 17 to 41% (Figs. 6.1, A6.21 and A6.22). The *F–W* interactions have more synergies, at 15%, than trade-offs (14%). The *E–F* interactions have an equal share of both synergies and trade-offs at 19% each. The only indicator with insufficient data for Thailand is access to drinking water services (W_1). Apart from W_1, seven and eight other indicators are isolated in the synergy and trade-off networks, respectively. In general, our results show that energy indicators have more interactions, while water indicators have fewer interactions.

In the synergies network, the most influential indicators E_1 and E_9 have links with 33% and 31% of the other WEF indicators, respectively, representing leveraging effects of the energy sector in general. Similarly, other energy indicators (E_2 and E_{10}) are positively linked to 28% of the other indicators. Since 2019, Thailand has provided electricity access (E_1) to 100% of its population, with 89% accessing clean fuel technologies (E_2). Our results indicate that progress in the energy sector has positively influenced other basic need indicators, such as reducing undernutrition (F_1 and F_3) and improving sanitation and hygiene facilities (W_2 and W_3).

In the trade-off network, emissions from the energy sector (E_{11}), water resources per capita (W_5), and water withdrawal (W_6) are linked to 31 to 37% of the other WEF indicators. W_5 and W_6 are negatively correlated with 13 and 11 other WEF indicators, respectively, reflecting water conflict across sectors in the country. Similarly, E_{11} is negatively linked to 12 other WEF indicators due to growing fossil fuel use to meet increased energy demand (IEA 2018d). Resource challenges are dominant in rapidly expanding cities in the East and Southeast Asian regions. They are interrelated with the complex WEF security nexus (Lehmann 2018), e.g., growing water demand for agriculture (Yamaguchi et al. 2019) and overexploitation of groundwater in coastal cities such as Bangkok (Kookana et al. 2020; Yamaguchi et al. 2019). There is potential for bioenergy development to increase domestic energy use from renewable sources in Thailand (Asafu-Adjaye and Wianwiwat 2012). However, a lack of understanding the interrelationships among bioenergy, water, and food policies has posed several challenges across the WEF sectors (Wattana 2014). To achieve sustainability in the energy sector, Thailand needs to develop specific policy measures to enhance energy security. Thus, a larger proportion of electricity must be produced by renewables by 2050 (Kumar 2016; Phdungsilp 2015). Furthermore, food security could be improved by conserving community-based natural resources and adapting traditional ecological knowledge (Phungpracha et al. 2016).

6.3.16 Vietnam (VNM)

We observe more synergies for the *E–W*, *F–F*, and *W–W* interactions than for the other interactions, ranging from 23 to 29% in Vietnam (Figs. 6.1, A6.23 and A6.24). Trade-offs are frequently observed in the *E–E*, *E–F*, and *F–W* interactions, ranging from 24 to 33%. Access to drinking water services (W_1) is the only indicator with insufficient data for Vietnam (Table A6.3). In addition to W_1, 7 and 4 other indicators are isolated in the synergy and trade-off networks, respectively. Our result depicts more interactions for energy indicators in the synergy and trade-off network with fewer interactions for water indicators.

In the synergies network, 25% of the WEF indicators are linked to 11–13 other indicators. These indicators include five food indicators, three energy indicators, and one water indicator, representing leveraging effects among and across sectors in the WEF security nexus. Most synergy indicators are basic need indicators that have been progressing within our analysis period. For example, 99% of the population has had electricity access (E_1) since 2011; 65% of the population had access to clean energy technology (E_2) in 2019, undernourishment (F_1) was reduced to 6.4% in 2018, and the percentage of the population without proper sanitation (W_2) diminished to 3% in 2017. These basic need indicators also leverage the progress in food supply in the food sector, including improving animal protein supply (F_9) and dietary energy supply (F_8).

We observe that 28% of the WEF indicators are linked to 11–13 other indicators in the trade-off network. Interestingly, E_9, F_5, and F_{10} are the most influential indicators in the trade-off network in addition to the synergy network. These indicators are negatively linked to 11 other WEF indicators, representing conflict within and across sectors. Electricity consumption (E_9) is mainly negatively correlated with the energy and water indicators, reflecting a high dependency on fossil sources and conflicts related to hydropower development. Despite the increase in total renewable generation, the majority of the total energy supply is covered by fossil sources (80%), followed by biofuels (11%) and hydroelectric sources (9%) (IEA 2018e). Our results indicate that increased electricity consumption (E_9) is related to growing fossil energy consumption (E_4, E_5, and E_{11}) and water stress (W_{12}). In addition, this increased electricity consumption is also negatively correlated with renewable consumption (E_3 and E_6) and water availability for other usages, e.g., agriculture (W_4) and industry (W_{10}), including water resources per capita (W_5).

6.4 Discussion

This study analysed WEF interactions for East and Southeast Asia by using open data sources at the country scale. We defined positive and negative correlations between the WEF security indicators as synergies and trade-offs, respectively, and identified the influential indicators in the WEF networks using the results of our correlation analysis. Our results generally highlight more trade-offs than synergies within and among the WEF sectors in East and Southeast Asia at the country and regional scales. Of the synergy indicators, the most influential indicators are electricity access and hygiene at the regional scale. Additionally, energy use per capita and animal protein supply are linked to more than 45% of the WEF indicators. However, bioenergy, arable land, water resources per capita, and water withdrawal per capita negatively influence the WEF nexus. The results indicate that extensive resource use for bioenergy development can hinder the WEF security nexus in the region. In addition, economic and population growth might be linked to the intensive use of resources.

In the lower-middle-income countries, most synergies are linked to improving basic needs that leverage overall sustainable development and the WEF security nexus. For example, improved electricity access catalyses progress in most lower-middle-income countries. Countries within the major river basins (e.g., Cambodia and Myanmar) benefit from hydroelectric development to leverage the WEF security nexus. Lao PDR and Myanmar have made progress in ensuring food security due to increased agricultural production and animal protein supply. However, a few countries still have a relatively high share of food insecurity and water security issues (e.g., DPR Korea and Mongolia). Electricity access or energy consumption, relying on fossil sources, has generated trade-offs across the WEF security nexus in most countries. In some countries (e.g., China, Indonesia, and the Philippines), bioenergy is also linked to trade-offs due to extensive resource use. In addition, in Lao PDR, Myanmar, and Vietnam, hydropower development relates to environmental and social impacts and increased competition between water users. These issues interfere with the provision of the WEF security nexus across the border.

Among the high-income countries, Brunei Darussalam has trade-offs that are linked with energy dependency on fossil sources. These trade-offs indicate that the country needs to shift its energy policy to promote a sustainable renewable energy supply. In Japan, healthy diets and progress in the WEF security nexus are closely connected. However, the mechanism behind these synergies is not clear and might be linked to a third factor. Synergies and trade-offs in the Republic of Korea are mainly related to interactions between the energy and food sectors. These interactions might be connected to agricultural intensification, resulting in reduced emission intensity, increased productivity, and improved food supply. In addition, increased energy demand in the Republic of Korea creates further conflict due to its link to fossil sources, hindering the WEF security nexus. In Singapore, the industrial sector is the largest consumer of water. Here, the food sector is negatively linked to the energy and water sectors due to limited arable land.

Our study also has some limitations. The findings are based on the selected indicators, which could change if different indicators are used. The data section matters to our understanding of synergies and trade-offs (Warchold et al. 2022). However, these indicators were chosen carefully based on the existing literature and availability of the data. We faced data unavailability even with these indicators for many countries. Thus, filling the data gaps will be crucial for new insights into the WEF interactions and networks. Our findings reflect the current situation, showing synergies and trade-offs across WEF security. These interactions might change under sustainable management. In particular, changing trade-offs to synergies or at least nonsignificant or unclassified relations would be crucial for ensuring the WEF security nexus. For the high-income countries that addressed basic needs decades ago, we have already observed many nonsignificant correlations or unclassified relations with isolated nodes. However, these countries still need to decouple environmental degradation (e.g., greenhouse gas emissions) and the provision of water, energy, and food demand, as reflected by existing trade-offs. Although our correlation analysis does not imply causality, it is the first step in quantifying WEF interactions. Wherever possible, we attempt to explain and interpret our results based on existing studies. Our study highlights the most influential WEF synergy and trade-off network indicators based on the first-order effect. Further research could explore the influences based on second-order effects and beyond using systems models in addition to network analysis (Anderson et al. 2021).

In summary, East and Southeast Asia have more trade-offs than synergies among the WEF sectors. East and Southeast Asian countries need to address these trade-offs and leverage synergies to ensure the region's WEF security. To accomplish this, promoting sustainable and clean energy is crucial in the region. Currently, many countries are fulfilling their water, energy, and food demand using fossil sources, resulting in greenhouse gas emissions and climate change. Renewable energy (e.g., wind and solar power) could also play an essential role in countries with a large share of hydroelectricity by providing an optimum energy mix for a stable supply (Neupane et al. 2022). Moreover, our study provides further evidence to account for the WEF security nexus as an integrated system, similar to SDG systems (Pradhan 2019; Putra et al. 2020). Thus, East and Southeast Asia needs to attain the WEF security nexus as a whole instead of selected sectoral nexuses.

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Annex: Supplementary Tables and Figures for This Chapter

See Tables A6.1, A6.2 and A6.3 and Figs. A6.1, A6.2, A6.3, A6.4, A6.5, A6.6, A6.7, A6.8, A6.9, A6.10, A6.11, A6.12, A6.13, A6.14, A6.15, A6.16, A6.17, A6.18, A6.19, A6.20, A6.21, A6.22, A6.23 and A6.24.

Table A6.1 Indicators used for our analysis of the water, energy, and food (WEF) sectors and their signs. We collected data from various sources, including sustainable development goals (SDGs)

Indicator	Short description	Sign	Description	Source
E_1	Access to electricity	1	Proportion of population with access to electricity, by urban/rural (%)	SDG 7.1.1
E_2	Access to clean fuels and technology	1	Proportion of population with primary reliance on clean fuels and technology (%)	SDG 7.1.2
E_3	Renewable energy consumption	1	Renewable energy share in total final energy consumption (%)	SDG 7.2.1
E_4	Fossil fuel consumption	−1	Fossil fuel energy consumption (% of total)	World Bank
E_5	Electricity production fossil fuel source	−1	Electricity production from oil, gas and coal sources (% of total)	World Bank
E_6	Electricity production hydroelectric	1	Electricity production from hydroelectric sources (% of total)	World Bank
E_7	Energy used in agriculture and forestry	1	Agricultural and forestry energy use as a % of total energy use Energy used in agriculture and forestry	FAOSTAT
E_8	Bioenergy production	1	Bioenergy production as a % of total renewable energy production Bioenergy production	FAOSTAT

(continued)

Table A6.1 (continued)

Indicator	Short description	Sign	Description	Source
E_9	Electricity consumption	1	Electric power consumption (kWh per capita)	World Bank
E_{10}	Energy use per-capita	1	Energy use (kg of oil equivalent per capita)	World Bank
E_{11}	Emissions from the energy sector	−1	Share of total emissions (AR5) energy	FAOSTAT
E_{12}	Energy intensity	−1	Energy intensity level of primary energy (megajoules per constant 2011 purchasing power parity GDP)	SDG 7.3.1
F_1	Undernourishment	−1	Prevalence of undernourishment (%)	SDG 2.1.1
F_2	Overweight indicator	−1	Proportion of children moderately or severely overweight (%)	SDG 2.2.2
F_3	Stunting indicator	−1	Proportion of children moderately or severely stunted in growth (%)	SDG 2.2.1
F_4	Wasting indicator	−1	Proportion of children moderately or severely wasting (%)	SDG 2.2.2
F_5	Cereal Yield per ha	1	Yield Cereals, total	FAOSTAT
F_6	Food supply per capita	1	Value per capita food supply variability (kcal/cap/day)	FAOSTAT
F_7	Fertilizer use per ha	1	Use per area of cropland nutrient nitrogen N (total)	FAOSTAT
F_8	Dietary energy supply	1	Value average dietary energy supply adequacy (percent) (3-year average)	FAOSTAT
F_9	Animal protein supply	1	Value average supply of protein of animal origin (g/cap/day) (3-year average)	FAOSTAT
F_{10}	Emissions from agricultural sector	−1	Share of total emissions (AR5) agriculture total	FAOSTAT
F_{11}	Arable land per capita	1	Arable land (hectares per person)	World Bank
F_{12}	Cereal import dependency	−1	Value cereal import dependency ratio (percent) (3-year average)	FAOSTAT
W_1	Safe drinking water services	1	Proportion of population using safely managed drinking water, by urban/rural (%)	SDG 6.1.1

(continued)

Table A6.1 (continued)

Indicator	Short description	Sign	Description	Source
W_2	Open defecation	−1	Proportion of population practising open defecation, by urban/rural (%)	SDG 6.2.1
W_3	Basic handwashing facilities	1	Proportion of population with basic handwashing facilities on premises, by urban/rural (%)	SDG 6.2.1
W_4	Agricultural water withdrawal	−1	Agricultural water withdrawal as % of total water withdrawal	AQUASTAT
W_5	Water resources per-capita	1	Total renewable water resources per capita	AQUASTAT
W_6	Water withdrawals per capita	1	Total water withdrawals per capita	AQUASTAT
W_7	Irrigated cultivated area	1	% of the cultivated area equipped for irrigation	AQUASTAT
W_8	Groundwater irrigation	1	% of area equipped for irrigation by groundwater	AQUASTAT
W_9	Surface water irrigation	1	% of area equipped for irrigation by surface water	AQUASTAT
W_{10}	Industrial water withdrawals	1	Industrial water withdrawals as % of total water withdrawals	AQUASTAT
W_{11}	Municipal water withdrawals	1	Municipal water withdrawals as % of total withdrawals	AQUASTAT
W_{12}	Water stress level SDG 6.4.2	−1	SDG 6.4.2. Water stress	AQUASTAT

AQUASTAT (FAO 2021a), World Bank (2021), FAOSTAT (FAO 2021b), and SDG databases (United Nations 2021)

Table A6.2 Number of data points significantly related in 15 East and Southeast Asian countries across the water (W), energy (E), and food (F) sectors. As each nexus sector consists of 12 indicators, when data are available, the total number of data points per sectoral pair in every country is 144

Interactions	Countries	Synergies	Trade-offs	Unclassified	% of data analysed
E–E	Brunei Darussalam	1	3	16	14
E–E	Cambodia	13	16	37	46
E–E	China	23	24	19	46
E–E	Democratic People's Republic of Korea	6	0	3	6
E–E	Indonesia	26	33	7	46
E–E	Japan	7	6	32	31
E–E	Lao People's Democratic Republic	1	2	6	6

(continued)

Table A6.2 (continued)

Interactions	Countries	Synergies	Trade-offs	Unclassified	% of data analysed
E–E	Malaysia	10	14	31	38
E–E	Mongolia	13	11	20	31
E–E	Myanmar	22	17	27	46
E–E	Philippines	14	19	33	46
E–E	Republic of Korea	14	16	15	31
E–E	Singapore	1	0	27	19
E–E	Thailand	12	13	41	46
E–E	Vietnam	19	22	25	46
E–F	Brunei Darussalam	2	2	50	38
E–F	Cambodia	32	22	90	100
E–F	China	48	48	48	100
E–F	Democratic People's Republic of Korea	10	13	23	32
E–F	Indonesia	30	29	85	100
E–F	Japan	11	14	65	63
E–F	Lao People's Democratic Republic	9	6	33	33
E–F	Malaysia	21	25	63	76
E–F	Mongolia	27	14	79	83
E–F	Myanmar	37	20	84	98
E–F	Philippines	24	31	89	100
E–F	Republic of Korea	30	29	43	71
E–F	Singapore	0	3	13	11
E–F	Thailand	25	25	80	90
E–F	Vietnam	27	34	83	100
E–W	Brunei Darussalam	6	5	7	13
E–W	Cambodia	23	19	21	44
E–W	China	27	27	66	83
E–W	Democratic People's Republic of Korea	7	12	12	22
E–W	Indonesia	28	27	77	92
E–W	Japan	7	18	62	60
E–W	Lao People's Democratic Republic	9	14	26	34

(continued)

Table A6.2 (continued)

Interactions	Countries	Synergies	Trade-offs	Unclassified	% of data analysed
E–W	Malaysia	14	16	81	77
E–W	Mongolia	27	25	59	77
E–W	Myanmar	19	30	78	88
E–W	Philippines	41	41	50	92
E–W	Republic of Korea	20	26	53	69
E–W	Singapore	3	4	41	33
E–W	Thailand	13	19	44	53
E–W	Vietnam	25	20	63	75
F–F	Brunei Darussalam	0	0	28	19
F–F	Cambodia	14	21	30	45
F–F	China	25	15	26	46
F–F	Democratic People's Republic of Korea	7	2	30	27
F–F	Indonesia	8	2	56	46
F–F	Japan	8	7	21	25
F–F	Lao People's Democratic Republic	10	4	29	30
F–F	Malaysia	13	16	31	42
F–F	Mongolia	10	3	53	46
F–F	Myanmar	16	7	43	46
F–F	Philippines	6	5	55	46
F–F	Republic of Korea	10	13	23	32
F–F	Singapore	0	0	1	1
F–F	Thailand	8	11	45	44
F–F	Vietnam	19	12	35	46
F–W	Brunei Darussalam	3	3	16	15
F–W	Cambodia	16	17	29	43
F–W	China	26	22	45	65
F–W	Democratic People's Republic of Korea	10	13	27	35
F–W	Indonesia	21	20	62	72
F–W	Japan	18	16	35	48
F–W	Lao People's Democratic Republic	21	33	28	57

(continued)

Table A6.2 (continued)

Interactions	Countries	Synergies	Trade-offs	Unclassified	% of data analysed
F–W	Malaysia	9	12	64	59
F–W	Mongolia	22	11	84	81
F–W	Myanmar	9	14	69	64
F–W	Philippines	24	25	63	78
F–W	Republic of Korea	18	18	46	57
F–W	Singapore	0	0	5	3
F–W	Thailand	10	9	46	45
F–W	Vietnam	17	28	59	72
W–W	Brunei Darussalam	2	0	0	1
W–W	Cambodia	6	8	0	10
W–W	China	8	13	24	31
W–W	Democratic People's Republic of Korea	8	8	5	15
W–W	Indonesia	11	12	30	37
W–W	Japan	7	10	16	23
W–W	Lao People's Democratic Republic	21	20	10	35
W–W	Malaysia	10	10	20	28
W–W	Mongolia	7	10	49	46
W–W	Myanmar	11	16	21	33
W–W	Philippines	21	14	31	46
W–W	Republic of Korea	8	9	23	28
W–W	Singapore	1	0	1	1
W–W	Thailand	3	7	7	12
W–W	Vietnam	7	5	15	19

Table A6.3 Data availability of the water, energy, and food sector indicators for the East and Southeast Asian countries. Their ISO codes represent the countries

Indicator	BRN	CHN	IDN	JPN	KHM	KOR	LAO	MMR	MNG	MYS	PHL	PRK	SGP	THA	VNM
E_1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
E_2	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
E_3	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19
E_4	15	25	25	26	20	26	0	25	25	25	25	0	25	25	24
E_5	26	26	26	26	21	26	0	26	26	26	26	0	26	26	26
E_6	26	26	26	26	21	26	0	26	26	26	26	0	26	26	26
E_7	1	20	20	20	6	20	0	16	20	19	20	0	20	20	20
E_8	3	20	20	20	15	20	0	20	20	20	20	20	12	20	20
E_9	25	25	25	25	20	25	0	25	25	25	25	0	25	25	25
E_{10}	25	25	25	26	20	26	0	25	25	25	25	0	25	25	24
E_{11}	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
E_{12}	19	19	19	19	19	19	19	19	19	19	19	0	19	19	19
F_1	18	18	18	18	18	18	0	18	18	18	18	18	0	18	18
F_2	1	7	7	1	5	2	5	4	7	2	6	3	1	3	14
F_3	1	7	7	1	5	2	5	4	7	3	6	6	1	3	16
F_4	1	7	7	1	5	2	5	4	7	2	6	6	1	3	15
F_5	30	30	30	30	30	30	30	30	30	30	30	30	0	30	30

(continued)

Table A6.3 (continued)

Indicator	BRN	CHN	IDN	JPN	KHM	KOR	LAO	MMR	MNG	MYS	PHL	PRK	SGP	THA	VNM
F_6	15	18	18	18	18	18	18	18	18	18	18	18	0	18	18
F_7	0	29	29	29	26	29	0	29	29	29	29	0	0	29	29
F_8	18	18	18	18	18	18	18	18	18	18	18	18	0	18	18
F_9	14	16	16	16	16	16	16	16	16	16	16	16	0	16	16
F_{10}	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
F_{11}	29	29	29	29	29	29	29	29	29	29	29	0	29	29	29
F_{12}	12	16	16	16	16	16	16	16	16	16	16	16	0	16	16
W_1	0	0	0	18	18	16	18	0	18	18	18	18	18	0	0
W_2	9	18	18	18	18	18	18	18	18	17	18	16	18	18	18
W_3	0	0	12	0	10	0	5	6	14	0	7	0	0	6	13
W_4	5	6	6	6	3	6	3	6	5	6	3	4	6	3	6
W_5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
W_6	6	6	6	6	3	6	3	6	5	6	3	4	6	3	6
W_7	5	6	6	6	5	6	5	6	5	6	6	6	0	6	6
W_8	0	6	5	0	0	5	5	5	5	5	5	6	0	6	3
W_9	5	6	5	5	5	5	5	5	5	5	5	6	0	5	3
W_{10}	0	6	6	6	3	6	3	6	5	6	3	4	6	3	6
W_{11}	3	6	6	6	3	6	3	6	5	6	3	4	6	3	6
W_{12}	6	6	6	6	3	6	3	6	5	6	3	4	6	3	6

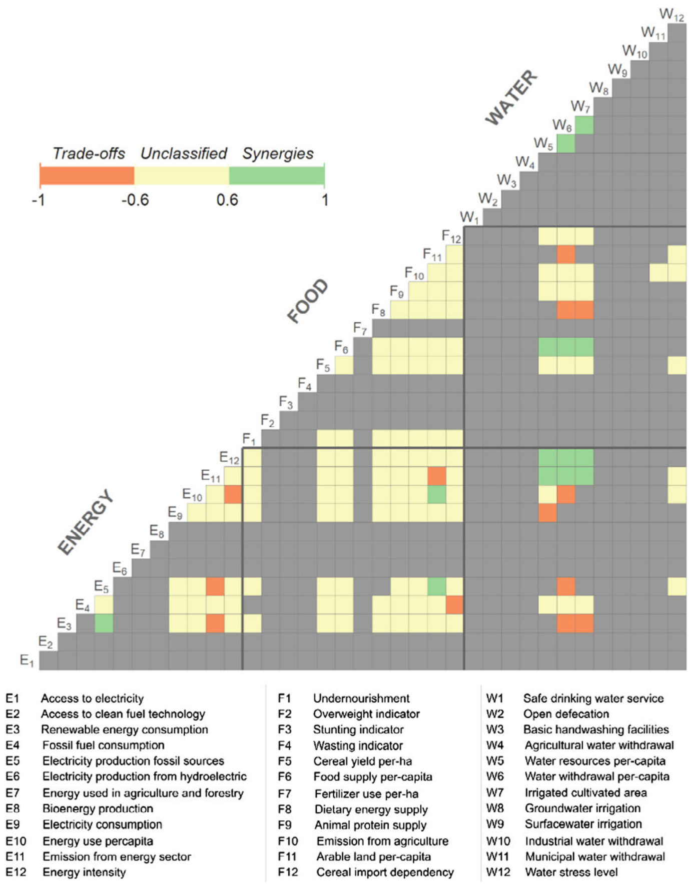

Fig. A6.1 Observed interactions between the water, energy, and food (WEF) sectors in Brunei Darussalam—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

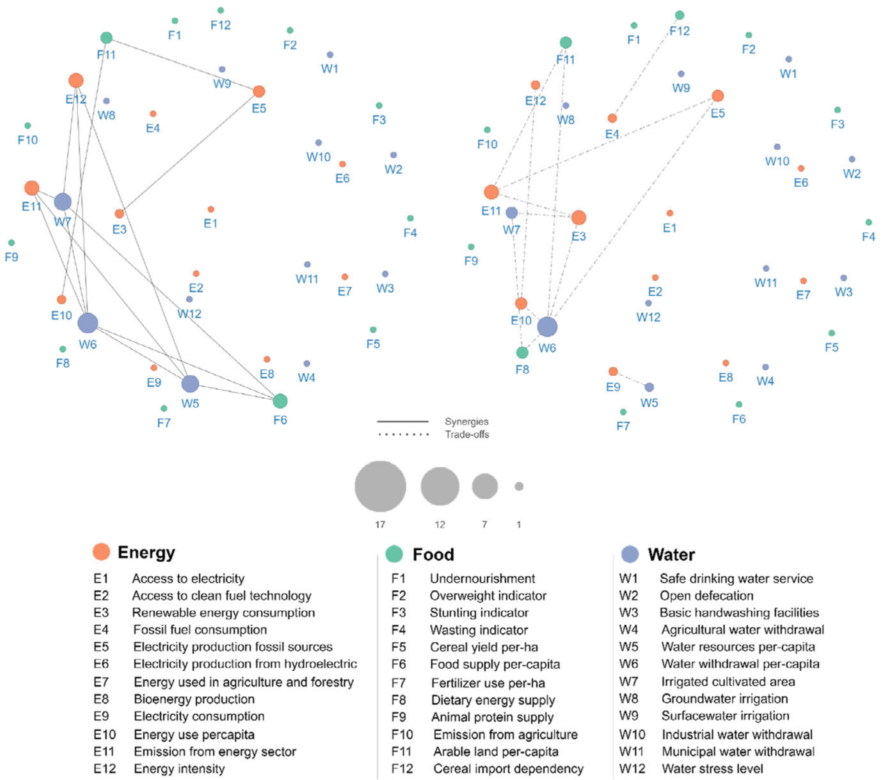

Fig. A6.2 We generated the synergy (left side) and trade-off (right side) network for Brunei Darussalam based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

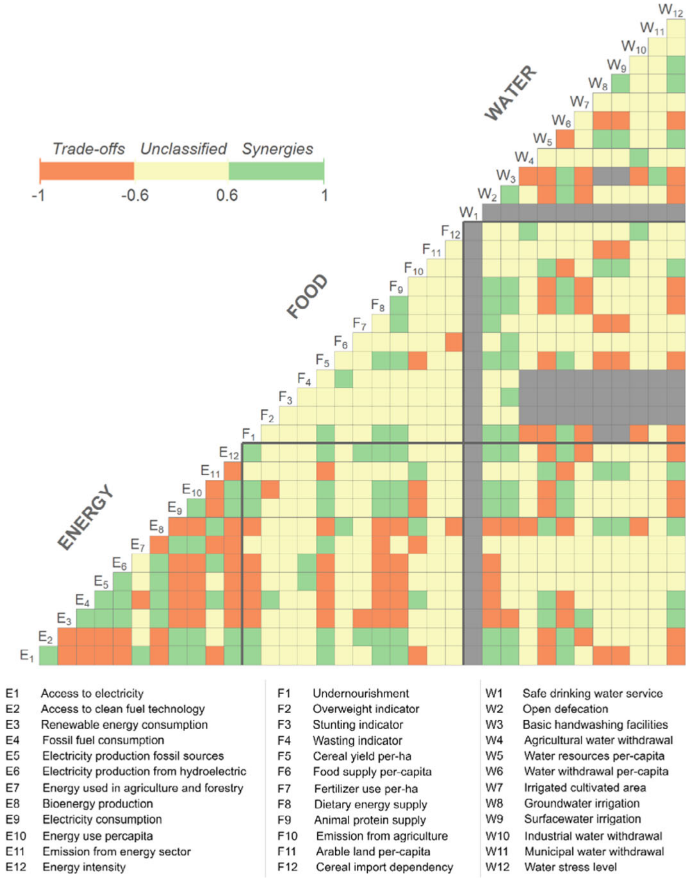

Fig. A6.3 Observed interactions between the water, energy, and food (WEF) sectors in Indonesia synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

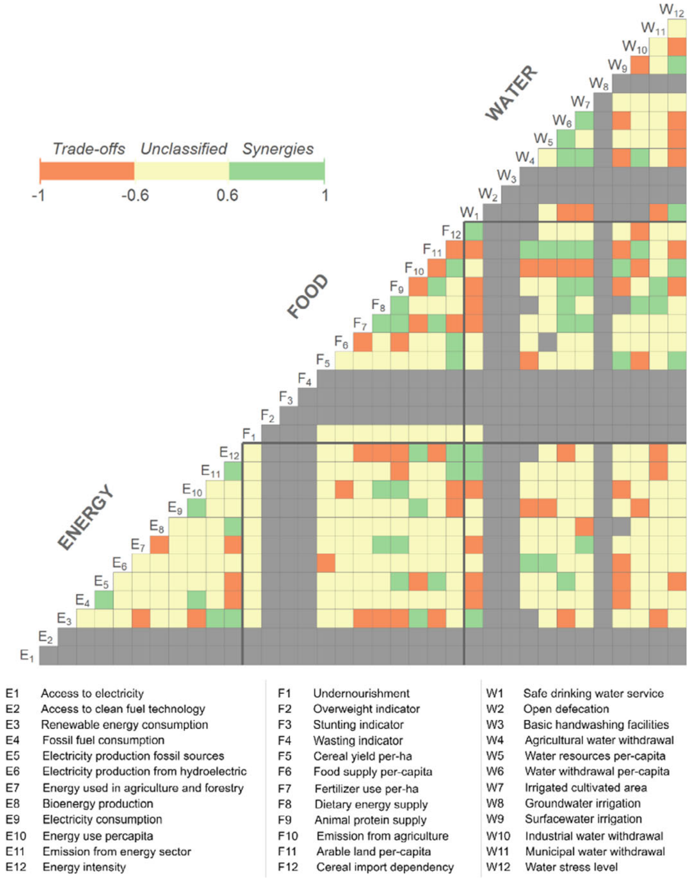

Fig. A6.4 Observed interactions between the water, energy, and food (WEF) sectors in Japan—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

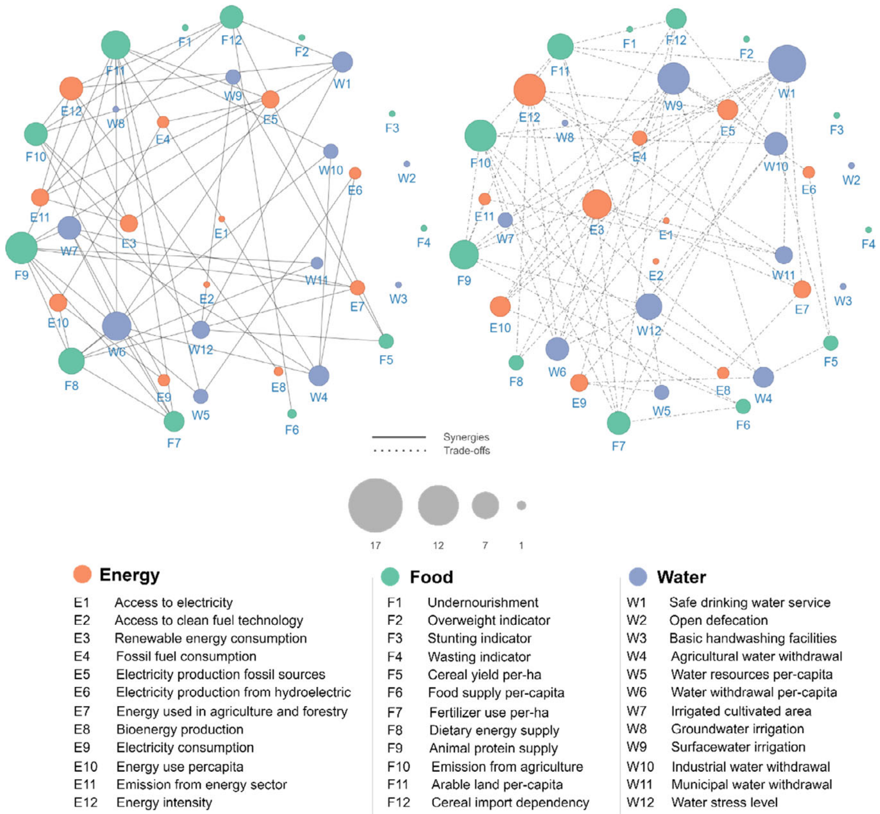

Fig. A6.5 We generated a synergy (left side) and trade-off (right side) network for Japan based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

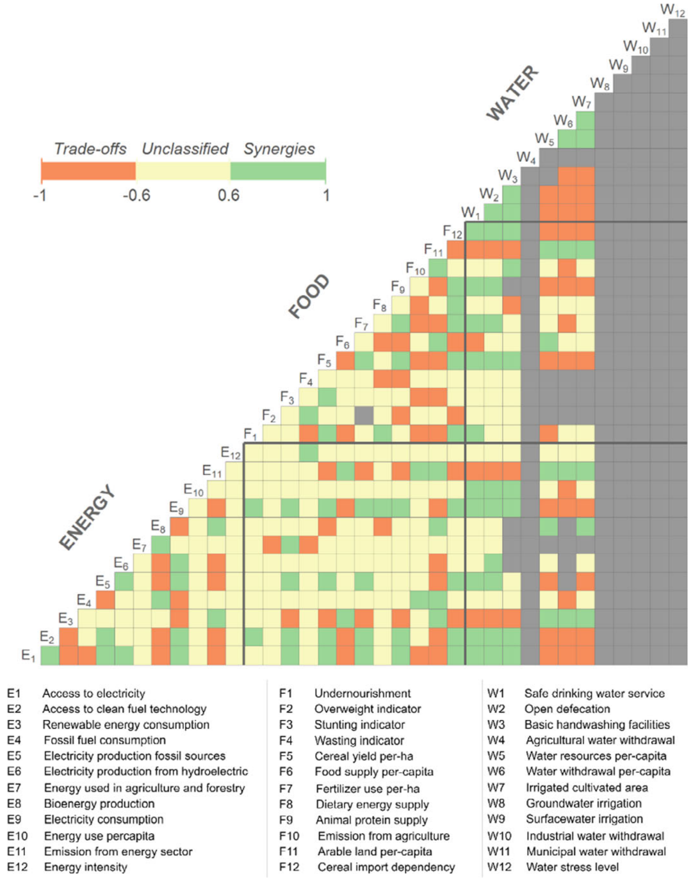

Fig. A6.6 Observed interactions between the water, energy, and food (WEF) sectors in Cambodia—synergies (green), trade-offs (orange), and unclassified (yellow). Grey insufficient data. The codes on the diagonal represent the indicators

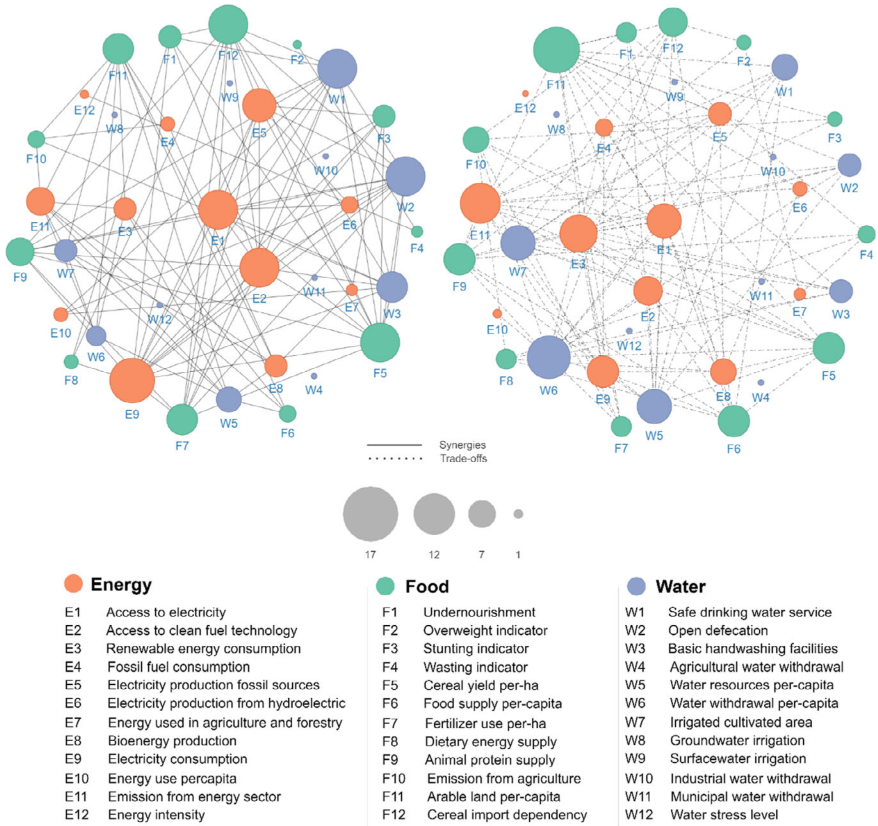

Fig. A6.7 We generated a synergy (left side) and trade-off (right side) network for Cambodia based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

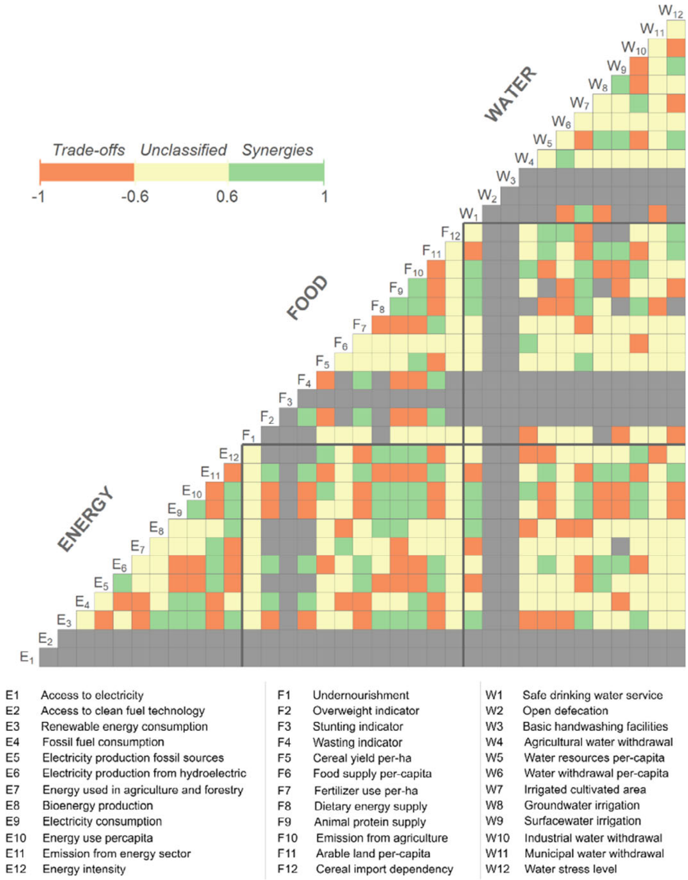

Fig. A6.8 Observed interactions between the water, energy, and food (WEF) sectors in the Republic of Korea—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

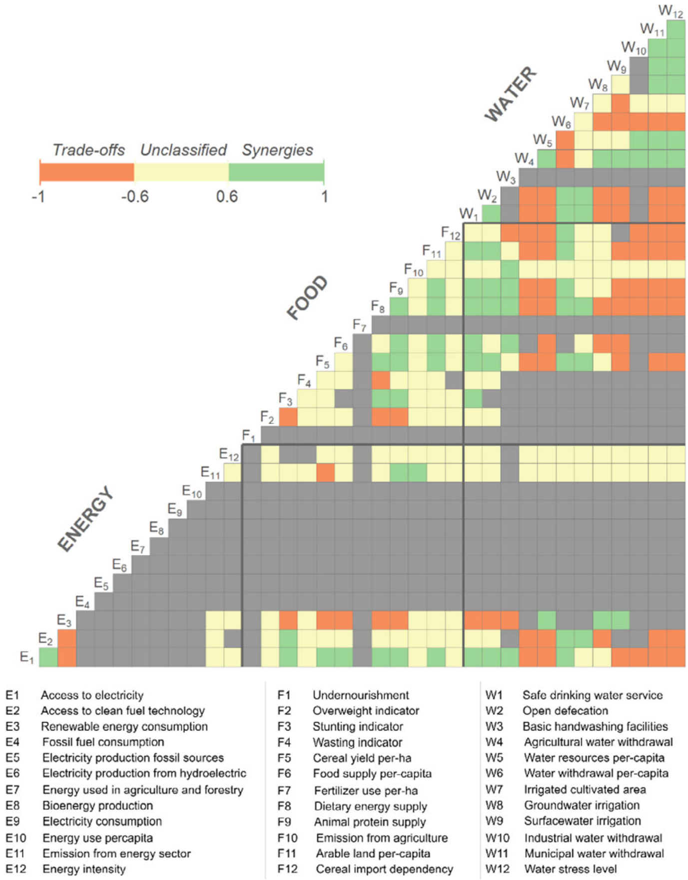

Fig. A6.9 Observed interactions between the water, energy, and food (WEF) sectors in Lao People's Democratic Republic—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

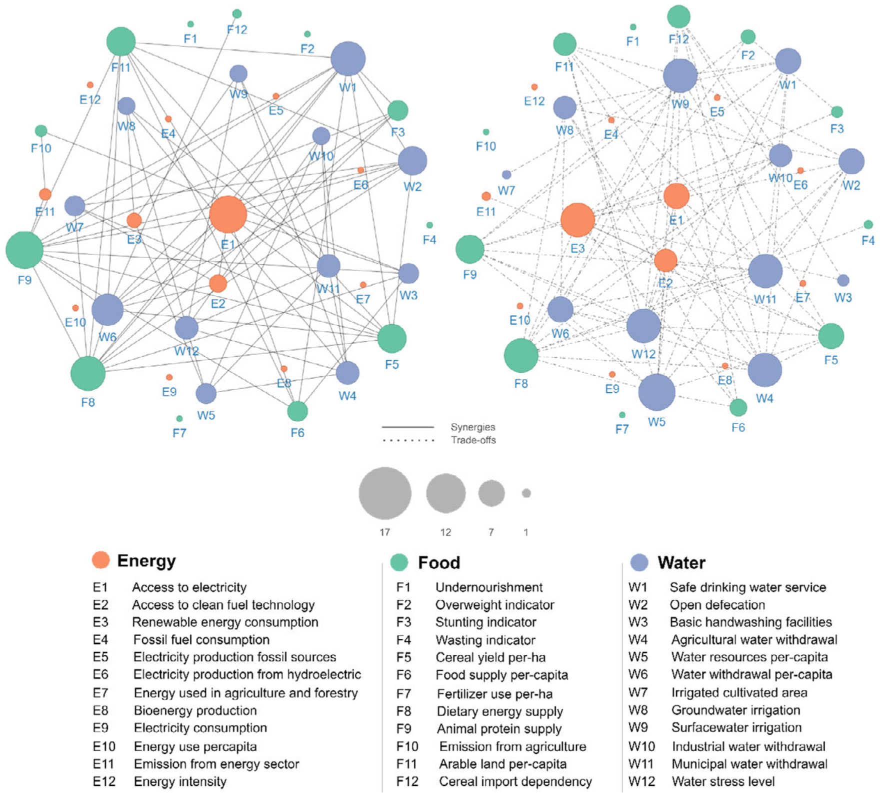

Fig. A6.10 We generated the synergy (left side) and trade-off (right side) network for Lao People's Democratic Republic based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

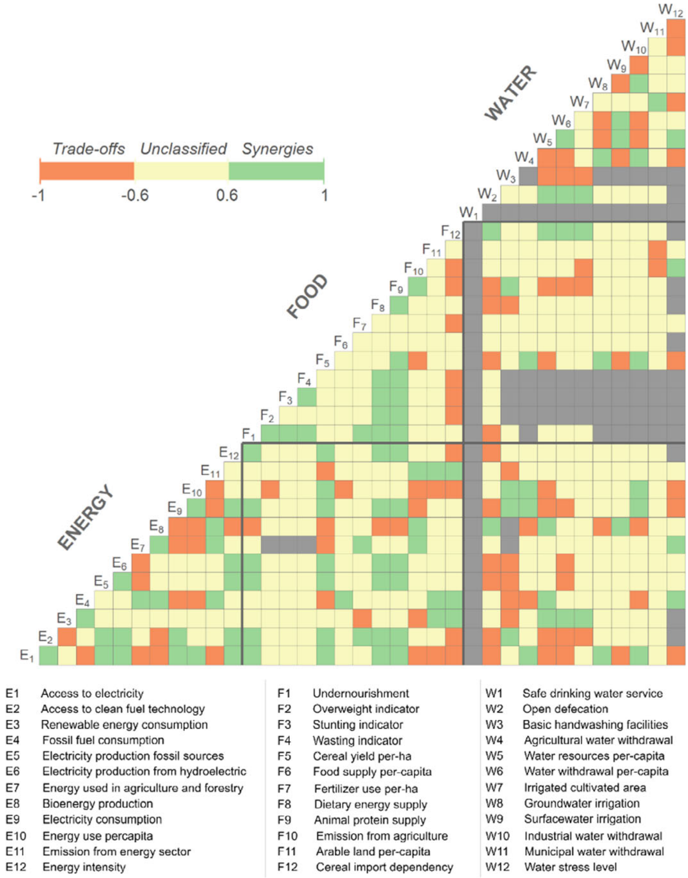

Fig. A6.11 Observed interactions between the water, energy, and food (WEF) sectors in Myanmar—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

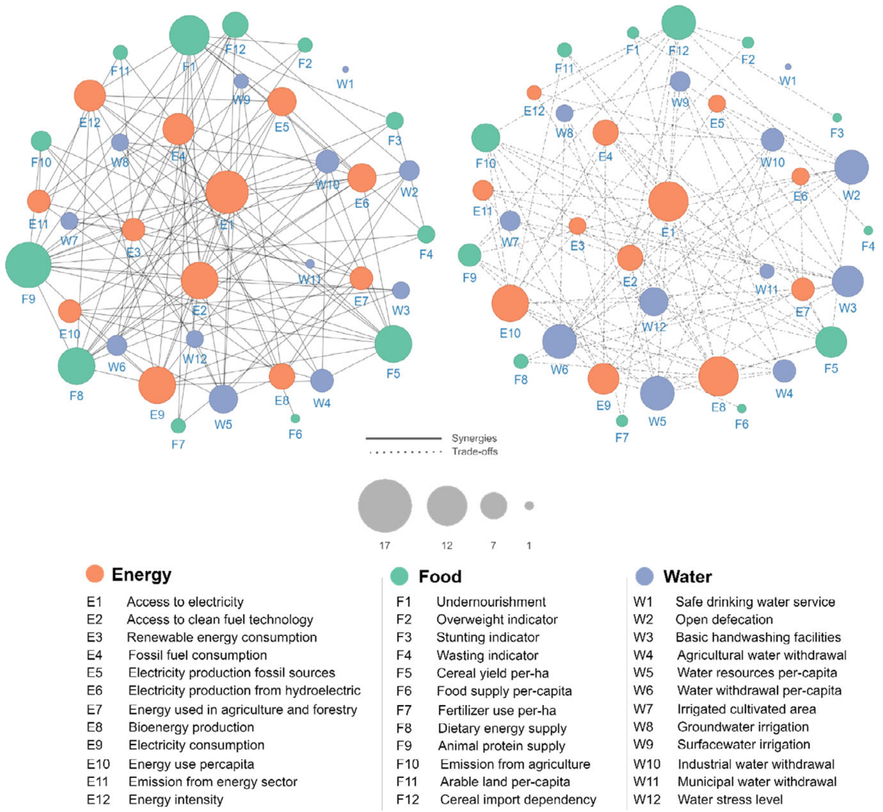

Fig. A6.12 We generated a synergy (left side) and trade-off (right side) network for Myanmar based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

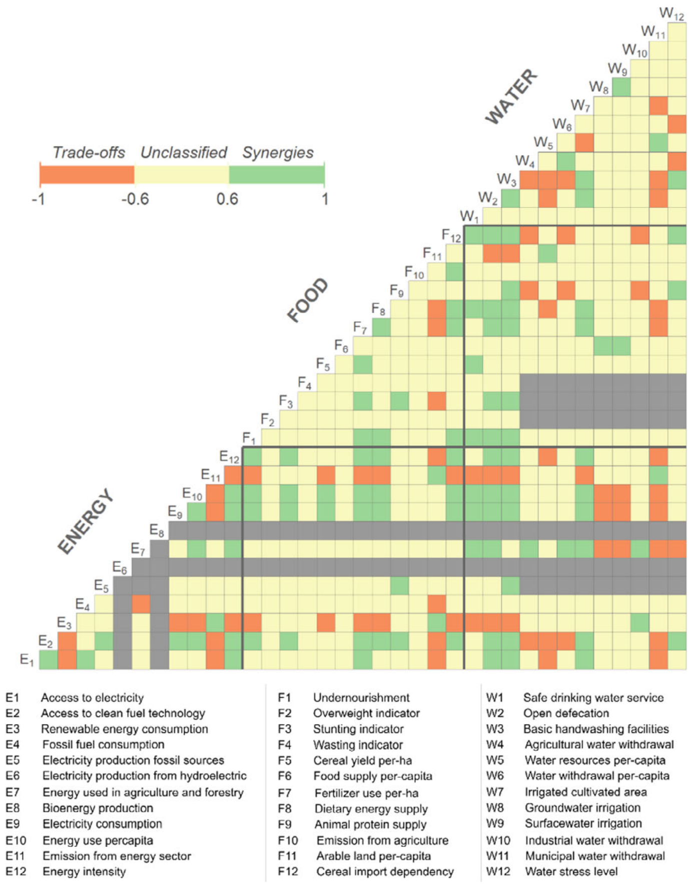

Fig. A6.13 Observed interactions between the water, energy, and food (WEF) sectors in Mongolia—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

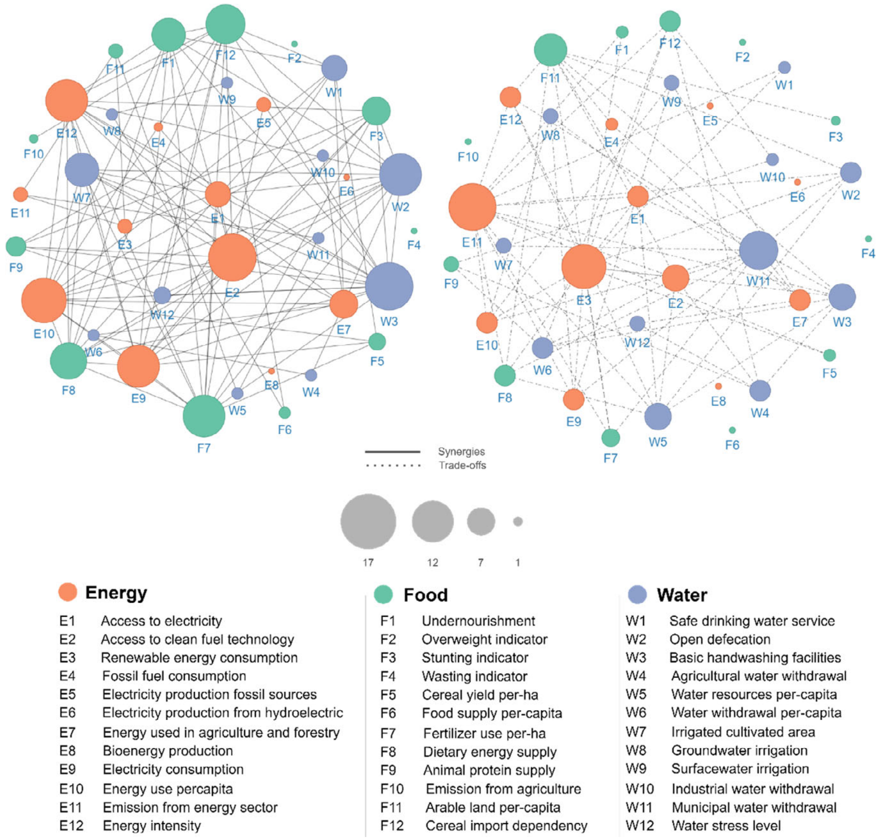

Fig. A6.14 We generated Mongolia's synergy (left side) and trade-off (right side) network based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

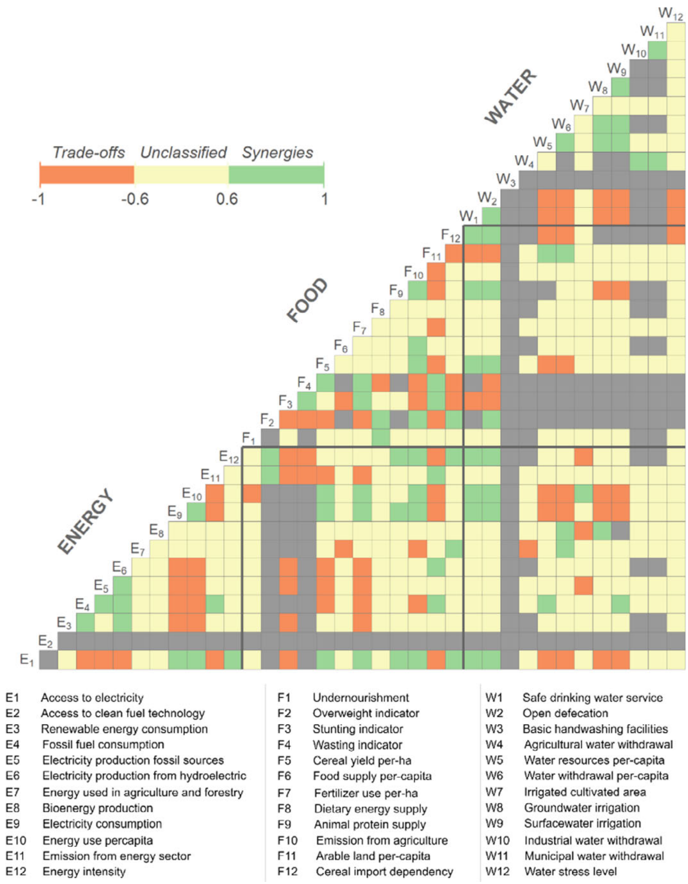

Fig. A6.15 Observed interactions between the water, energy, and food (WEF) sectors in Malaysia—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

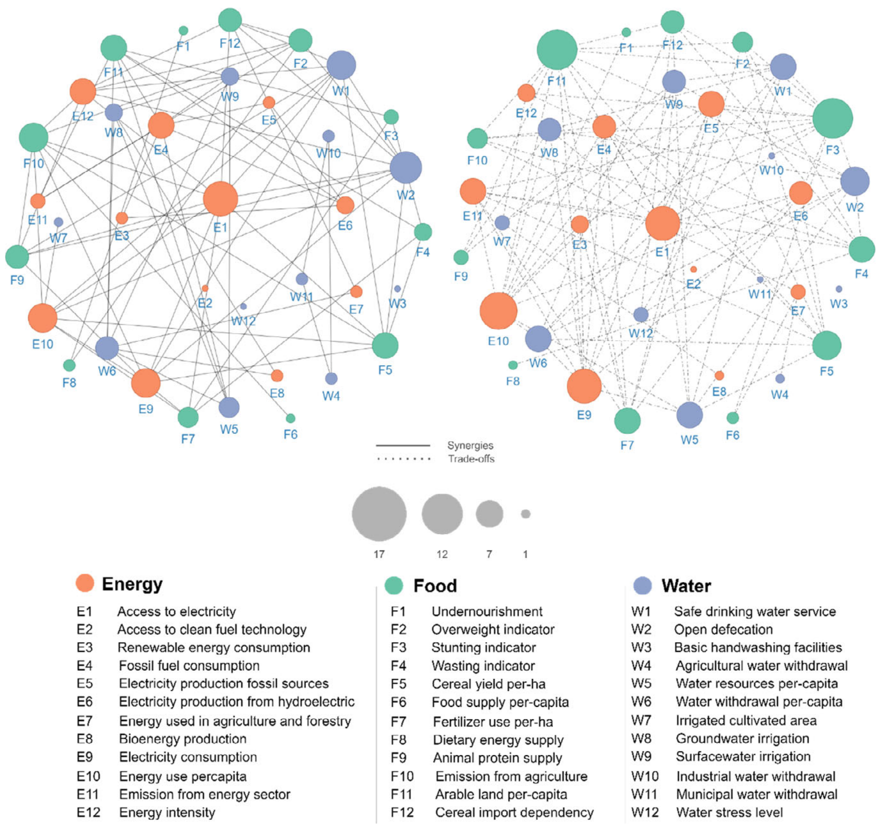

Fig. A6.16 We generated Malaysia's synergy (left side) and trade-off (right side) network based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

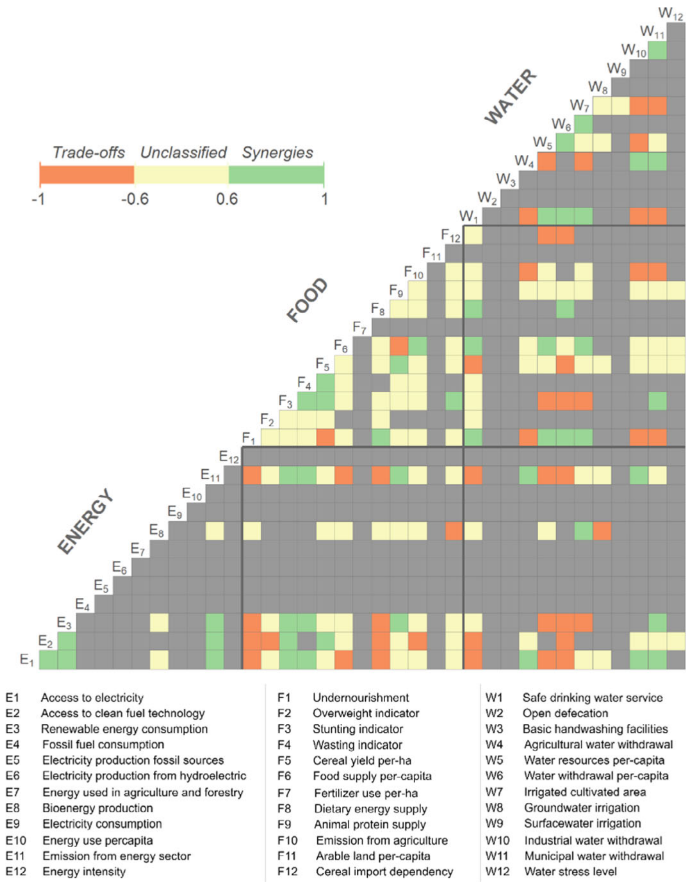

Fig. A6.17 Observed interactions between the water, energy, and food (WEF) sectors in the Democratic People's Republic of Korea—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

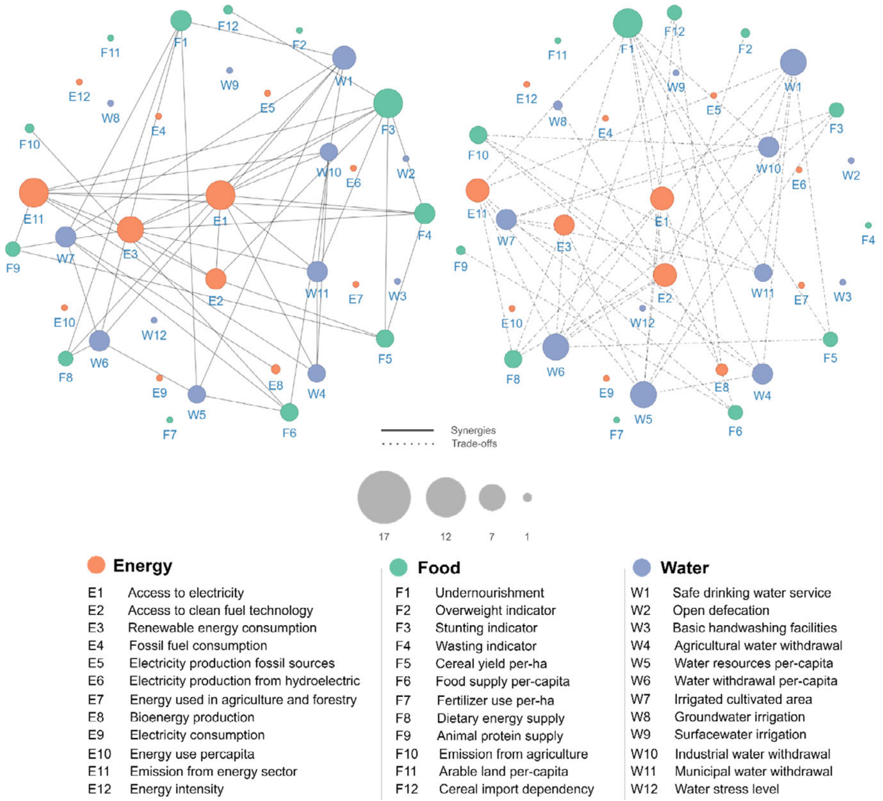

Fig. A6.18 We generated the synergy (left side) and trade-off (right side) network for the Democratic People's Republic of Korea based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

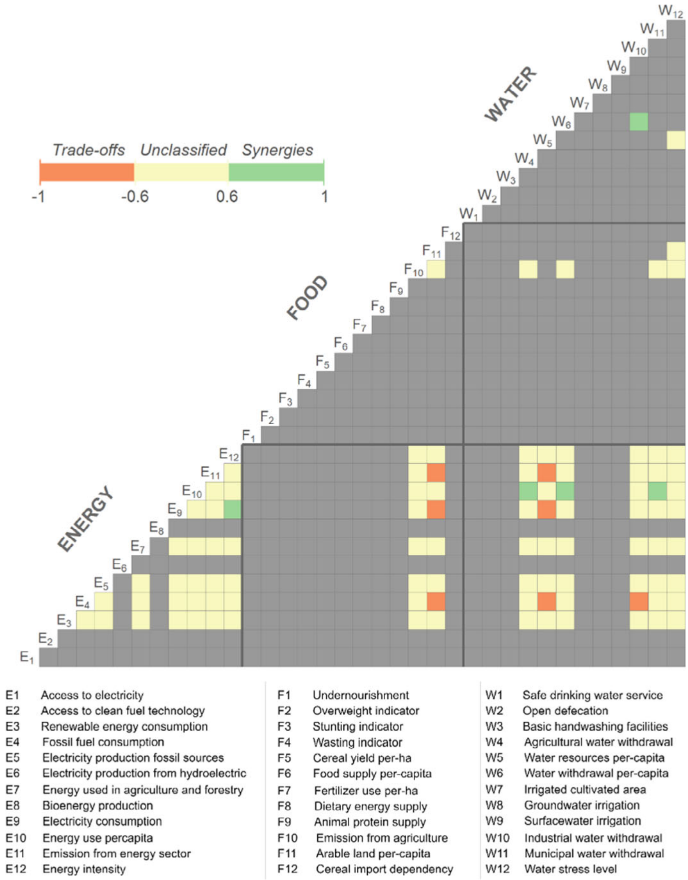

Fig. A6.19 Observed interactions between the water, energy, and food (WEF) sectors in Singapore—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

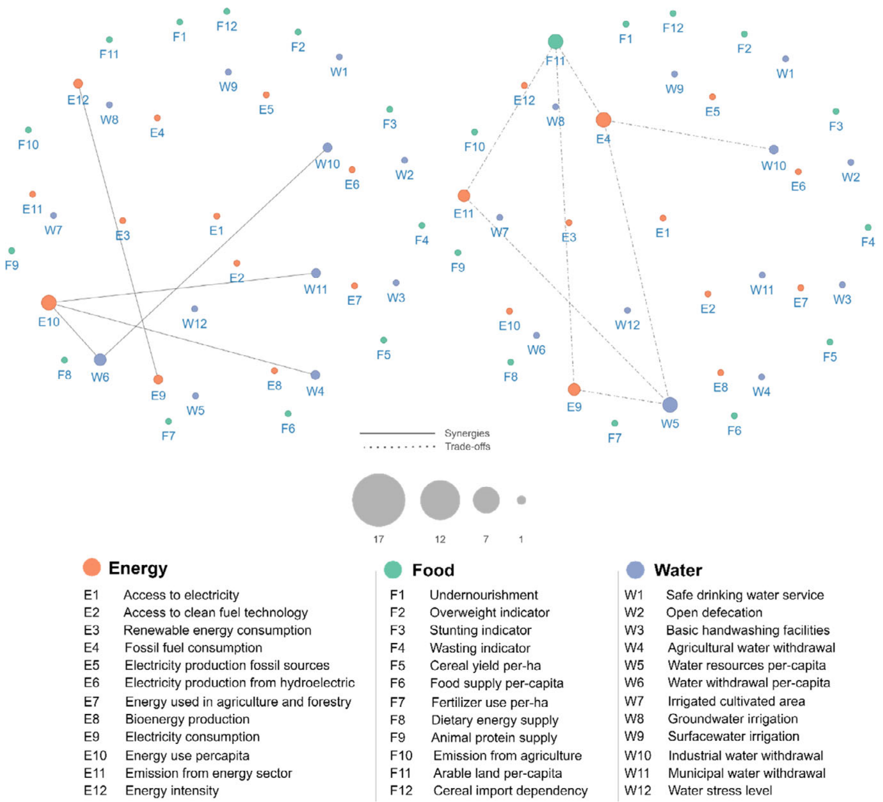

Fig. A6.20 We generated a synergy (left side) and trade-off (right side) network for Singapore based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

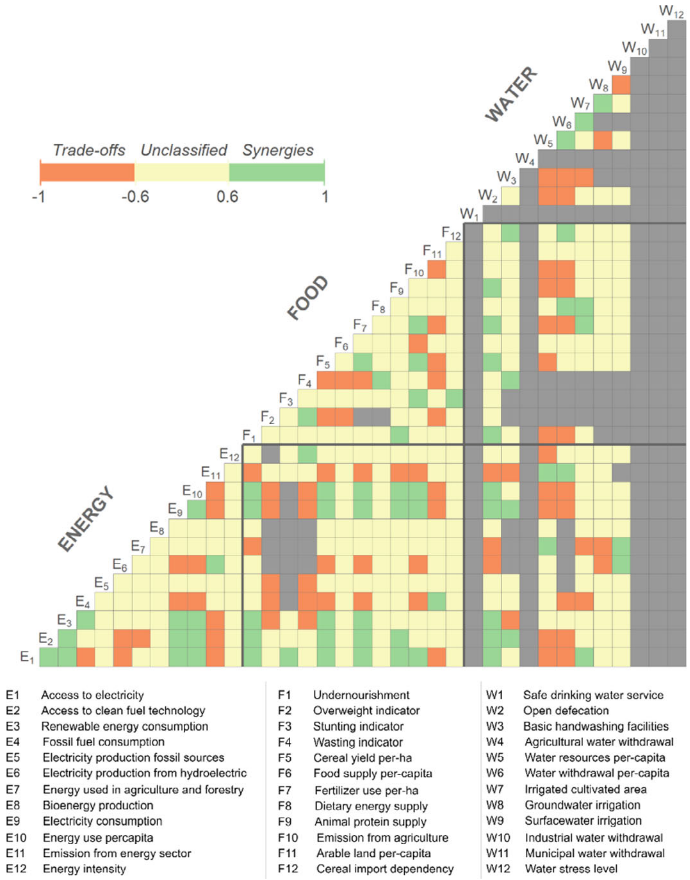

Fig. A6.21 Observed interactions between the water, energy, and food (WEF) sectors in Thailand—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

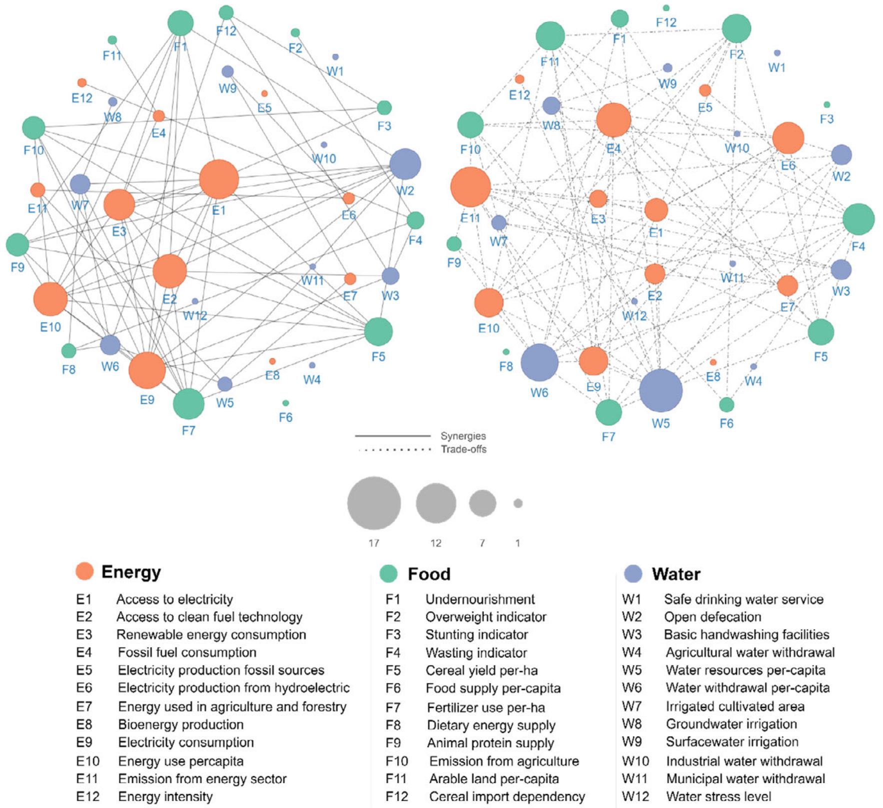

Fig. A6.22 We generated Thailand's synergy (left side) and trade-off (right side) network based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

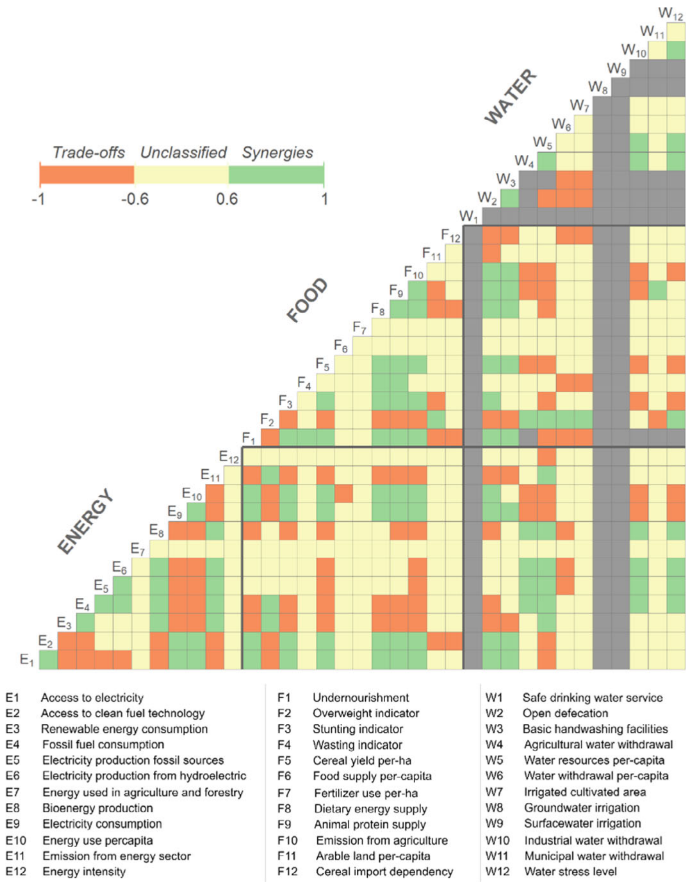

Fig. A6.23 Observed interactions between the water, energy, and food (WEF) sectors in Vietnam—synergies (green), trade-offs (orange), and unclassified (yellow). Grey depicts insufficient data. The codes on the diagonal represent the indicators

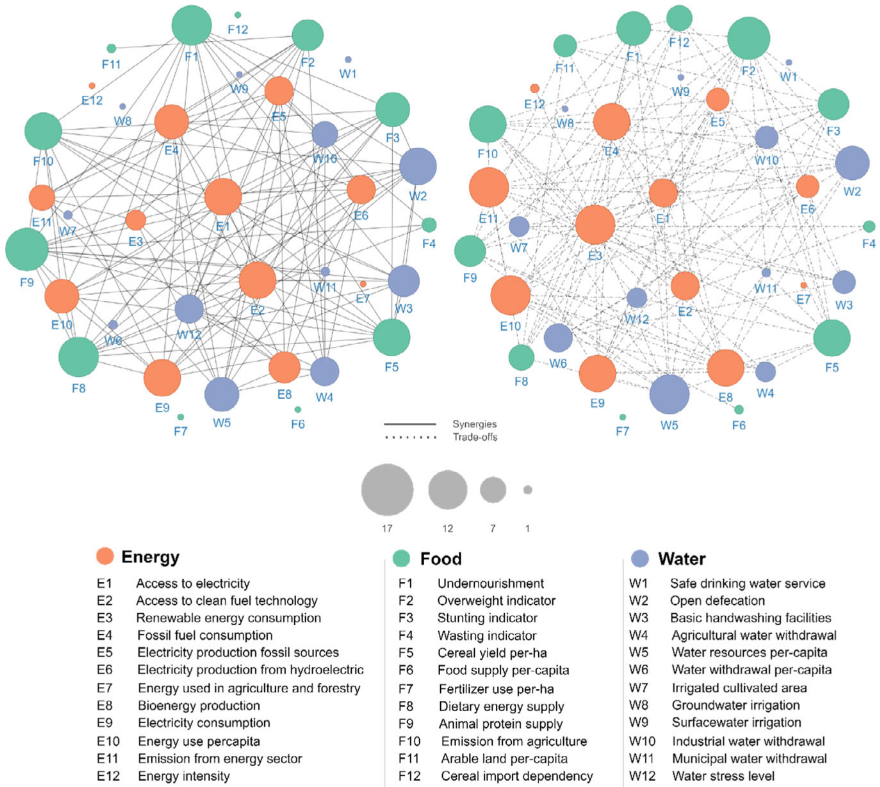

Fig. A6.24 We generated Vietnam's synergy (left side) and trade-off (right side) network based on interactions among the water, energy, and food sectors. In comparison to the smaller notes, the larger nodes have more edges and larger influences in the networks

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Chapter 7
Water, Energy, and Food Nexus: Review of Thailand's Resource Security

Pongsak Suttinon

Abstract The government of Thailand has continuously placed importance on water management to meet the challenges of future sustainable socioeconomic development. Water security is always related to energy and food security, suggesting that a holistic analysis encompassing different water, food, and energy (WEF) nexus dimensions is the key to achieving sustainable and efficient resource management. One of the important nexus examples from Thailand is rice production, its main export to the world market. Despite the significant revenue rice adds to the national economy, the increasing export of rice could increase risks to energy and water security. For example, exported water from rice production may cause economic damage in the form of water shortages in other economic sectors. One recommendation to policymakers is the proactive application of the WEF nexus approach during policy-making and project planning processes.

Keywords Water security · Energy security · Food security · Rice · Thailand

7.1 Thailand's Water Security

7.1.1 Thailand's National Efforts to Attain Water Resource Security

The government of Thailand has continuously emphasized the importance of water security and has made substantial progress in water management over the past few years. With regard to departmental responsibility, for example, the National Committee of Water Resources was established as a major central unit in 2015 to coordinate national and local water-related policies. The Prime Minister chaired the

P. Suttinon (✉)
Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand
e-mail: pongsak.su@chula.ac.th

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committee, and its duty was to push and drive water resource management strategies and achieve the integration of water policies, strategies, and programmes at all levels. The Office of National Water Resources (ONWR) was also established in 2016 to integrate information technology, plans, projects, and budgets and to follow up on the assessment of water resource management administration.

In 2017, the government of Thailand published "The National Water Resources Act" in the government gazette. It was considered the first law in Thailand to have the purpose of being an overall law to administer the water resource systems of the whole country (ONWR 2021a). This law addressed the issue of different departments being responsible for different and overlapping duties in water management, which caused a lack of coherence, duplication of efforts, and coordination deficits. The new law integrated the use, development, administration, maintenance, restoration, and conservation of water resources as a unified and integrated process and practice. The law also clarified the government's role in preventing droughts and flooding through policies and technical solutions and addressed basic rights with regard to access to public water resources. Accordingly, water resource management organizations were established at the national, river basin, and water user levels to reflect equal water rights across the country.

In terms of strategies, the government prepared the 20-year National Strategy (2018–2037) (NESDC 2021a) and the 20-year Water Resources Management Master Plan (2018–2037) (ONWR 2021b). It is also notable that the Thai government stated that the government's strategy to attain national water resources is clearly linked to the United Nation's Sustainable Development Goals (SDGs) 2030. Based on the definition of water security in relation to SDGs 2030, water security is directly linked to the sixth goal (SDG 6), which relates to ensuring the availability of clean water and good sanitation systems and addressing the problem of deficiencies in providing clean or potable water (ONWR 2021c).

7.1.2 Water Resource Security of Thailand

In this section, we assess the status of water resource security in Thailand from both the water demand and supply sides.

7.1.2.1 State of Available Water Resources in Thailand

The quantity of a water budget, corresponding to water supply, is generally based on the distribution of natural water resources such as the amount of rainfall, surface water, and groundwater. Table 7.1 shows the estimated amount of natural water resources in Thailand (ONWR 2021b). Thailand is situated in a monsoon climate zone; thus, the country has benefits from abundant surface water resources. However, the strong seasonality in rainfall and increasing frequency of droughts and rainfall are increasingly threatening water resource security.

Table 7.1 Natural water resources in Thailand (1987–2017)

Natural water resources	Quantity
Rainfall in 25 river basins	
Average annual rainfall	1455 mm
Surface water in 25 river basins	
Natural flow	285,227 million m^3
Runoff	224,024 million m^3
	79% of natural runoff
Groundwater in 25 river basins	
Groundwater in aquifer	1.13 trillion m^3
Groundwater capacity for development	45,385 million m^3 per year

Source ONWR (2021b) adapted by the author

In addition to natural water resources, the share of nonconventional water resources in national water budgeting has received growing attention in Thailand, and these resources include desalinizing processes and water recycling. Desalination plants are increasingly used to convert seawater to freshwater for a community or a factory situated close to the sea. Desalination plants are usually set up where freshwater shortages also result in a higher price of water. An example of a desalination plant for a factory is that of PTT Global Chemical Public Company Limited. The company assessed and analysed the risks of water management and established a reverse osmosis system to produce freshwater from seawater to be used in case of drought and to reduce possible conflicts in the community. The program produced 7.23 million m^3 of water in 2018 (PTT Global Chemical Public Company Limited 2021), contributing to the reduced use of freshwater by the company.

An example of water saving or recycling in Thailand can also be described based on the case study of PTT Global Chemical Public Company Limited. The company established guidelines for sustainable water management, which covered both internal and external water management based on the 3 W Principle of Internal Water Management. The 3 W principle consists of (1) water saving: to reduce water consumption according to the 3Rs (reduce, reuse, and recycle) to promote the most efficient water use; (2) water innovation: to minimize the risk of water scarcity and reduce the use of water from the same source as the community by producing freshwater from sea water; and (3) water stewardship: to assess water use both directly and indirectly throughout the product life cycle by calculating the water footprint. Consequently, the company was able to save 8.08 million m^3 of water per year, which accounted for 15.3% of the total water use of the company (PTT Global Chemical Public Company Limited 2021).

7.1.2.2 Water Uses in Thailand

Thailand has strong seasonal variation in its available water resources. Consequently, despite the abundant rainfall during the rainy season, the country occasionally undergoes water shortages during the dry season. To cope with national water shortages during the dry season, the government of Thailand established the following priority order for water management:

- 1st priority: store some water for use at the beginning of the rainy season to support wet season rice farming
- 2nd priority: distribute water for consumption during the dry season
- 3rd priority: distribute water to maintain the ecosystem during the dry season
- 4th priority: distribute water for agriculture
- 5th priority: distribute water for industry.

Table 7.2 summarizes the estimated amount of total water consumption by different sectors in Thailand. The table shows that agriculture consumes more than 77% of national water resources. In Thailand, more than 57% of agricultural water requirements are covered by irrigation, whereas the remaining 43% depend on natural rainfall. Industrial water use, households, and ecosystems account for 1.3, 3.2 and 18.3% of the use of available water resources in Thailand, respectively. The projected water demand suggests that by 2037, industrial and household water consumption will increase by 80% and 25%, respectively. This scenario implies that without a proper water supply strategy, different economic sectors of the country may undergo increasing competition over finite water resources. The water needed to preserve ecosystems indicates that a small amount of water is reserved for the ecosystem during the dry season. This water is preserved to support ecosystem activities that contribute to the survival of species such as fish, aquatic animals, and plants.

Table 7.2 Estimated and projected water uses by different sectors

Water use	Quantity million m^3	
	2005	2037
Agricultural sector		
Irrigation area 52,400 km^2	65,000	–
Rainfed area 187,200 km^2	48,961	
Industrial sector	1913	3488
Household consumption and service sector	4783	5991
Ecosystem preservation	27,090	–
Total	147,749	–

7.1.2.3 Water-Related Issues in Thailand

The major risks of securing water resources in Thailand include the following:

- The problem of water shortages has affected economic and social development. Droughts can severely affect farmers' incomes, resulting in the economic losses in the country in relation to agricultural, industrial, and service sectors as well as household consumption.
- Flooding is a main cause of natural damage that affects lives, property, and the economy. For example, in 2011, the economic losses caused by flooding were as high as USD 46.5 billion (ONWR 2021b). Landslides caused by heavy rainfall are another main issue threatening the security of people's livelihoods and economies.
- Surface water quality problems caused by wastewater and soil erosion with chemical residue from agriculture and livestock are emerging water issues in Thailand. At present, wastewater treatment systems in Thailand support only 26% of the total amount of wastewater produced (ONWR 2021c). In addition, saltwater intrusion of the lower Chao Phraya, Tha Chin, Bangpakong and Mae Klong Rivers affects farming, water supply, fisheries, industry, and human water consumption along the riverbanks.
- In Thailand, the quality of groundwater generally meets safe drinking standards. However, there are still some areas where the chemical balance of groundwater exceeds acceptable safe drinking standards. In the coastal area and north-eastern part of Thailand, saltwater intrusion through the coastal aquifer and detection of fossil saline groundwater (associated with halite dissolution and groundwater overexploitation) have been considered important water supply issues. There are also illegal toxic waste and wastewater disposal issues, which could contaminate groundwater (ONWR 2021c).

7.2 Thailand's Energy Security

7.2.1 Thailand's Energy Use for Each Economic Sector

Table 7.3 shows Thailand's energy use for each economic sector, based on the Thailand Energy Balance 2018 (DEDE 2021). According to the table, the transportation sector accounts for the largest share of energy consumption, followed by the manufacturing sector. Although the use of energy by the agricultural sector is small compared to that used by transportation and other sectors, the use of electricity in the food industry, which comprises the agricultural sector's supply chain, accounts for the additional share of the national energy consumption from the food sector. For example, in Thailand, the production of food, beverages, and tobacco accounted for approximately 10% of the total amount of electricity used (Ministry of Energy 2018).

Table 7.3 Thailand's energy use for each economic sector

Economic sectors	Coal (toe[a])	Petroleum (toe)	Electricity (toe)	Renewable energy (toe)	Total (toe)
Agriculture	–	2846	31	–	2877
Mining	–	12	105	–	117
Manufacturing	6865	8463	6838	7659	29,825
Construction	–	122	–	–	122
Household	–	1922	3891	5211	11,024
Service	–	603	5904	10	6517
Transportation	–	33,185	24	–	33,209
Total	6865	47,153	16,793	12,880	83,691

Source DEDE (2021) adapted by the author
[a] toe: tons of oil equivalent

7.2.2 Thailand's Energy Supply Strategy

According to the 'Power Development Plan (2018–2037)' (Ministry of Energy 2018), the future demand for national energy and electricity in Thailand will substantially increase. Thailand will need to increase its new electricity generation capacity to 56,431 megawatts to meet the increasing energy demand. Consequently, the government of Thailand has adopted multiple approaches to increase its energy supply capacity. One of the interesting energy supply sources of Thailand is imported electricity from neighbouring countries, including hydropower from Lao PDR. Thailand expects that small and large hydroelectric power plants will be the main source of renewable energy in the future. Unfortunately, Thailand's hydropower capacity cannot meet the current and projected energy demand; thus, the country is increasingly dependent on the import of electricity from neighbouring countries. The interconnectedness of water for energy production is shown through the case of large hydroelectric power plants.

Regarding the issue of energy imports from abroad, the Ministry of Energy has specified the purchase of electricity from neighbouring countries as an electricity sourcing policy in Thailand's National Economic and Social Development Plan (Ministry of Energy 2018). This is an alternative option for sourcing electricity if there is a limit to the availability of electricity sources in Thailand. Thailand expects that by importing electricity, the country will benefit from (1) a reduced cost of building power plants, (2) a reduced burden related to finding energy sources for electricity generation in the country, and (3) the formation of good relationships with neighbouring countries through energy collaboration.

Purchasing electricity from neighbouring countries is based on bilateral collaboration between the governments of the two countries. At present, Thailand has a Memorandum of Understanding (MoU) on Energy Cooperation with Lao PDR, Myanmar, and Cambodia to strengthen their energy cooperation (Ministry of Energy

2018). As of 2018, there were four projects for purchasing electricity from neighbouring countries: (1) the Xayaburi hydroelectric dam project for 1220 megawatts, which began electricity generation in 2019; (2) the Sapien-Sanamnoi hydroelectric dam project for 354 megawatts, which began generating electricity in 2019; (3) the Namngieb hydroelectric dam project for 269 megawatts, which began generating electricity in 2019; and (4) the Namtuen hydroelectric dam project for 1514 megawatts, which will start generating electricity for the system in 2022.

In the near future, diversification of renewable energy sources and introduction of energy saving measures will be Thailand's main policy focus. Electricity generation from renewable energy power plants is considered in accordance with the following:

1. Potential of remaining renewable energy in the country;
2. Behavioural changes in electricity users;
3. Technological innovation to enhance energy-generation efficiency and minimize electricity loss; and
4. Compatibility with the agreement of COP21 through the diversification of renewable energy sources, including biomass, biogas, solar energy, floating solar power generation systems with hydroelectric power plants, and other renewable energy sources. A floating solar power generation system with hydroelectric power plants could produce approximately 10% of the total renewable energy/saving energy production capacity in 2037 (Ministry of Energy 2018).

7.2.3 Analysis of Thailand's Energy Security

The projected national energy demand of Thailand suggests that the country will need more energy to propel economic and social growth (Ministry of Energy 2018). Despite the government's continuous efforts and the consequent improvement in the amount of electricity generated, the low self-dependency of the energy ratio has been regarded as a major risk to energy security (i.e., stability). Thailand has been increasingly dependent on imported energy, and therefore, there is a risk of not being able to access sufficient energy in the case of an immediate crisis, for example, if energy (coal, natural gas, or electricity) could not be imported from the partner countries due to any number of environmental and political reasons. The primary data on the use, production and import of commercial energy have confirmed this stability issue, as Thailand currently depends on imported energy sources for more than half of its electricity consumption (Ministry of Energy 2018).

With rapid economic growth and an increasing standard of life, the energy consumption pattern in Thailand shows an increase in the total energy consumption per capita (The World Bank 2021). Most ASEAN (Association of Southeast Asian Nations) countries except for Singapore and Brunei have experienced similar patterns: the higher the gross domestic product (GDP) per capita is, the more energy per capita that is used (The World Bank 2021). This scenario indicates that improving energy efficiency in terms of both production and use is one of the major tasks that needs to be achieved to attain energy security in Thailand. Similarly, most OECD countries show low energy use per capita despite their high GDP, indicating the higher energy efficiency or productivity of these countries (The World Bank 2021). According to Thailand's energy plan, priority has been given to the development of energy-saving technology or alternative energy to increase energy efficiency.

7.3 Thailand's Food Security

Food is another important issue in the WEF nexus. Food security is a part of the SDGs to guarantee universal access to safe, nutritious, and sufficient food for all (UNSTAT 2021). For Thailand, food security is of critical importance at the national policy level. The Food and Agriculture Organization of the United Nations (FAO) divides the definition of food security into four dimensions: (1) food availability, (2) access to food, (3) food utilization, and (4) stability (FAO 2018). In this chapter, therefore, we review the food security of Thailand, focusing on rice, which is a staple crop for most East and Southeast Asian countries.

7.3.1 Food Security

Table 7.4 shows the national rice supply and demand of Thailand. On average, approximately 20 million tons of rice are produced in Thailand, with 10 million tons for domestic consumption and the other 10 million tons for export. In terms of food supply, domestic consumption and exports of rice matched the level of production in the country, indicating that Thailand does not have serious rice supply issues. Moreover, other indicators, such as the self-sufficiency ratio, which refers to the ratio of each year's production rate compared to that year's consumption rate, show that the country is self-sufficient in terms of crop production and does not need to rely on imports from the world market.

In terms of food accessibility, however, Thailand still has issues associated with income gaps and the increasing costs of gaining access to food. Although Thai people should be able to access food based on individual rights and physical needs for good health, poverty is an obstacle to such accessibility. Income gaps are still prevalent among Thai citizens, particularly in rural areas. Additionally, the costs to gain access to food and services have tended to increase each year, especially in large cities where people need higher incomes. When individuals do not have a sufficiently high income, there might be problems related to individual food shortages.

Fortunately, an analysis of the number of people below the poverty line reveals that the situation is improving steadily across the country. It was found that for the past 20 years, the number of people below the poverty line has decreased approximately fivefold, which is equivalent to five million people. However, there is still an income gap problem, especially in the north-eastern region (NESDC 2021b).

Table 7.4 Rice supply and demand of Thailand

Rice supply and demand	2016	2017	2018
Beginning stock: Million tons	11.3	8.4	4.2
Production: Million tons	15.8	19.2	20.6
Import: Million tons	0.3	0.3	0.3
Total supply: Million tons	**27.4**	**27.9**	**25.1**
Consumption: Million tons	9.1	12.0	11
Export: Million tons	9.9	11.7	11
Ending stock: Million tons	8.4	4.2	3.0
Total demand: Million tons	**27.4**	**27.9**	**25.1**
Self-sufficiency ratio: %[a]	**173.6**	**160.0**	**187.1**
Food-security ratio: %[b]	**124.3**	**70.0**	**38.5**

Source Thai Rice Exporters Association (2021) adapted by the author
[a]Self-sufficiency ratio (%) = the ratio of each year's rice production rate compared to that year's consumption rate
[b]Food security ratio (%) = the ratio of rice stock quantity compared to the amount of consumption in the same year
Total supply: Million tons = Beginning stock + Production + Import
Total demand: Million tons = Consumption + Export + Ending stock

Food utilization refers to '*having access to adequate food, clean water and health care, and hygiene to allow for good nutritional life conditions with all physical needs being met'* (FAO 2018). The malnutrition ratio is considered an indicator representing food security from the food utilization perspective. Table 7.5 show the historical changes in the malnutrition ratio of Thailand. As of 2016, approximately 9% of Thai people suffered from malnutrition. This value has been reduced approximately twofold over the past 20 years. The data indicate that Thailand has continuously improved its food utilization, partly as a result of the development of agricultural products, which has allowed farmers to receive higher incomes and to access more diverse and nutritious food. Despite the promising progress, Thailand still has problems with food utility, indicating that there are some people who suffer from malnutrition. The high malnutrition ratio is also comparable with the high self-sufficiency ratio of the country (Table 7.1).

Table 7.5 Percentages of Thai people as a function of the total population who suffer from malnutrition

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Percent	18.8	18.3	17.1	15.8	14.2	12.5	11	10.3	10
Year	2009	2010	2011	2012	2013	2014	2015	2016	
Percent	9.8	9.2	8.8	8.8	9	9.2	9.2	9	

Source FAO (2021) adapted by the author

The food stability of people, households, and individuals implies '*having sufficient food accessibility at any time with no risks of food shortages due to immediate crises such as economic or climate crises or cyclical events such as seasonal food insecurities'* (FAO 2018). In this study, we employed the food security ratio of rice as a representative of food security in Thailand (Table 7.4). The food security ratio refers to the ratio of rice stock quantity compared to the amount of consumption in the same year. If the ratio is 100 percent, then the country would have the ability to consume rice without producing or importing rice from abroad for one year. In 2018, the food security rate was approximately 40%, which meant that there was enough rice for consumption in the country for approximately 150 days or one harvesting season. This result indicates that if there were natural disasters and no rice could be produced for one harvesting season, there would still be enough rice for domestic consumption without importing rice from the world market. This scenario indicates that Thailand still has no serious problem with food stability, especially with rice, which is a staple food. However, the continuous decrease in the food security ratio between 2016 and 2018 (Table 7.4) may need to be carefully monitored to ensure the long-term food security of the country.

7.3.2 Review of Food Security Issues in Thailand

An analysis of food-related indices suggests that Thailand has achieved food security in terms of food availability and stability. However, improvements in access and use are needed, as issues related to poverty and malnutrition still remain. Therefore, a strategy to achieve food security needs to focus on increasing food access and use with enhanced water and energy supplies. These factors would help lessen the income gap in rural areas by reducing costs and adding value to products. For example, advanced agricultural technology that uses less water and energy could generate higher income from products, which could support farmers with minimal incomes in rural areas.

Some important issues related to food security in Thailand are as follows:

1. Promoting the long-term stability of agricultural product prices to increase farmers' economic power (food and economy): Thailand needs to develop food security strategies that promote security and stability for farmers.
2. Using energy crops such as biofuel (food and energy): The promotion and in-depth analysis of the relationship between food security and energy is necessary to meet the future energy demand and to address with the energy crisis. The increasing use of energy crops, however, could lead to intensive use of land and water; thus, careful analysis of the synergies and trade-off between the food, water, and energy is important.

3. Increasing food productivity with less resource utilization: Considering the limited availability of land, energy, and water resources, increases in food productivity through technological innovations and the addition of value to the agricultural sector would be an important measure to attain both socioeconomic growth and resource security.

7.4 Water-Food Nexus for the Economic and Social Development of Thailand

In the previous sections, the water, energy, and food security dimensions were analysed separately. In this section, we will analyse an example of the WF nexus relationship in Thailand, focusing on rice, a staple food in Thailand.

7.4.1 Rice Production of Thailand

Rice is an important staple crop that enables national food security in Thailand. It also significantly contributes to the economic growth of the country. Every year, excess rice from domestic consumption is exported to the world market, contributing approximately 6000 million USD per year in revenue (Thai Rice Exporters Association 2021). Socially, rice farming is a job that creates income for farmers in rural areas. Despite its significant contribution to food security and economic growth, the amount of resources needed (especially water) to produce rice for economic and social security is still a question for Thai policy-makers.

To better understand the water dimension of food security (rice production), issues related to the economy, society, culture, and resources of Thailand need to be reviewed first. It is important to understand what type of rice is exported, where it is produced, what resources are used, how much water is used, and how much rice production is related to other sectors. In Thailand, three-quarters of the exported rice is white and parboiled rice (Thai Rice Exporters Association 2021). Rice is mostly grown in the central and lower north-eastern parts of the country during both the dry and wet seasons. These areas can produce approximately 20 million tons of milled rice per year (Thai Rice Exporters Association 2021). White rice is largely grown in the Chao Phraya River Basin or the central part of Thailand, where the water irrigation system supports both wet-season and dry-season rice farming. White rice has higher productivity per hectare than other types of rice and makes up approximately 40% of all rice farming areas.

7.4.2 Water Resource Availability for Rice Production

Water is an essential resource for rice farming; therefore, appropriate and efficient water management is important. In Thailand, water sources for rice farming can be classified into two types: rainwater and irrigation water. Due to the strong seasonality in rainfall, rice is largely grown during the rainy season, accounting for 84% of the annual production (ONWR 2021b). Thus, rice production highly relies on natural conditions, indicating that rice productivity could vary depending on annual weather conditions. This could be an important issue, particularly in the north-eastern region, where the water irrigation system is not yet fully developed, and farmers rely strongly on rainwater for rice farming.

As mentioned previously, rice farming that depends on rainwater or occurs outside of a water irrigation zone mostly takes place in the north-eastern region, where a steep topographical relief and other physical conditions make it unsuitable for the construction of a large dam. This area contains sticky rice fields in the upper north-eastern region and jasmine rice fields in the lower north-eastern region of Thailand. On the other hand, the central region of the country mainly relies on a water irrigation system with large dams, and this area includes the 'white rice' fields in Thailand. The Royal Irrigation Department manages the water used in the water irrigation zone.

During the dry season, the main sources of rice production inside the water irrigation zone in the central region are the Bhumibhol and Sirikit dams. In the northern region, groundwater is used as a supplementary source of water. Water shortages during the dry season require a prioritized water allocation strategy among different sectors. From a cost–benefit perspective, the preferred method used during water shortages is asking farmers to cooperate in terms of growing less rice during the dry season (Royal Irrigation Department 2020). However, the limited production of rice during the dry season could affect the food security of the country. This scenario shows the importance of limited water management for economic and social development with regard to water users in the agricultural, industrial, service, household, and environmental protection (including saltwater push) sectors.

7.4.3 Virtual Water Flow

Throughout the rice production and selling process, water is mainly used in the farming process. If rice is exported abroad, then the water used for rice farming is also exported, i.e., trade in virtual water (Suttinon et al. 2020). Virtual water flow accounts for a considerable portion of national water security. Importing water for food might be an opportunity to compensate for the water shortages resulting from consumption, economic and social development, environmental protection, and saltwater intrusion. For example, countries with less water that need rice must rely on importing rice from other countries, while countries with more water and excess rice could export rice and water to the world market.

Table 7.6 Rice and virtual water export of Thailand

Year	Total exported quantity (ton)	Total value (million USD)	Virtual water export of rice ($\times 10^6$ m^3)
2018	11,083,359	5,400	44,781

Source Rice Department (2021); Thai Rice Exporters Association (2021) adapted by the author

In the case of virtual water for Thai rice in the world market in 2018, approximately 11 million tons of Thai rice was exported to the world market, which accounted for approximately 5400 million USD (Table 7.6). The exported virtual water embodied in the rice was approximately 44,000 million m^3 (Suttinon et al. 2020). At present, Thailand's dam water storage capacity is approximately 71,000 million cubic metres (Suttinon et al. 2020). This information indicates that in 2018, Thailand exported approximately 60% of the dam's total water storage capacity as trade in virtual water. Thus, important questions are: how to increase the productivity of the water used for rice production given the relationship between water and food security, and how to add value to exported rice products, e.g., processing rice more efficiently using water such as through waste reduction and more water saving measures.

7.5 Conclusion

Thailand has experienced rapid socioeconomic growth in recent decades and has heavily relied on natural resources such as water, food, and energy to meet increasing resource demands. Recently, the interconnections between the WEF nexus has been increasingly recognized among policy-makers, academia, and societies in Thailand. For example, the development of a water strategy that does not consider energy and food issues would have negative impacts on national security. Water shortages in agricultural production result in food insecurity. Imported power from other countries results in power insecurity. These scenarios suggest that Thailand needs to actively adopt the WEF nexus approach to link water security, energy security, and food security. Thailand needs to create new development and business plans, which are in line with resource management under the WEF nexus approach. Concepts of water and energy productivity should be employed to attain higher water security and greater incomes. An example of using these concepts is the use of phases of precision farming technology for higher value crops that use less water in place of rice farming. However, funding sources and knowledge are needed for farmers to create a prototype in their areas for results that can be applied elsewhere. In addition, the bioeconomy, which involves the use of modern technology to add value or to practically use and process agricultural products, should be applied to add economic value to traditional agricultural products. This approach is in accordance with water productivity and energy efficiency concepts in the agricultural sectors.

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Chapter 8 Water-Energy-Food Nexus in the Urban–Rural Relationship

Makoto Taniguchi, Sang-Hyun Lee, and Naoki Masuhara

Abstract Many countries in East and Southeast Asia are experiencing challenges associated with rapid urbanization and population growth. In this chapter, the nexus situations at multiple scales, including cities and nations in sub-regions of Asia, as well as at the Asian and global scales, will be analysed. The connections between urban areas as consumption areas and rural areas as production areas will be discussed as a water-energy-food nexus, including trade-offs among resources and global and local environmental impacts for sustainability.

Keywords Urban nexus · East and Southeast Asia · Urban–rural relationship

8.1 Introduction

Known as planetary boundaries (Rockström et al. 2009) and Hothouse Earth (Steffen et al. 2018), human impacts on the earth are extended globally as the Great Acceleration (Steffen et al. 2004). It has been pointed out that we have already entered a new geological era known as the Anthropocene (Crutzen 2002). A recent global risk assessment (Fig. 8.1, World Economic Forum 2020) shows that water and food crises, energy price shocks, and climate change are regarded as high risks for global sustainability in terms of likelihood and impacts. The demand for water, energy, and food resources, which are the basis for humans and society, is expected to increase by 55%, 80%, and 60%, respectively, by 2050 (OECD 2012). These resources are

M. Taniguchi (✉) · N. Masuhara
Research Institute for Humanity and Nature, Kyoto, Japan
e-mail: makoto@chikyu.ac.jp

N. Masuhara
e-mail: masuhara@chikyu.ac.jp

S.-H. Lee
Department of Agricultural and Rural Engineering, Chungbuk National University, Cheongju, Republic of Korea
e-mail: sanghyun@chungbuk.ac.kr

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connected to each other on land, and there are trade-offs in which the production of one resource reduces the production of another. For instance, 70% of water consumption is related to use for agricultural food production, and approximately 55% of water facility operating costs are accounted for by the energy sector (IRENA 2015). Therefore, integrated multi-resource management, such as the water-energy-food nexus (Fig. 8.2), is required for global sustainability.

In today's globally connected world, the connections of resources through all processes of production, transportation, consumption, and waste occur not only in adjacent regions but also in distant regions, known as "telecoupling." Virtual water is one example of how water is connected indirectly through agricultural food trade. The water footprint shows the environmental connections between food consumption in urban areas and production areas in rural areas. Greenhouse gas (GHG) emissions, which have a global environmental impact, are connected through the water footprint of the food trade to the local environmental impact on water. Therefore, an environmental trade-off exists between global and local impacts.

In this chapter, we present how production areas (rural areas) and consumption areas (urban areas on land) are connected as the water-energy-food nexus, particularly regarding the connection of water through the food trade at different spatial scales, including global, Asian, sub-Asian, national, and local scales, as a multi-scale issue.

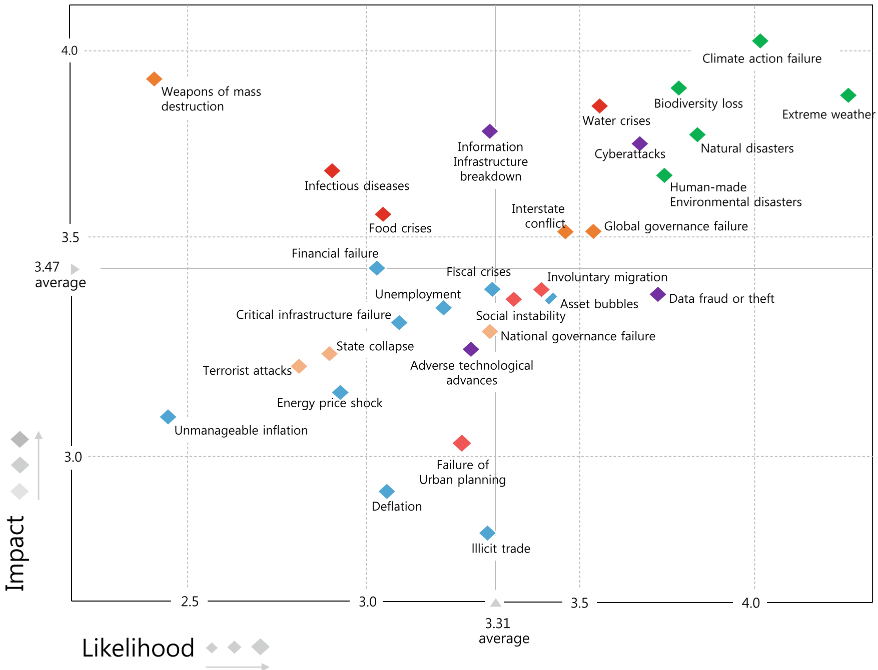

Fig. 8.1 Global risk assessments in terms of likelihood and impact (©World Economic Forum 2020). https://www3.weforum.org/docs/WEF_Global_Risk_Report_2020.pdf

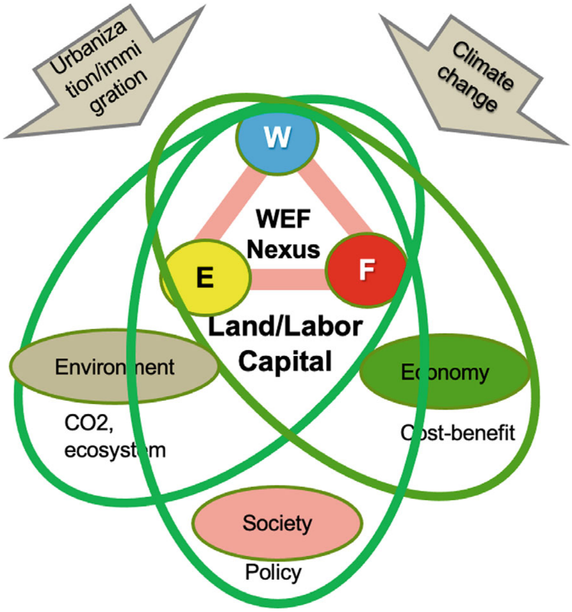

Fig. 8.2 Schematic diagram of the water-energy-food nexus under climate and demographic changes

8.2 Urbanization and Resource Management

Urbanization is one of the significant characteristics of the Anthropocene. Since 2007, more than half of the global population has lived in urban areas (UNDESA 2015), and many GHG emissions are created in urban areas. This is because they are mainly caused by human and social activities in urban areas due to the consumption of resources, even though production areas are located in rural areas.

Many megacities in Asia are located in coastal zones, with some exceptions in China, because of abundant water resources downstream of basins and easy access to energy from ports to obtain imported fuel and other energy resources. The combination of abundant water and energy in coastal zones in Asia led to an industrial revolution in these coastal zones after World War II (Sugihara 2020). This is the synergy of water and energy for economic development. However, trade-offs between economic development and the environment have occurred, such as land subsidence, water pollution, and other environmental problems. The Research Institute for Humanity and Nature Project (C05) analysed the relationship between the development stage of cities in Southeast and East Asia and the degree of subsurface environmental impacts and problems over the last 100 years (1900–2000) in Tokyo, Osaka, Seoul, Taipei, Bangkok, Jakarta, and Manila (Taniguchi 2011).

Land subsidence due to excessive groundwater pumping, groundwater contamination, and subsurface thermal anomalies have occurred frequently in Asian coastal cities, greatly disturbing urban aquifers and the subsurface environment. New

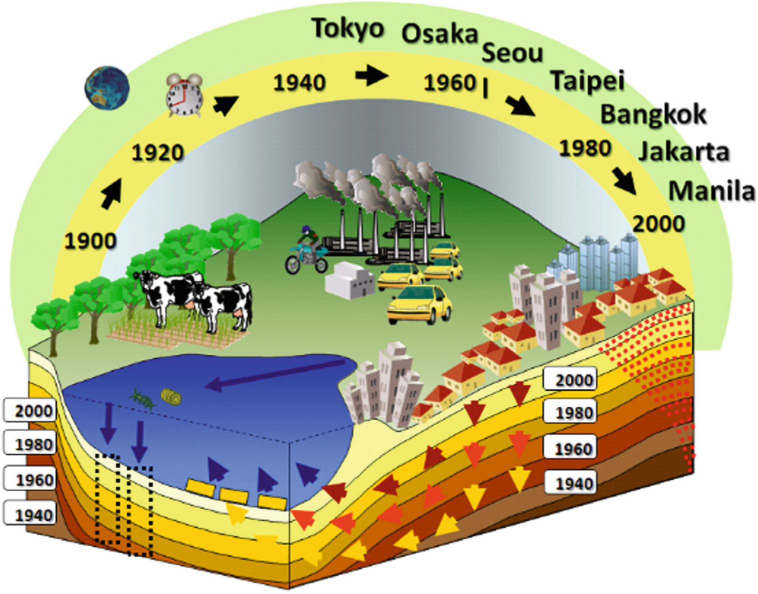

Fig. 8.3 Schematic diagram of the relationship between the development stage of cities and subsurface problems in Asia

advanced methods, including the use of satellite data, tracer techniques, and socio-economic models have been developed to evaluate subsurface conditions based on the stage of a city's development (Taniguchi 2011Fig. 8.3).

Figure 8.4 shows an example of the stage of land subsidence from early urbanization, industrialization, recognition of the problem, regulation and settlement, and partial resolution in six cities in Asia. These analyses were based on the natural capacities in each city, such as groundwater storage and the recharge rate, and social changes, such as resource demand due to economic development. Analyses have also been performed for groundwater contamination in terms of loads and the storage of contamination, as well as heat anomalies due to global warming and heat island effects (Taniguchi 2011). Water, materials, and heat are connected to each other, and analyses show that Asian coastal cities are categorized as the over-development type, follower's benefit type, large capacity type, and others.

The relationship between groundwater use and land use management from the historical point of view of the water-industry-land nexus was analysed in Asian megacities by Taniguchi and Lee (2020). They found that the regulation of excessive groundwater pumping started when land subsidence reached 1.5–2.0 m, although the time duration between the beginning of land subsidence and the regulation of groundwater pumping was different because of the follower's benefit. They found this "social tipping point" with other case studies in Asia and applied it to global analyses of the relationship between social responses and inundation disasters such as flooding in coastal zones. Global analysis of inundation disasters considering

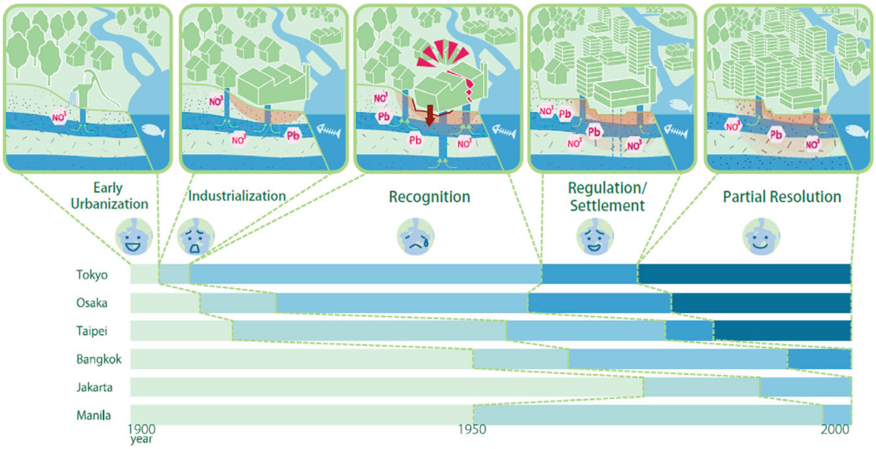

Fig. 8.4 Five stages of land subsidence in six Asian cities

population and land elevation shows that the largest number of people living in an area where the land elevation is below a couple of metres was found in Asia, and the population increase in these areas was also the most rapid in Asia (Taniguchi and Lee 2020, Fig. 8.5).

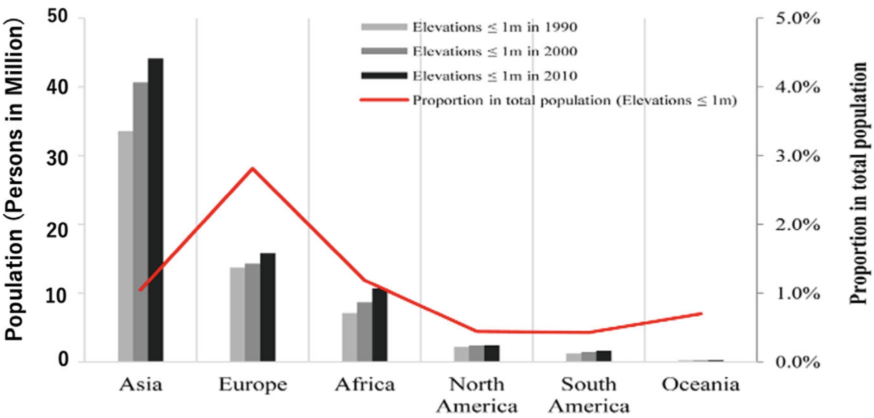

Fig. 8.5 Population number and ratio who live under the social tipping point (1 m) on each continent (@Taniguchi and Lee 2020)

8.3 Global Nexus Between Urban and Rural Areas Through the Food Trade

The spatial connections between rural and urban areas through transportation of goods are not limited to being within a country but occur globally. In particular, for the global food trade, the multi-spatial scale is important to connect locally, nationally, and globally, and these are related to global environmental problems such as GHG emissions from transportation and the water footprint as environmental impacts at the local scale. For instance, trade treaties such as the TPP (Trans-Pacific Partnership) and European Union are key for the water-energy-food nexus through the food trade to connect global and regional trade, such as trade in the EU or Asian countries, and local trade. It is important to evaluate the water-energy-food nexus at different spatial scales for a sustainable society. For that purpose, it is also important to build a multi-scale system dynamic model that can flexibly change the parameters and analyse the range of production, distribution, and consumption of each resource and evaluate it by changing the boundaries of each shed in a region or country at a multi-spatial scale (Taniguchi et al. 2017).

Indicators such as the water footprint and carbon footprint are linked to each region as telecoupling by economic activities, including agriculture in rural areas as production areas and trade and consumption in urban areas as consumption areas. Figure 8.6 shows the virtual water flow by continent through the global food trade in 1986 and 2007. The outer circle indicates exports, the inner circle indicates imports, and the colour of the ribbon indicates virtual water transportation through food exports by continent (Dalin et al. 2019). In 1986, the most virtual water transferred to Asia was from North America. However, the virtual water transferred to Asia from South America increased rapidly by 2007, and was 1.5 times larger than that from North America in 2007 (Dalin et al. 2019).

8.4 Regional Nexus Through the Food Trade

According to Lee et al. (2017), approximately 51 Gm^3/yr of green water and 15 Gm^3/yr of blue water were exported from Asia, and 46.9% of the total green water exports and 40.9% of the total blue water exports were exported to non-Asian countries (Hoekstra and Chapagain 2008). The green water footprint of crops indicates the volume of water from rainwater stored as soil water and consumed by crops, while the blue water footprint of crops indicates the volume of irrigation water (surface and groundwater) consumed by crops. For instance, Thailand, which is the main exporter in Asia, accounted for 55.5% of the total virtual water exports to non-Asian countries, and Kazakhstan accounted for 63.8% of the total virtual water exports to European countries.

However, in the EU, only 30.2% of the total green water exports and 25.2% of the total blue water exports were exported to non-EU countries. Even France, which is

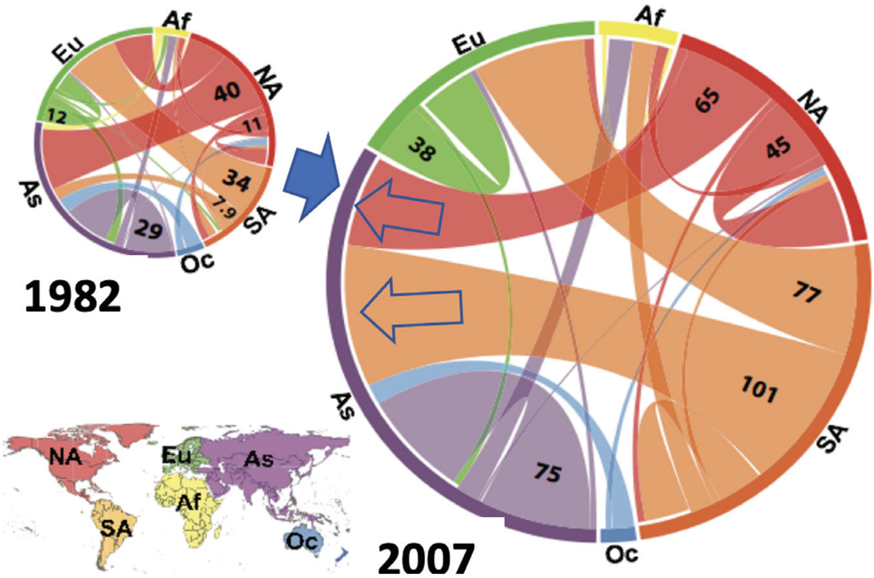

Fig. 8.6 Continental scale of the virtual water flow via the food trade in 1986 and 2007 (©Dalin et al. 2019)

the largest virtual water exporter in the EU, had 34.7% of total virtual water exports to non-EU countries.

These virtual waters represent the connection between water and food as well as the local, regional, and global connection because the food trade is a global issue, and the water footprint has local environmental impacts. Footprints, such as the water footprint are a tool for sustainability to internalize the external environment at a multi-spatial scale.

8.5 Layered Sheds of Water, Energy, and Food

To manage resources such as water, we usually need an integrated method because of conflicts of resource use with various stakeholders. For example, integrated water management (IWM), or the cascade use of water, is a single resource management with integrated methods for multiple sectors and users. In this case, areal boundaries such as "basins" or "sheds" are important for management because the area of production, transport, and consumption of the resource is usually closed within the basin/shed, although some resources are transported beyond the boundary as transboundary resources.

However, an integrated management of multiple resources, such as the water-energy-food nexus, needs to overlay different sheds, that is, the water shed, energy shed, and food shed. Figure 8.7 shows the three resource sheds in the Kansai region of central Japan. The blue boundary in Fig. 8.7 is a “water shed”, which is the Lake Biwa-Yodo River basin. The red boundary in Fig. 8.7, which includes six prefectures, is the “energy shed”, with electricity operated by Kansai Electric Power Co. The energy shed usually consists of municipal units. The food shed is different from the other two sheds because food production areas are not necessarily connected to food consumption areas. The green coloured areas in Fig. 8.7 show agricultural areas, which are food production areas. On the other hand, the orange-coloured areas show urban areas, which are usually food consumption areas. In the case of the food shed, foods are transported from production areas (agricultural areas) to consumption areas (cities), and these two types of areas do not necessarily need to be adjacent. Therefore, production and consumption areas are located as patched areas including outside of the country.

8.6 Urban–rural Relationship and the Water-Energy-Food Nexus

Urban and rural areas are usually connected as consumption areas and production areas of goods such as food. The food trade is usually determined by the consumption side in urban areas. Consumers decide to buy goods based on price, quality, safety and other factors. Recent trends in the local production and consumption of goods (e.g., food), are based on safety and environmental concerns over reducing GHGs with importance placed on shorter transportation distance of the foods rather than price. Although the main factor in consumers’ decision to buy food is still price, consumers have started considering environmental impacts such as lower carbon emissions and contamination of the environment, as well as food quality, such as organic food and that produced with fewer pesticides. This kind of change on the consumer side leads to a change in the relationship between urban areas as consumption areas and rural areas as production areas.

Figure 8.8 shows the rice production and consumption areas in Japan. As shown in Fig. 8.8, there is more rice production in the Tohoku and Hokkaido areas, which are northern parts of Japan and have more water efficiency for rice production. There is more rice consumption where more people live, that is, in urban areas, such as Tokyo, Nagoya, and Osaka. Therefore, a great amount of rice is transported from northern Japan to Central Japan by trucks and trains, which consume energy and discharge GHGs. We analysed the change in virtual water through rice transportation by using the weighted and non-weighted distance between production and consumption areas. We found an increase in the water footprint with the recent trend of consumers preferring local food production and consumption. This is because the water efficiency of rice production in Tohoku is the highest in Japan, and an increase in self-sufficiency causes an increase in water use in Japan. This result shows the trade-off between not only water, food, and energy, but also between global environmental impacts such as carbon emissions and local impacts, for example, on the water environment.

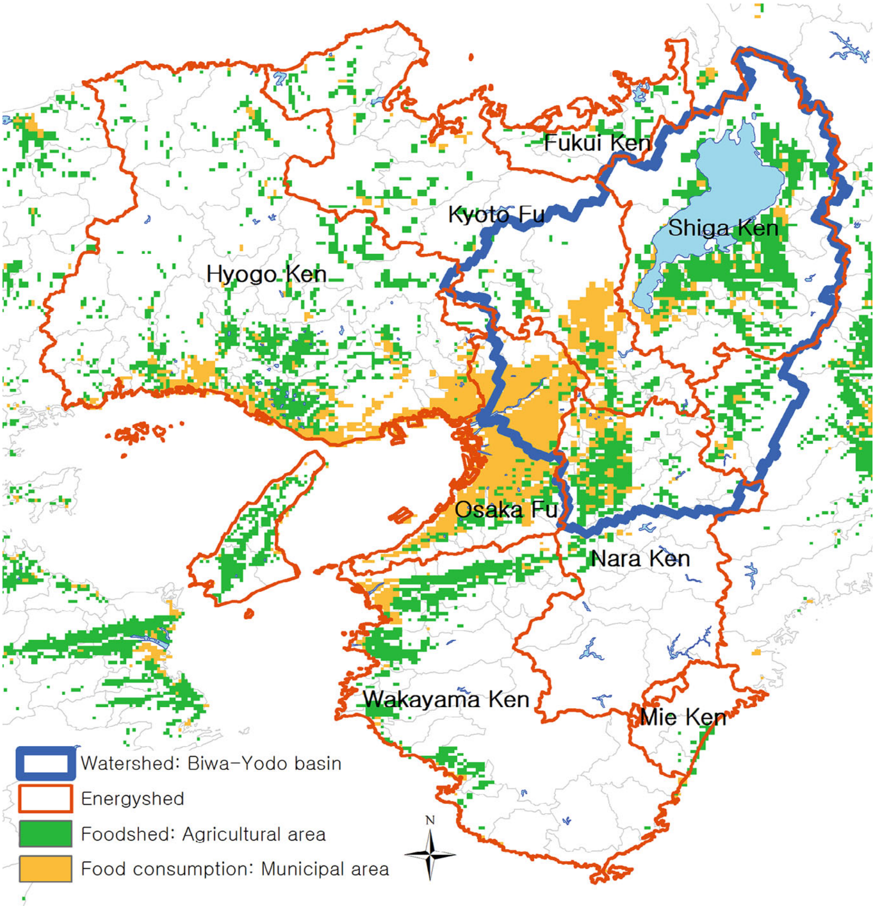

Fig. 8.7 Three layered sheds; water (blue), energy (red) and food (green: production, orange: consumption)

8.7 Conclusion

Production areas in rural areas and consumption areas in urban areas are connected as a water-energy-food nexus. In particular, multi-scale water connections, such as the virtual water flow through the food trade, are shown in this chapter at different spatial scales, including global, Asian, sub-Asian, national, and local scales. The urbanization of megacities in Asian coastal zones have a similar pattern of synergy with abundant water resources and energy resources in these coastal zones. However, this connection of water and energy on limited land has caused a trade-off between economic growth, such as industrialization, and environmental problems, such as land subsidence and water/air contamination.

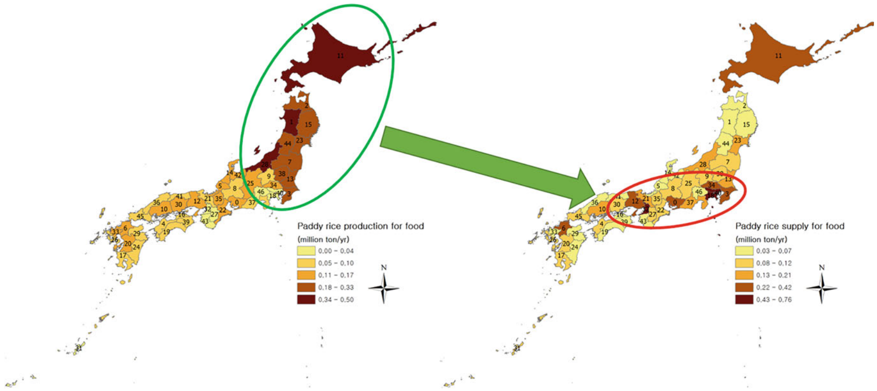

Fig. 8.8 Rice production areas (left) and consumption areas (right) in Japan

For integrated multi-resource management for sustainability, we need the concept of bounded sheds of water, energy, and food. This includes physical flows and virtual flows such as the virtual water flow. As footprints such as the water footprint and carbon footprint can internalize the external environment when each shed is not the same, these footprints are useful for the connection between production areas in rural areas and consumption areas in urban areas. The relationship between the carbon footprint and water footprint can show the trade-off between global and local environmental impacts.

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Chapter 9
Interlinkage Between the Agriculture and Water Sectors and Climate Change Impacts in East and Southeast Asia

Chul-Hee Lim, Jong Ahn Chun, Daeha Kim, and Woo-Kyun Lee

Abstract Climate change and variability, including increases in the frequency and intensity of extremes, are projected to adversely impact food security and ecosystems. This chapter aimed (1) to provide an overview of the impacts of climate change on the agriculture and water sectors in East and Southeast Asia, (2) to summarize adaptation approaches to cope with climate change in the region, and (3) to propose a nexus approach for the effective and sustainable use of resources under a changing climate through a better understanding of the interlinkage between food and water. Based on the projected changes in temperature and precipitation in East and Southeast Asia, we discussed adaptations to climate change for the agriculture and water sectors and investigated the synergies and trade-offs between the two sectors. Finally, we highlighted that a better understanding of the interdependency between those sectors through a nexus approach can provide an efficacious measure for the effective and sustainable use of water resources and for enhancing food security.

Keywords Climate change · Food security · Water resources · Adaptations · Nexus

C.-H. Lim
College of General Education, Kookmin University, Seoul 02707, Republic of Korea
e-mail: clim@kookmin.ac.kr

J. A. Chun (✉)
Prediction Research Department, APEC Climate Center, 12 Centum 7-ro, Haeundae-gu, Busan 48058, Republic of Korea
e-mail: jachun@apcc21.org

D. Kim
Department of Civil Engineering, Jeonbuk National University, Jeonju, Jeollabuk-do 54896, Republic of Korea
e-mail: daeha.kim@jbnu.ac.kr

W.-K. Lee
OJEong Resilience Institute (OJERI), Korea University, Seoul 02841, Republic of Korea
e-mail: leewk@korea.ac.kr

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9.1 Introduction

Since the pre-industrial period, the land surface air temperature has risen nearly twice as much as the global average temperature (IPCC 2019a). Recent climate change, including increases in the frequency and intensity of extremes, has adversely impacted food security and terrestrial ecosystems (Lipper et al. 2014). Food security will be increasingly affected by projected future climate change (IPCC 2019a). Among all industries, the impact of climate change, which continues to intensify, has the greatest connection with agriculture (Lim et al. 2019a). The impact of climate change on the agricultural sector will be critical, particularly in the East and Southeast Asian regions, where agriculture accounts for a significant proportion of the region's economic contribution (Chun et al. 2016; Lim et al. 2017a). Considering that a hydrological change such as a drought or flood is strongly linked to agricultural water demand, an interlinking solution for water and agriculture is strongly needed for the regions.

In the East Asian region, including China, the Democratic People's Republic of Korea (hereafter North Korea), Japan, Mongolia, and the Republic of Korea (hereafter South Korea), rice is the major staple crop. These East Asian countries are located between 90–145°E and 30°S–50°N. These countries, except for Mongolia and North Korea, have advanced economies and mature industries. On the other hand, North Korea has suffered severe food shortages for a long time; Mongolia's climate is unfavourable to agriculture, and most of the land is grasslands. In particular, Mongolia produces only some wheat and potatoes among food crops, and most of the remaining proportion of crops depends on imports. Detailed statistics on the rice production and harvested area in East Asian countries except for Mongolia are summarized in Table 9.1.

In most of the East Asian region, the climate is classified as temperate monsoon, except for inland China and Mongolia, which are characterized by arid land (Choi et al. 2019). Dry conditions increase with the distance from the ocean; thus, suitable crop and cultivation methods vary accordingly. In East Asia excluding Mongolia, droughts and floods associated with the summer monsoon occur frequently, and the frequency of extreme weather events continues to rise. For example, a large-scale drought between 2014 and 2015 occurred throughout the Korean Peninsula, causing a significant shortage of agricultural water (Ryu et al. 2019).

Table 9.1 Statistics on the rice production of selected countries in East Asia as of 2018

Area	Harvested area (ha)	Production (t)	Yield (t ha^{-1})
China	30,460,956	214,078,796	7.03
Japan	1,470,000	9,727,500	6.62
North Korea	471,000	2,088,000	4.43
South Korea	737,673	5,195,437	7.04

Source FAOSTAT database collections, FAO (2020) adapted by the author

Table 9.2 Statistics on the rice production of seven selected countries in Southeast Asia

Area	Harvested area (ha)	Production (t)	Yield (t ha^{-1})
Cambodia	2,981,680	10,647,212[a]	3.6
Indonesia	15,995,000	83,037,000[b]	5.2
Laos	848,174	3,584,700[b]	4.2
Myanmar	6,705,577	25,418,142[a]	3.8
Philippines	4,800,406	19,066,094[b]	4.0
Thailand	10,407,272	32,192,087[a]	3.1
Vietnam	7,570,741	44,046,250[b]	5.8

Source FAOSTAT database collections, FAO (2020) adapted by the author

Rice is a major staple crop in the Southeast Asian region, including Cambodia, Indonesia, Lao PDR (People's Democratic Republic, hereafter Laos), Myanmar, the Philippines, Thailand, and Vietnam. These countries are located between 90–145°E and 10°S–30°N. In these countries, agriculture is one of the most important economic sectors. In 2018, the agriculture sector accounted for 22% of the GDP of Cambodia, 13% of the GDP of Indonesia, 16% of the GDP of Laos, 21% of the GDP of Myanmar, 10% of the GDP of the Philippines, 8% of the GDP of Thailand, and 15% of the GDP of Vietnam (WBG 2020). More detailed statistics on the rice production and harvested area in the seven countries are summarized in Table 9.2.

In most of the Southeast Asian region, the climate is classified as a tropical climate with two seasons: wet and dry. This region is widely known for chronic droughts and floods. For rice production, drought is one of the major limiting factors and can cause massive crop failures as well as water shortages. For example, droughts were reported in 16 out of 34 provinces in Indonesia, and agricultural damage amounted to approximately 19.2 million USD in a province in the Philippines (OCHA 2020). Twenty-eight provinces across Thailand were announced as being at high risk of water shortages in 2016, and approximately 300 villages in Myanmar suffered from water shortages in 2016 (OCHA 2020).

Most climate change impacts on the agriculture and water sectors have been assessed by biophysical crop models. Internationally verified crop models such as Decision Support System for Agrotechnology Transfer (DSSAT), Environmental Policy Integrated Climate (EPIC), and General Large-Area Model (GLAM) have been used to project agricultural productivity and water use at the national or regional level. The optimal adaptation plan can be found by simulating changes in agricultural management practices such as water management and fertilizer application (Chun et al. 2016). Studies have also noted that although projected climate change will cause negative impacts on agricultural productivity in the East and Southeast Asian regions without adaptation measures, there is the potential to increase productivity if sufficient adaptation measures are taken (Chun et al. 2016; Lim et al. 2017a).

In terms of climate change, the nexus (particularly the water-food nexus) or integrated approaches have emerged as tools for sustainability in agriculture and water use (Smajgl et al. 2016; Lim 2017). One of the most common approaches for water-food nexus analysis is based on inter- or cross-sectoral modelling approaches or analysis of the interrelationships at a specific spatial level, such as a watershed or local province (Kahil et al. 2019; Rasul et al. 2019). These approaches are expected to reduce the potential damage of climate change by sharing necessary factors across sectors (Rasul and Sharma 2016). In particular, the importance of adaptation measures to climate change through the nexus between the agriculture and water sectors and their benefits have been highlighted in these contexts.

The aims of this chapter are (1) to provide an overview of the impacts of climate change on the agriculture and water sectors in East and Southeast Asia, (2) to summarize adaptation approaches to cope with climate change in the region, and (3) to propose a nexus approach for the effective and sustainable use of resources under a changing climate through a better understanding of the interlinkage between food and water.

9.2 Climate Change in East and Southeast Asia

9.2.1 Changes in Temperature and Precipitation in East Asia

Choi et al. (2017) and Choi et al. (2019) presented projected climate data from multiple climate models based on CMIP5 (Coupled Model Inter-comparison Project 5) to explore bioclimatic changes in Northeast Asia. The changes in temperature-related and precipitation-related variables relative to the baseline period (1971–2000) for Northeast Asia located between 111–147°E and 18°S–57°N are portrayed in Fig. 9.1. They describe a clear warming trend in temperature-related variables such as growing degree days (GDDs) under the representative concentration pathway (RCP) 4.5 and 8.5 scenarios. The meteorological aridity with the aridity index (AI) shows an increase relative to the baseline period, although its increasing trend is not appreciable. The indices related to seasonality also show a significant increase compared to the present.

In the case of South Korea, increases in temperature up to 5.2 °C and 3.1 °C are projected by the end of the twenty-first century under the RCP 8.5 and 4.5 scenarios, respectively. (Fig. 9.2). The warming trend under RCP 8.5 is higher than that under RCP 4.5 in the whole East Asian region (Lee et al. 2014). The variability and intensity of precipitation in the twenty-first century are also projected to occur more frequently than those in the twentieth century, particularly under the RCP 8.5 scenario (Oh et al. 2014). These results imply a significant increase in flood frequency and droughts in these monsoon regions (IPCC 2019b).

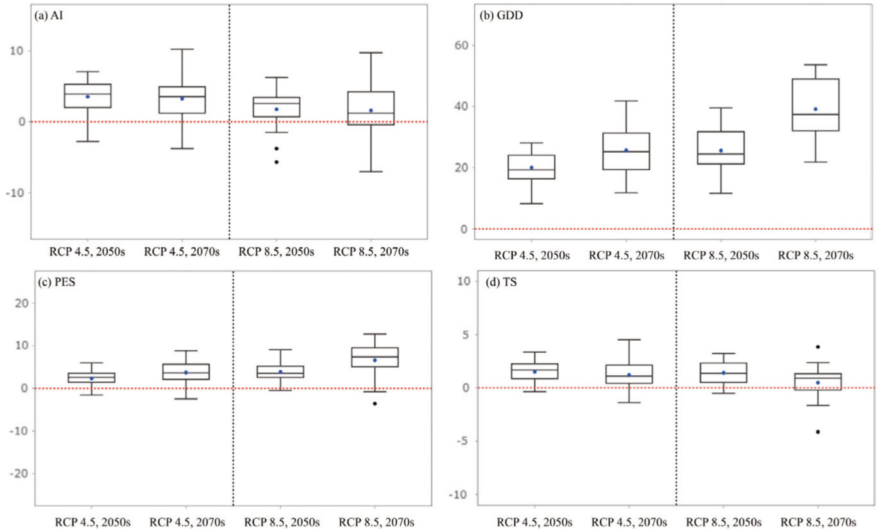

Fig. 9.1 Change rate of the main bioclimatic variables in Northeast Asia: **a** the aridity index (AI), **b** growing degree days (GDD), **c** potential evapotranspiration seasonality (PES), and **d** temperature seasonality (TS) (©Choi et al. 2018)

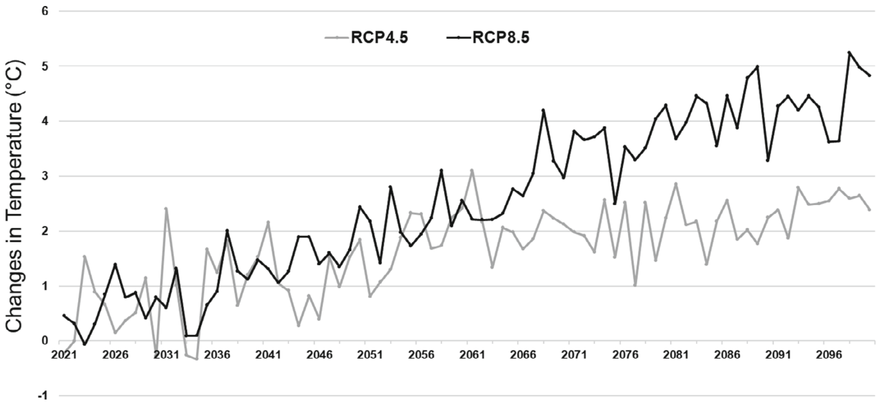

Fig. 9.2 Temperature changes under RCP 4.5 and 8.5 in South Korea in the twenty-first century

9.2.2 Changes in Temperature and Precipitation in Southeast Asia

Chun et al. (2016) used climate change scenarios collected from the COordinated Regional climate Downscaling EXperiment (CORDEX)-East Asia to assess the impacts of climate change on rice yields in Southeast Asia. More detailed information on CORDEX-East Asia can be found on the CORDEX-East Asia webpage (https://cordex-ea.climate.go.kr/cordex/). The changes in temperature and precipitation relative to the baseline period (1991–2000) for the five countries (Cambodia, Thailand, Laos, Myanmar, and Vietnam) in the Southeast Asian region are portrayed in Fig. 9.3. They report that a clear warming trend will result in maximum 4.1 °C (Myanmar) and 5.3 °C (Thailand) increases in temperature by the 2080s under the RCP 8.5 scenario. The ADB (2009) also reported a temperature increase of 4.8 °C by 2100 in Southeast Asian countries. The warming trend under RCP 8.5 was much higher than that under RCP 4.5. In terms of precipitation, they noted higher variability in precipitation under RCP 8.5 than under RCP 4.5. This higher variability of precipitation patterns suggests that better water management practices may be required for a stable water supply for the agriculture sector and other sectors. Regarding precipitation patterns, no appreciable trend in the region was found.

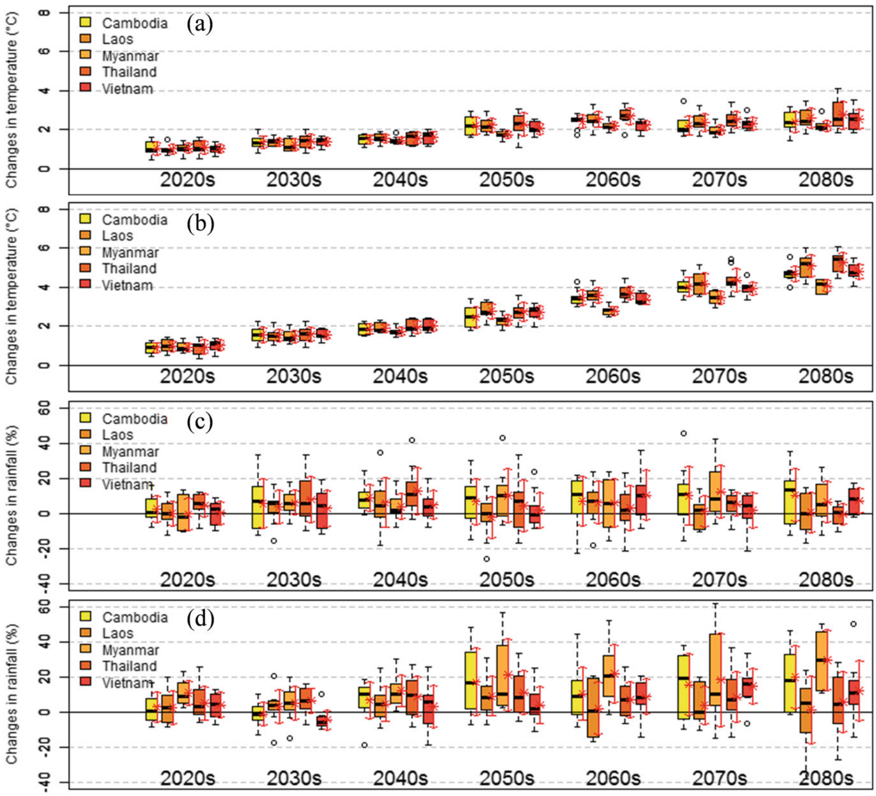

Fig. 9.3 Changes in temperature and precipitation relative to the baseline (1991–2000): **a** change in temperature under RCP 4.5, **b** change in temperature under RCP 8.5, **c** change in precipitation under RCP 4.5, and **d** change in precipitation under RCP 8.5 (©Chun et al. 2016)

9.3 Adaptations for the Effective and Sustainable Use of Resources Under a Changing Climate

9.3.1 Adaptations to Climate Change for the Agriculture and Water Sectors in East Asia

In East Asia, agricultural damage associated with climate disasters such as heatwaves, droughts, and floods has been increasingly reported. The International Food Policy Research Institute reported that crop yields in 2050 will decline relative to yields in 2000 by up to 20% for rice, 13% for soybean, 16% for wheat, and 4% for maize because of climate change in East Asia (IFPRI 2009). To counteract the adverse impacts of climate change on food and nutrition, South Asia requires additional annual investments of 1.5 billion USD in rural development, and East Asia and the Pacific require almost 1 billion USD/year (IFPRI 2009). Over half of these investments in both regions must be allocated for irrigation expansion.

Lim (2021) reported that the reduction in rice yield reduction will range from 25 to 45% in most of the Korean Peninsula under rain-fed cropping conditions by the 2070s relative to the baseline (1981–2010). Furthermore, a significant increase in agricultural drought risk was projected in most of the Korean Peninsula under both the RCP 4.5 and 8.5 scenarios (Lim et al. 2019a). In a multi-model ensemble study in China, if the CO_2 fertilization effect is not considered, the production of representative crops (rice, maize, soybean, and wheat) is expected to decrease up to 30% for most of the late twenty-first century (2060–2080) (Yin et al. 2015). Although some studies suggest the possibility of increased agricultural productivity with temperature increases in the northeast region, this growth will still be accompanied by increasing risks of climate disasters (Rashid et al. 2019). Furthermore, Yoshida et al. (2015) expected that the warming trend in temperature could increase rice production in Japan, but at the same time, they also warned of the potential risk of heat waves or floods to agricultural productivity.

To reduce the impact of climate change, various adaptations, such as irrigation management, fertilizer application, and cultivar change, have been suggested and applied through a modelling approach. Lim (2021) suggested that water management and irrigation application can be critical for rice production under the future climate. In particular, the study stressed the growing need for agricultural water management to meet the potential increase in irrigation demand (up to 35%). It is necessary to manage the water supply through forests and to accordingly develop irrigation-related infrastructure. In the case of China, irrigation as a form of agricultural adaptation has been shown to be most important for Northwest China due to chronic dryness. South and Southwest China will also need additional irrigation systems. On the other hand, Zhang et al. (2019) suggested an interesting study result: China's irrigation water requirement in the long term might decrease with an increase in CO_2. However, they noted that this does not necessarily indicate that this decrease can solve water scarcity. Ultimately, they argued that efficacious agricultural measures are needed to meet increasing irrigation requirements and to conserve water, and that advanced irrigation technologies are a major factor in adaptation. In terms of cultivar, Yoshida et al. (2015) predicted that the subregion will experience reduced low-temperature stresses, whereas high-temperature stresses will become more apparent. This suggests that countermeasures against heat damage will be required under the future climate. According to multi-cultivar simulation, the yield advantage of cultivar replacement compared with the existing cultivar was 22% (Fig. 9.4).

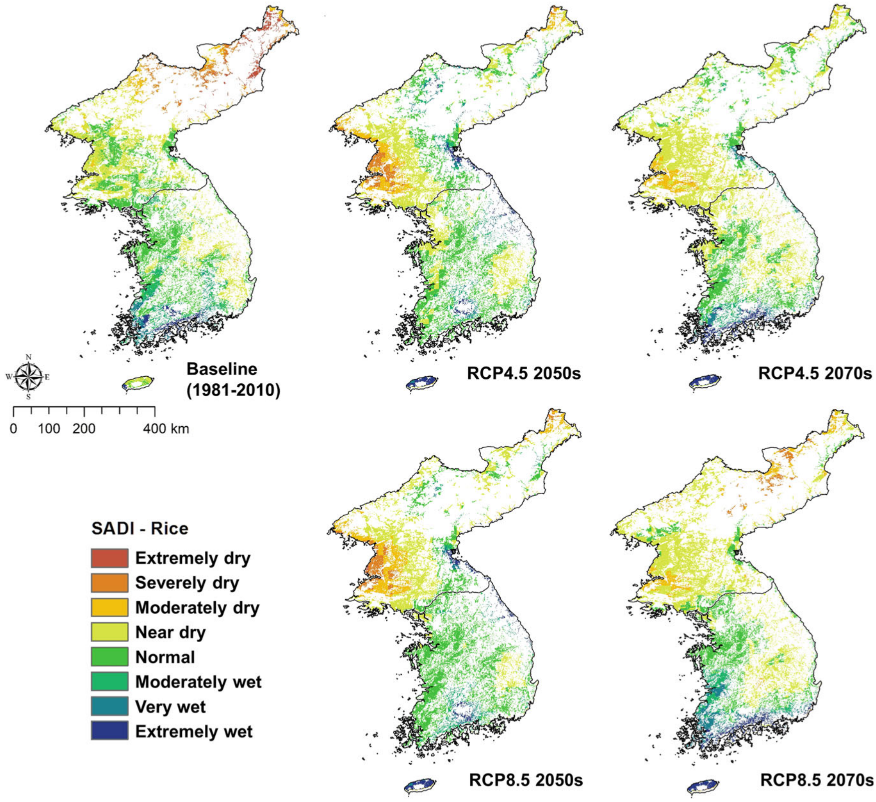

Fig. 9.4 Standardized Agricultural Drought Index of rice (SADI-Rice) under the baseline and future climate scenarios in the Korean Peninsula (©Lim et al. 2019a)

9.3.2 *Adaptations to Climate Change for the Agriculture and Water Sectors in Southeast Asia*

It is widely known that Southeast Asia is one of the most vulnerable regions to climate change in the world. Due to increasing climate risks, a reduction in agricultural production has been projected in this region. For example, ADB (2009) reported that without adequate adaptation measures, rice yields in Thailand and Vietnam will decrease by approximately 50% by 2100, and the yields in Indonesia and the Philippines will decrease by approximately 34% and 75%, respectively. Even though slight increases in the rice yield were simulated in the northern parts of Thailand, Vietnam, or Myanmar in the 2040s and the 2080s under both the RCP 4.5 and 8.5 scenarios, most of these regions were projected to experience reduced rice yields under both climate change scenarios (Fig. 9.5). Chun et al. (2016) also reported that rice yield reductions ranged from 15 to 45% in most of Thailand and Cambodia. Some southern parts of Thailand and Cambodia will experience a rice yield reduction of more than 45% by the 2080s relative to the baseline (1991–2000). Li et al. (2017) showed that the increase in seasonal mean temperature in the region is the main factor controlling the decreases in rice yield (Vietnam: 92%, Myanmar: 86%, Thailand: 73%, Cambodia: 64%, Laos: 54%). These projections suggest that adequate adaptation strategies will be necessary to offset the negative impacts of climate change on agricultural production.

Various adaptations, such as water management practices, nitrogen fertilizer application rates, and adjustment of planting dates, have been assessed through modelling approaches. Li et al. (2017) found that irrigation will be most beneficial to reduce the negative impacts of climate change on rice production in Southeast Asia, especially in Cambodia, Thailand, Vietnam (approximately 7.9–19.8%) and Myanmar (approximately 1.7–3.4%). The responses of the rice yield to shifting planting dates will vary with large ranges in this region. In some cases, a decrease in rice yield was simulated with shifting planting days (Li et al. 2017). With these agricultural management practices, adaptation strategies at different scales, including the national and farmer levels, have also been assessed. Chun et al. (2016) proposed a multi-scale crop modelling approach. They first identified the country with the most reduced rice yield and suggested the most beneficial adaptation strategy in the country based on the GLAM-Rice model (Li et al. 2017), a large-scale crop model. Through a further investigation of the spatial distribution of the effects of the adaptation in the country, the most beneficial place (a grid cell) was identified. Finally, various combinations of adaptation measures were assessed by the CERES-Rice model to maximize the rice yield considering future environmental changes. They found that a combination of the nitrogen fertilizer application rate and adjustment of planting dates will be efficacious at the farmer level.

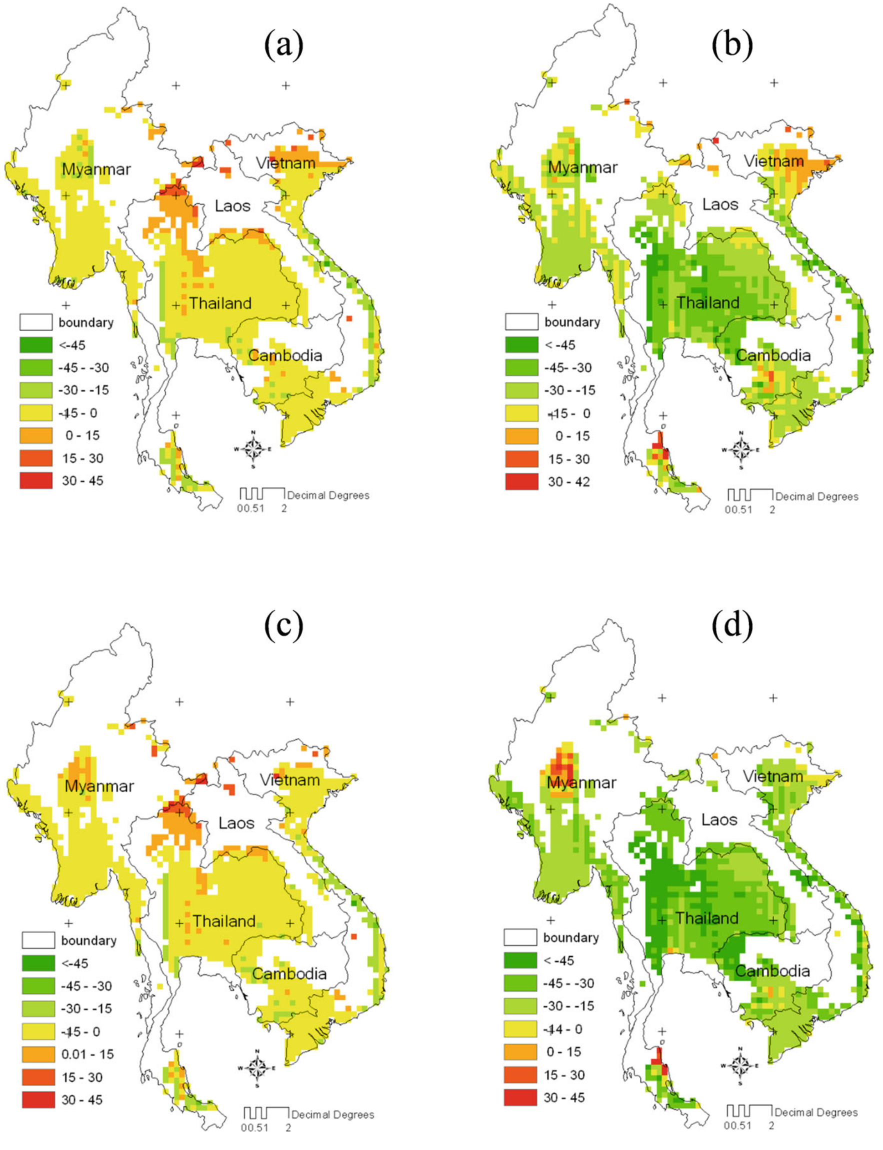

Fig. 9.5 The projected rice yield change (%) relative to the baseline (1991–2000) under the RCP 4.5 and RCP 8.5 climate change scenarios: changes in rice yield under RCP 4.5 in **a** the 2040s and **b** the 2080s; changes in rice yield under RCP 8.5 in **c** the 2040s and **d** the 2080s (©Chun et al. 2016)

9.3.3 Synergies and Trade-Offs with the Adaptations for the Agriculture and Water Sectors

Various concepts of the agriculture-water nexus for adaptation have been suggested in previous studies focusing on East and Southeast Asian countries. Most of these models aimed to devise an irrigation-based agriculture-water nexus and suggested adaptation planning for climate change. Some studies have focused on the trade-off between water and food and assessed consumption and crop production using national statistics (Taniguchi et al. 2018). In other studies, the nexus system, including water and food, was quantified based on life cycle assessment (Mannan et al. 2018). In the context of climate change, crop models have mainly been used to quantitatively estimate crop production and water consumption. Recent studies have attempted to demonstrate the feasibility of these integrated models in a local province and a watershed. Rasul et al. (2019) suggested an integrated basin management approach for creating co-benefits that support multiple uses. Lim (2021) proposed a water-centric nexus of agriculture and forests for the response to climate change at the watershed level (Fig. 9.6).

Irrigation has been identified as one of the most efficacious adaptation measures (Chun et al. 2016; Li et al. 2017). Many countries have planned to enhance their irrigation infrastructures (e.g., Basin Development Plan 20-year of the Mekong River Commission Secretariat, BDP2030), acknowledging that water allocation must be optimized to meet the increasing water demands of the agricultural sector. Thus, an

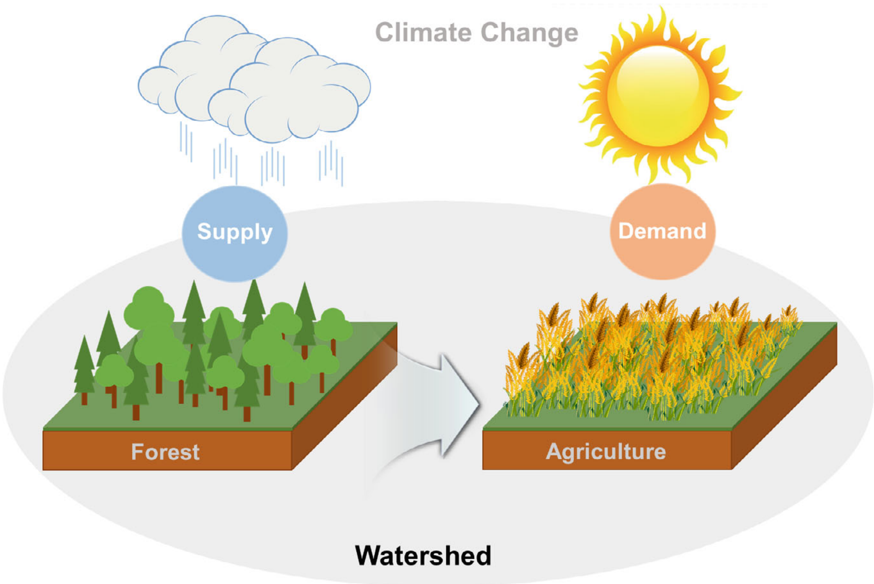

Fig. 9.6 The concept of a water-centric nexus at the watershed level (©Lim 2021)

enhanced irrigation system is of crucial importance for dealing with the growing variabilities of future precipitation patterns such as droughts and floods (ADB 2009; Chun et al. 2016; Li et al. 2017).

In the East Asian region, with a projected increase in precipitation under a changing climate, more water could be supplied through forests. In the proposed water-centric nexus at the watershed level, an increase in overall irrigation demand can be met by the increased amount of water supply if the proper management of land use and the forest ecosystem is carried out in parallel (Lim 2021). To utilize the potential water supply to the agricultural field, a holistic approach is necessary to adequately link forest management with agriculture.

In the case of North Korea, as a strategy for adaptation to climate change in the agriculture and water sectors, ecosystem restoration must take place first. Lim et al. (2019b) suggested that the water demand–supply balance has collapsed due to deforestation, which means that forest restoration could be a major factor in implementing the water-centric adaptation. The restoration of the forest ecosystem can create synergies such as improving the supply of water resources, reducing cropland runoff, reducing soil erosion, and fulfilling irrigation water requirements (Lim et al. 2017b, 2019b).

Li et al. (2019) proposed a water-food-energy nexus approach for sustainable agricultural management using an integrated model and applied the model to the Heihe River basin in China. The interrelationships and trade-offs among system components, including water supply–demand, food production, land demand, and the water and energy footprints, were quantitatively examined under different management scenarios. The integrated model has advantages in managing the interactions among the agricultural water, food, and energy subsystems in a sustainable way by simultaneously considering economic benefits and environmental concerns. A better understanding of the interdependency between those sectors can provide an efficacious measure for the effective and sustainable use of water resources and for enhancing food security.

9.4 Summary and Conclusions

In this chapter, we (1) provided an overview of the impacts of climate change on the agriculture and water sectors in East and Southeast Asia, (2) summarized adaptation approaches to cope with climate change in the region, and (3) proposed a nexus approach for the effective and sustainable use of resources under a changing climate through a better understanding of the interlinkage between food and water. In this review, we highlighted the following:

(1) Climate models predict an apparent warming trend in temperature and increasing variability in precipitation patterns (droughts, extreme rainfalls) in East and Southeast Asia.

(2) Many studies have proposed that a sustainable water supply plays a key role in food security in the future. As efficacious adaptations to climate change and variability for agriculture, more attention should be paid to smart and sustainable irrigation, with a careful investigation of synergies and trade-offs with the adaptations for the agriculture and water sectors.
(3) An integrated model has promise as a tool for managing the interactions among the agricultural water, food, and energy subsystems in a sustainable way by simultaneously considering economic benefits and environmental concerns.

Finally, we concluded that a better understanding of the interdependency between those sectors can provide an efficacious measure for the effective and sustainable use of water resources and for enhancing food security.

Acknowledgements Figures 9.3 and 9.5 were reprinted from Agricultural Systems, 143, Jong Ahn Chun, Sanai Li, Qingguo Wang, Woo-Seop Lee, Eun-Jeong Lee, Nina Horstmann, Hojeong Park, Touch Veasna, Lim Vanndy, Khok Pros, Seng Vang, Assessing rice productivity and adaptation strategies for Southeast Asia under climate change through multi-scale crop modeling, 14-21, 2016, with permission from Elsevier.

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Chapter 10
Multidisciplinary and Inter-Sectoral Collaborations in the Water-Energy-Food Nexus: Examples from Japan and Thailand

Kimberly M. Burnett, Sittidaj Pongkijvorasin, and Christopher A. Wada

Abstract This chapter provides a brief overview of the water-energy-food nexus and lays out a framework that describes the interlinkages between each nexus component. Case studies from Japan and Thailand are explored in the context of the developed framework, with particular emphasis on the water and food components of the nexus. The example from Kumamoto (Japan), a managed agricultural water ponding program for groundwater recharge that supports both the local farming industry and a multitude of downstream water users, has been operating successfully for nearly two decades. Costs, benefits, and implementation challenges of the program are discussed. The Thailand case study similarly considers how upstream agricultural production affects downstream water users, although the focus is more on the negative impacts of such activities, including higher streamflow volatility and hence increased likelihood of extreme events like droughts and floods. We conclude that a decentralized approach like the payment for ecosystem services program implemented in Kumamoto could be used in a portfolio of management options to incentivize efficient upstream land management in Thailand, ultimately resulting in reduced negative impacts to downstream users.

Keywords Groundwater · Agriculture · Deforestation · Flood · Drought · Nexus · Interlinkages

K. M. Burnett (✉) · C. A. Wada
University of Hawai'i Economic Research Organization, 2424 Maile Way, Saunders Hall 540, Honolulu, HI 96822, USA
e-mail: kburnett@hawaii.edu

C. A. Wada
e-mail: cawada@hawaii.edu

S. Pongkijvorasin
Faculty of Economics, Chulalongkorn University, Phayathai Road, Bangkok 10330, Thailand
e-mail: sittidaj.p@chula.ac.th

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10.1 Introduction

Water, energy, and food are essential resources, judicious management of which is crucial going forward, given ever-increasing pressures from climate change, population growth, globalization, economic growth, and urbanization. Demand for water, energy, and food are projected to increase worldwide by 55, 80, and 60% respectively by 2050 (IRENA 2015), which will result in a growing number of trade-offs and potential conflicts for many communities. In response to these concerns, a number of studies have been undertaken in recent years to improve our understanding of the complex relationships amongst the three resources that make up the water-energy-food (WEF) nexus. Overviews of the WEF nexus framework emphasize the importance of identifying and quantifying interlinkages and tradeoffs within the WEF systems (Allan et al. 2015; Al-Saidi and Elagib 2017; Endo et al. 2015; Taniguchi et al. 2015). Specific applications range from global issues such as food security, poverty reduction, and environmental sustainability (Biggs et al. 2015; Mirzabaev et al. 2015; Vanham 2016) to local-level resource management and planning issues (Burnett et al. 2018; Hang et al. 2016; Shifflett et al. 2016).

The WEF nexus can generally be defined as the relationship between water, energy, and food in human-environmental systems. Depending on the water, energy, and/or food resources under consideration, linkages between each component can go in one or both directions simultaneously (Fig. 10.1). For example, water can be used for hydroelectric power generation, thermoelectric power generation, power plant cooling, and fracking, while energy can be used to transport, pump, or heat water. Water can also be used for food via agricultural irrigation or rainwater harvesting, and food production decisions affect how much freshwater is available for other competing uses. Lastly, food production and transport are highly dependent on energy, and biofuels can be used to supplement more traditional sources of energy.

Once identified, relationships between WEF nexus components can be further classified into several types. For example, Burnett and Wada (2018) use the following distinctions: (1) direct dependencies, (2) direct competition, and (3) externalities. Taniguchi et al. (2019) similarly discuss three distinct categories: (1) direct tradeoffs, (2) alterations/interactions, and (3) linkages/synergies. In this chapter, we focus on two examples, one each from Japan and Thailand, of direct dependencies/tradeoffs, wherein one component of the nexus is consumed or used in the production of another component (Fig. 10.1). While every linkage can be considered in a similar framework, in this chapter we focus on the food-water relationship in both Japan and Thailand. More generally, the energy component will affect both the availability and price of food and water so should not be omitted from consideration.

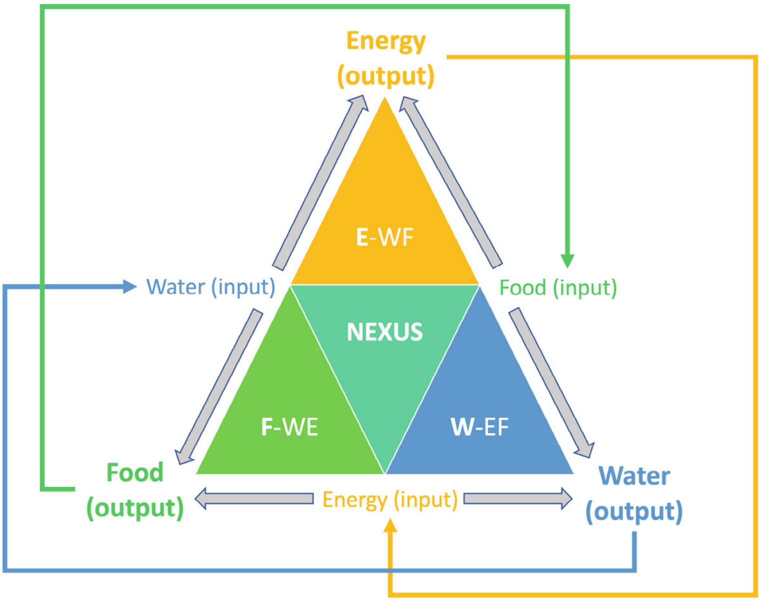

Fig. 10.1 The water-energy-food-nexus. Each nexus component serves as an input to production of the other components. Most of the produced outputs are delivered to end users, but a fraction re-enters the system and contributes to one or more of the production processes

10.2 Managed Agricultural Water Ponding for Groundwater Recharge in Kumamoto, Japan

Located on Kyushu, the third largest of Japan's five main islands, the city of Kumamoto is home to over 730,000 people, whose freshwater needs are met entirely by groundwater. The Kumamoto groundwater area, which extends beyond the boundaries of the city proper, is bounded by the Shira River to the north, Mount Aso to the east, the Midori River to the south, and the Ariake Sea to the west (Hosono et al. 2013). The aquifer system consists of an unconfined aquifer (<60 m in depth) and an underlying confined aquifer (70–200 m in depth), separated by an impermeable aquitard. Much of the recharge for the confined aquifer, which is the major source of drinking water for inhabitants of Kumamoto, comes from the mid-stream region of the Shira River, where the aquitard layer becomes discontinuous (Shimada et al. 2012). When groundwater levels continued to fall in the decades leading up to the turn of the century—using data from three observation wells (Suizenji, Kikuyo, and Mashiki) where Taniguchi et al. (2019) estimated an average decline of 0.02–0.24 m/yr over the period 1982–2004 (Fig. 10.2a)—residents and the local government quickly recognized the need to increase efforts to protect the aquifer system (Shimada 2010). This relationship between inputs into the food system and the corresponding water supply is represented by the blue WEF triangle in Fig. 10.1.

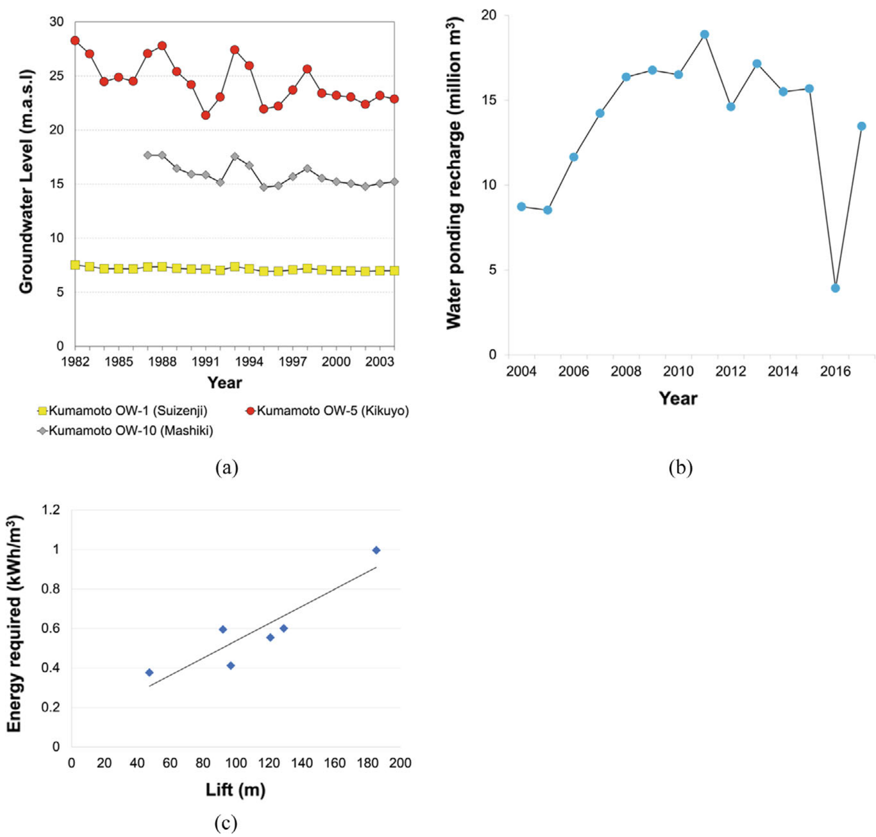

Fig. 10.2 Nexus relationships in Kumamoto: **a** observed groundwater decline in the decades prior to the subsidy program, **b** estimated contribution of the water ponding program to recharge of the Kumamoto aquifer system, **c** estimated relationship between energy and lift for pumping groundwater (©Taniguchi et al. 2019) adapted by the authors

Historically, rice farmers in the mid-stream area of the Shira River, located to the northeast of Kumamoto City, contributed to recharge of the confined aquifer via surface water irrigation. However, after years of declining rice cultivation and increasing urbanization and industrialization, mounting concerns about groundwater scarcity led to the development of numerous policies aimed at enhancing recharge, including "greening" parts of urban zones to allow for recharge in areas that would otherwise be covered by impervious surfaces, mandating installation of rainwater infiltration systems in certain buildings, and providing water ponding subsidies to local farmers in areas upgradient of the Kumamoto aquifer system. The water ponding subsidy program in particular has been especially effective and is touted as one of the few examples of a successful payment for ecosystem services (PES) program that incentivizes the augmentation of groundwater recharge via natural infrastructure (Shivakoti et al. 2018). Although there are rivers in the area, groundwater is the preferred drinking water source due to its seasonal stability and superior quality, as well as the prohibitive cost of infrastructure that would be required for capturing surface water (Hosono et al. 2018).

Introduced by the Kumamoto City government in 2004, the subsidy program has provided financial assistance for farmers in the mid-stream recharge area, including Kumamoto, Ozu, and Kikuyo towns, to flood fallow rice paddies with river water. Over the period 2004–2017, an average of 456 farmers participated in the program annually, 4.6 million m^2 of paddy fields were watered per year, 48.6 million JPY was paid in subsidies per year, and an estimated 13.7 million m^3 of recharge were captured annually (Fig. 10.2b, Taniguchi et al. 2019), which accounts for roughly 13% of total water demand in Kumamoto (Shivakoti et al. 2018). In addition to the substantial benefit of avoiding groundwater replacement costs, the program reduces groundwater pumping costs via its impact on water levels and supports continued crop production by some families who might have otherwise ceased farming operations, given concerns about increasing production input costs, a shift in the local economy toward other industries, and an aging population (Shivakoti et al. 2018).

Quantifying the program's impact on pumping costs requires an understanding of the factors underlying those costs. The greater the distance between the water table and the ground surface, the more expensive it is to pump each subsequent unit of water because more lift requires more energy. Taniguchi et al. (2019) estimated that a 1-m increase in lift increases the total energy required for pumping groundwater to the surface in Kumamoto by 0.0044 kWh/m^3 (Fig. 10.2c). Combining this with an average electricity cost of 13.51 JPY/kWh and the fact that the ponding subsidy program increases groundwater levels in the region (or at least avoids a continued decline in water levels) yielded an estimated cumulative cost saving of 41.1 million JPY over 20 years. In this example, energy is being used as an input for the production (pumping) of groundwater (blue WEF triangle in Fig. 10.1). And while the produced groundwater is primarily used by residents for drinking and other household purposes, the program also benefits larger entities like Suntory, a Japanese brewing and distilling company, that depend on high quality groundwater for food/beverage production (green FWE triangle in Fig. 10.1).

Although groundwater in Kumamoto is not used for crop irrigation, the ponding subsidy program supports on-farm production of food indirectly. Participating farmers in Ozu and Kikuyo towns, which are located in the mid-stream recharge area, receive financial assistance for flooding empty rice paddy fields with river water 30–90 days out of the year. During the remainder of the year however, farmlands can be used to grow crops. Given that farming would be unsustainable for some families in the absence of the subsidy program (Shivakoti et al. 2018), water can be viewed as a vital input for food production (green FWE triangle in Fig. 10.1), both directly (surface water used for crop irrigation) and indirectly (subsidy received for recharging the underlying aquifer used to support farm operations). Taniguchi et al. (2019) estimated that farmer benefits (avoided income loss) from the subsidy program likely falls in the range of 12.1–48.6 billion JPY when aggregated over 20 years, which suggests that for this particular case study, the FWE relationship (green triangle in Fig. 10.1) plays an especially important role in the nexus system.

Table 10.1 Estimated net benefit of the subsidy program under different assumptions about captured recharge, groundwater demand, energy costs, and farm income

	Billion JPY	
	Baseline farmer benefit	Reduced farmer benefit (25% of baseline)
Baseline pumping benefit	47.64	11.21
Higher recharge benefit (0.3 m/yr increase in head level)	47.72	11.29
Higher groundwater demand (1 million m^3/yr increase in pumping)	47.65	11.23
Higher energy costs (0.5 JPY/kWh/yr increase in energy price)	47.66	11.23

Under a range of assumptions, Taniguchi et al. (2019) estimated that the Kumamoto ponding subsidy program generates a total net benefit of 11.2–47.7 billion JPY over 20 years (Table 10.1), even without accounting for the avoided costs of an expensive dam system (several trillion yen) that would become necessary at some point in the near future in the absence of the program. This relationship characterizes the green F-WE triangle from Fig. 10.1. By that metric, one might quickly conclude that the subsidy program is a desirable win–win solution. However, traversing the path from program conceptualization to implementation required a multidisciplinary approach and strong inter-sectoral collaboration. Groundwater expertise was required to understand how and where recharge occurs in the Kumamoto aquifer system, irrigation expertise was required to understand how the program-induced ponding contributes to recharge, and economic expertise was required to evaluate the monetary benefits and costs of the program. In addition, cooperation was required between the agricultural sector in Kikuyo and Ozu, the water utility in Kumamoto, commercial and domestic users of groundwater in Kumamoto, and several city governments. If even one of the parties chose not to participate, the entire program would have been in jeopardy given the multiple interlinkages across sectors. In general, the success of water-energy-food nexus programs hinges on the effective engagement of all stakeholders in the policy development process.

10.3 Growing Food Demand and Downstream Water Instability in Thailand

Thailand has long been recognized as one of the major food exporters in the world. In 2019, food exported from Thailand was valued at more than $32 billion, ranked 11th highest worldwide. The country's top food exports include rice (17.5%), chicken (10.7%), sugar (8.5%), processed tuna (7.1%), and shrimp (5.7%). Among the top items, Thailand has become a major exporter of chicken during the past decade. In 2019, Thailand chicken exports totaled more than $3.4 billion, making it the 3rd largest chicken exporter worldwide. The number has increased rapidly from $2.2 billion in 2013, growing at a rate of almost 10% annually (NFI 2020).

With higher exports of chicken and shrimp, the demand for animal-feed has also increased drastically. The demand for maize, one of the main ingredients of animal-feed, has increased from 4.8 million tons in 2013 to 6.6 million tons in 2020 and is expected to reach 7.7 million tons in 2032 (Thai Feed Mill Association 2014). This also implies that the demand for maize cultivating area will increase from about 1.1 million ha in 2013 to 1.84 million ha in 2032, if one assumes the same productivity per unit of area.

About 70% of maize in Thailand is grown in the northern part of the country. The data in 2013 shows that about half of maize cultivation took place in prohibited forest areas (data from Land Development Department cited in Thai Feed Mill Association 2014). During the past decade, an expansion of maize cultivation area has resulted in massive deforestation, especially in Northern Thailand. The land conversion and deforestation have created many on-site environmental concerns, e.g., loss of soil, biodiversity loss, forest fires and haze problems (e.g., Valentin et al. 2008; Turkelboom et al. 2008; Sirimongkonlertkun 2014; Gistnorth and Greenpeace Thailand 2020). However, one severe externality, which has not been addressed extensively, relates to the effect on the stability of water downstream.

There are many studies showing that land conversion affects the amount and variation of water downstream. For example, Wittawatchutikul et al. (2009) measured and compared surface runoff in forest versus rubber plantation areas in Chiangmai province, located in Northern Thailand. The study showed that rubber plantations increase annual average runoff from 16.10 to 25.33% of annual rainfall, and moreover, the stability of monthly runoff is clearly reduced. With rubber plantations, runoff almost triples in the wet season. However, in the dry season, runoff decreases significantly; Wittawatchutikul et al. (2009) observed six months with no runoff during the dry season for rubber plantations, compared to only one month in forested areas.

A study by Tangtham and Yuwananont (1996) compared streamflow characteristics of the Pasak river basin in Central Thailand. During the period 1973–1991, the Pasak river basin experienced massive deforestation. The data showed that, in the upper Pasak river basin, the forested area decreased from 50% in 1973 to 30% in 1982. As a result, the percentage of streamflow in the wet season increased from 65% (1973–1977) to 78% (1978–1982) of annual streamflow; while the percentage of streamflow in the dry season decreased from 35 to 22%. In terms of rainfall, the percentage of streamflow in the wet season increased from 11 to 14% of annual rainfall in the area; while in the dry season, the number decreased from 6 to 4% during the same period.

A higher variation of runoff and streamflow causes downstream areas to face a higher risk of disaster events, i.e., floods in the wet season and droughts in the dry season. In Thailand, there are many areas commonly facing both floods and droughts in the same year. The estimated average economic losses from floods in Thailand during the period 2009–2016 is almost $170 million per year. Over the same period, the average losses from droughts exceed $24 million annually. In 2013, estimated losses from droughts peaked at almost $100 million (ONEP 2018). The data reveals that Thailand faces challenges in dealing with large water fluctuations that occur in a given year. As deforestation increases in accordance with an increase in food demand and production, downstream water is expected to be even more volatile. Thus, the damages from floods and droughts are expected to be more significant.

In terms of instruments used to combat deforestation, the Thai government currently relies solely on laws and regulations (command and control approach). However, given the large number of remote forested areas, and the fact that the government has limited monitoring and enforcement capabilities for controlling deforestation, the law and regulation approach has not been an effective tool. Recent research suggests that alternative market-based instruments may be more effective. For example, PES has been mentioned as one possible measure (see e.g., Pongkijvorasin and Teerasuwannajak 2019). In the PES framework, downstream users who benefit from water availability and stability should pay upstream communities to protect the forest. Positive externalities of forest protection, and negative externalities of growing upland maize, will thus be embedded into individual decision-making.

Community forestry, a rights-based approach, is among other suggested policies to discourage deforestation. Chankrajang (2019) shows that community forestry has positive impacts on environmental outcomes, including increased forest cover and reduced fire incidence. Another suggested instrument is to ban animal feed or meat for which upland maize is an input. For example, implementation of Responsible Agricultural Investment (RAI) where agricultural exporters are required to meet certain sustainable standards, is being encouraged for products exported for international trade.[1] With these alternative instruments, e.g., PES, community forestry, and RAI, downstream impacts of upstream land-use changes will be taken into account and upstream land will be used more efficiently.

10.4 Conclusion

The Kumamoto ponding subsidy program analyzed by Taniguchi et al. (2019) generates a total net benefit of 11.2–47.7 billion JPY over 20 years, a win–win solution, but one that requires a multidisciplinary approach and strong inter-sectoral collaboration. Annual damages from floods and droughts in Thailand range from $100–$170 million, but could be mitigated with PES land management programs upstream. In both case studies, because the relationships between each nexus component are complex and varying across both spatial and temporal dimensions, effective solutions for minimizing tradeoffs and conflict amongst stakeholders will often require a combination of multidisciplinary research and inter-sectoral collaborations. PES

[1] Although RAI can be viewed as another command and control approach, monitoring and enforcement are conducted mainly by buyers and sellers instead of the government.

programs, for example, which are already in place in Kumamoto and are being considered for implementation in Thailand, call for a clear scientific understanding of the link between the nexus components of interest, in this case, food production and water. Without this quantitative information, incentivizing payments is difficult because many downstream users will likely not be willing to buy into a program for which the benefits are unclear. At the same time, designing and implementing an effective PES program often requires input from social scientists. Although PES is market-based, in the sense that participation is voluntary, some kind of platform is typically needed to coordinate transactions, particularly when many parties are involved. Such parties can span many different sectors of the economy. In the Japan case study, for example, downstream beneficiaries of the subsidized groundwater ponding program range from individual residential water users to a large commercial beverage company. Although a single downstream residential user would not be capable of unilaterally supporting upstream groundwater recharge enhancement activities, inter-sectoral collaboration amongst beneficiaries can lead to effective cost-sharing mechanisms.

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Chapter 11
Current Status and Challenges of Water, Energy, and Food in China and Resource Sharing Through International Trades

Yonghui Yang, Xinyao Zhou, and Linna Wang

Abstract Since the launch of the policy of reform and opening up in 1978, China's rapid economic and population growth has caused enormous changes in water, food, and energy consumption and production. This chapter reviewed the recent increase in production, importation, and consumption in the water, food, and energy sectors in China. In the water sector, the general decrease in per capita water resources driven by population growth, increases in water shortages in northern regions, and stabilized total water consumption and agricultural water use as a result of strong policy intentions were analysed. In the energy sector, the review suggested a strong increase in energy consumption, a shift from being an exporting country to being an importing country, especially in gas and crude oil, and China's ambition to achieve peak carbon emissions in 2030 and carbon neutrality before 2060. In the food sector, it reveals the rapid growth in China's total food production from 354 million tons in 1982 to 618 million tons in 2017, helping to solve China's large population living in poverty. Even though the production of major crops continues to increase, the shift from being a society with a grain diet to being a society with a mixture of grain and meat consumption is causing a quick growth in soybean imports from the US, Brazil, and other countries. Studying the water-energy-food nexus provides an insightful perspective on the present and future demands to maintain water, energy, and food sustainability, and China's policy emphases on an ecologically and environmentally friendly society for China and the world.

Y. Yang (✉) · X. Zhou · L. Wang
Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, 286 Huaizhong Road, Shijiazhuang 050021, China
e-mail: yonghui.yang@sjziam.ac.cn

X. Zhou
e-mail: zhouxy@sjziam.ac.cn

L. Wang
e-mail: lnwang@sjziam.ac.cn

Y. Yang · L. Wang
University of Chinese Academy of Sciences, Beijing 100049, China

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Keywords Water-energy-food nexus · Production and consumption · Importation and exportation · International trade · Sustainability

11.1 Introduction

China has experienced both rapid economic development and population growth since launching its national policy of reform and opening up in 1978. Over this period, China's GDP has increased over 30 times from only 1.3% of global GDP to 15.2% in 2018. The demand for water, food, and energy is also increasing. From the 1980s to the 2010s, China's food consumption increased 3.2 times, 8.3 times, 17.1 times and 10.5 times for cereals, meat, dairy, and vegetables and fruits, respectively (Sheng and Song 2019). At the same time, China's total energy consumption has soared almost 10 times (Crompton and Wu 2005; Wang et al. 2014; Tang et al. 2018).

The increase in food and energy production, especially food, has also caused a shortage of water, especially in the northern part of the country, owing to the uneven distribution of precipitation. Both food production and energy generation consume enormous quantities of water, accounting for 65% and 10% of the total water use in China, respectively (China Water Resources Bulletin 2018). As a consequence, China's total water use has continued to grow, from 440 km^3 in the 1980s to over 600 km^3 in the 2010s (Yang et al. 2012), leading to severe water scarcity.

China has tried to solve its water problems by restricting the total water use, improving water use efficiency, and reducing water pollution (GWP 2015). The close linkage between water, food, and energy shows that the solution to water problems should involve not only water but also food and energy. In this context, the water-energy-food (WEF) nexus has emerged to help us understand the complex system, systematically analyse the interactions between the three factors, and work towards more coordinated management (FAO 2014). To date, there have been many WEF nexus case studies around the world.

All three factors are important for meeting the sustainable development goals (SDGs) presented by the United Nations, with water related to SDG 6 (clean water and sanitation), energy related to SDG 7 (affordable and clean energy) and food related to SDG 2 (zero hunger). Moreover, they are closely coupled to affect SDG 13 (climate actions), SDG 9 (industry, innovation and infrastructure), SDG 11 (sustainable cities and communities) and so on. Since all of them are limited resources and influence each other, it will be useful to summarize the current status of each and to understand their feedback from others for relevant policy-makers to formulate feasible policies. Moreover, at the global level, China's food and energy have a strong linkage with the world market. It has become necessary for us to clarify the present situation and challenges of water, energy, and food in China and their linkage through international trade, providing a base for policy-making globally and within China.

11.2 Current Situation of Water, Food, and Energy in China

11.2.1 Water Demand, Supply, and Shortage

China's annual total renewable water resources amount to approximately 2800 km^3, ranking sixth in the world (Cheng et al. 2009). Due to its rapid population increase, however, the water resource per capita dropped from nearly 4000 m^3 in the 1960s to 2400 m^3 in 1990 and to 2000 m^3 per capita in 2018 (Fig. 11.1). Furthermore, it is expected to further decline as China's population rises to its peak by 2030 (Xie et al. 2009).

The major natural reason for China's water shortage is the uneven distribution of annual precipitation. While most parts of southern China have relatively rich annual precipitation, generally over 1000 mm, the northern parts, especially those to the north of the Huaihe River, have annual precipitation of less than 800 mm or even less than 500 mm. Thus, approximately 80% of the national water resources are located to the south of the Yangtze River Basin, serving 60% of the population (China Water Resources Bulletin 2018). In contrast, 40% of the population in the northern parts is served by only 20% of the nation's water resources. For instance, the North China Plain, one of the most important food production regions in China, has the smallest per capita water resources, below 500 m^3 per year.

The river runoff analysis of China's major basin also shows a dramatic decline in surface water resources between the 1950–2015 period and the 2010–2018 period, particularly in the downstream river basins of northern China (Yang and Tian 2009).

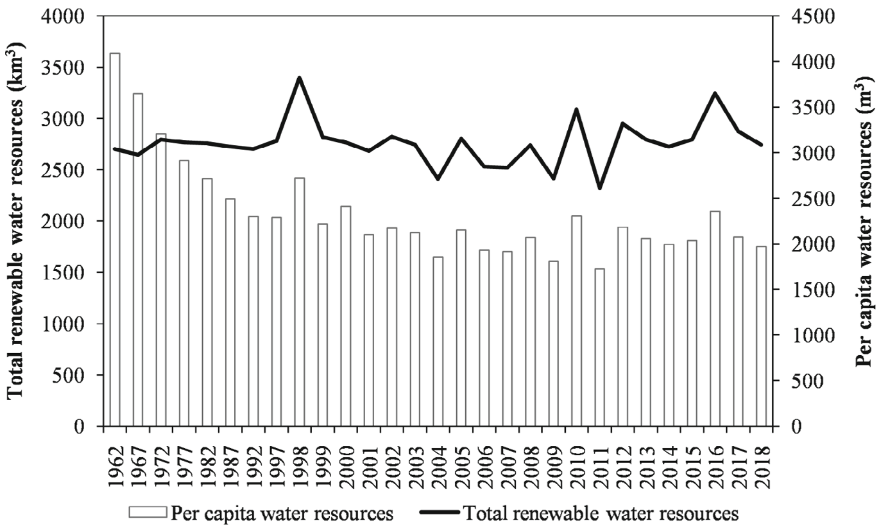

Fig. 11.1 Changes in national renewable water resources and water per capita

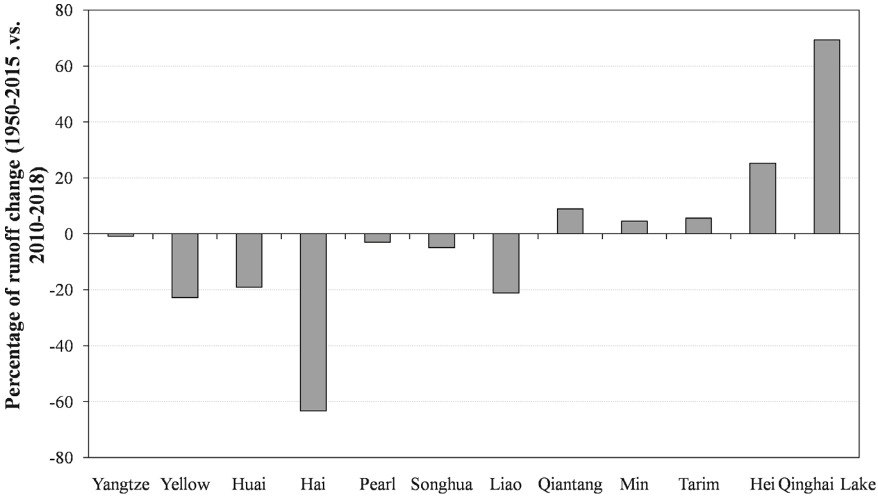

Fig. 11.2 Surface runoff change in China's major basins (*Source* River Sediment Bulletin of China 2018) adapted by the author

For example, Fig. 11.2 shows that most catchments have a downward trend of runoff except the rivers in the northwest, where the runoff from increased rainfall caused by climate change is beneficial. While surface runoff decreases slightly in southern basins such as those of the Yangtze and Pearl Rivers, the Hai River Basin, where Beijing, Tianjin, and Hebei are located, has the most significant decrease in runoff, that is, a decrease of over 60% (River Sediment Bulletin of China 2018). On the other hand, surface runoff increases in south-eastern basins and upstream north-western basins, with a slight increase in the southeast and a significant increase in upstream north-western basins.

Figure 11.3 shows a comparison between a theoretically constructed natural river flow and the real water flow in China's major rivers. While both climate change and human activities contribute to reducing surface runoff, the human influence is apparently the major driver for rivers in the eastern part of the country. In rivers such as the Hai River, Shiyang River, Hei River, Tarim River, Yellow River, Liao River, and Huai River, a large amount of natural runoff has eliminated by human water use (Zhou et al. 2019).

China's water use also confirmed the reason for the decrease in river runoff. Since the 1980s, the total water use has changed from approximately 450 km^3 in the 1980s to 550 km^3 in the 1990s and to approximately 600 km^3 in the 2000s (China Water Resources Bulletin 2018). Aiming to maximize its sustainable development, China proposed the strictest water regulations, called "Three Red Lines", in 2011, capping the annual maximum total water use at 670 km^3 (including 400 km^3 for agricultural water use), improving water use efficiency, and reducing water pollution by 2030 (GWP 2015). Since then, China's total water use has begun to stabilize (Fig. 11.4). Agriculture and industry are the two largest sectors, together accounting for over

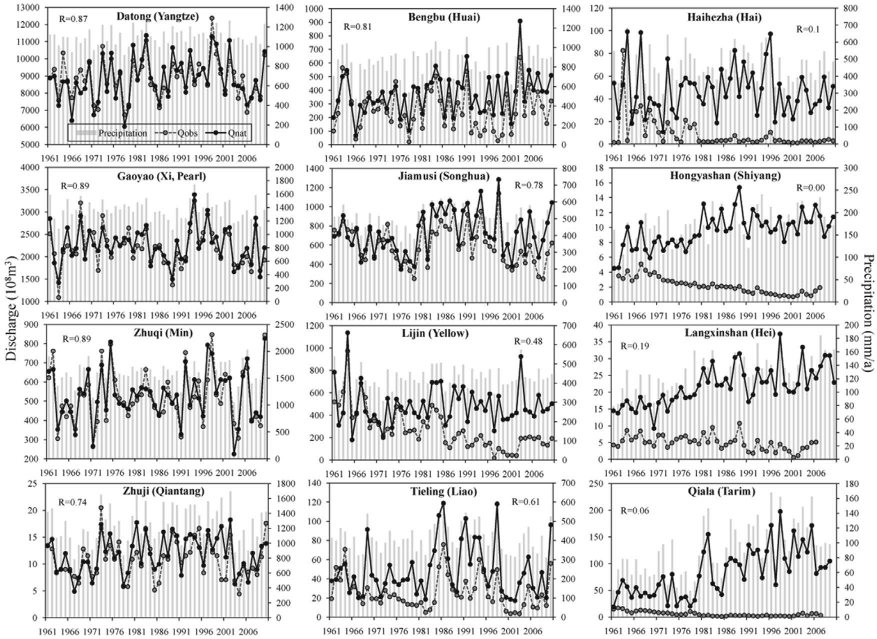

Fig. 11.3 The observed surface runoff (grey dashed line) and natural runoff without human intervention (black solid line) in China's major basins as predicted by the Budyko framework (*Source* Zhou et al. 2019) adapted by the author

90% of the total water use before 2000. Since then, domestic and environmental water use has gradually increased to ~ 20% along with the improvement in people's living standards.

Since agriculture and industry are the two major sectors of water use, it is necessary to further understand the drivers of this change to provide a basis for China's WEF nexus.

11.2.2 Food Production and Water Consumption

Since 1980, the increase in food consumption per capita has been significant in terms of both the amount and diversity of food. In fact, the annual total consumption of grains has steadily increased (Cui and Shoemaker 2018), although the consumption of cereals per capita is decreasing (Zhou et al. 2008). The annual consumption of three main cereals (wheat, corn, and rice) continued to increase and, in the 2010s, reached ~7 times, 16 times, and 2 times the consumption level in the 1960s, respectively. Because of the food elf-sufficiency policy, annual cereal production also increased concurrently, and net imports from overseas remained small except for soybeans (Fig. 11.5). In fact, China has even sometimes sold its food production abroad. The

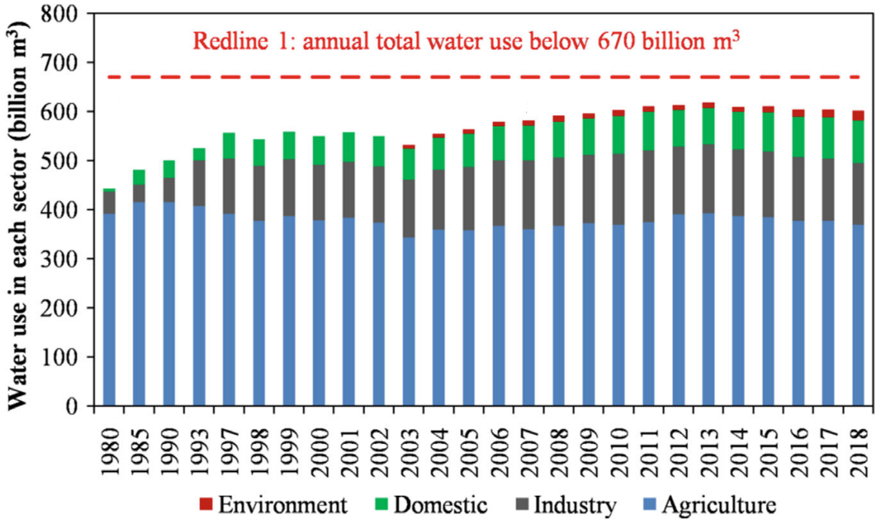

Fig. 11.4 China's total water use in each sector from 1980 to 2018 (*Source* China Water Resources Bulletin 2018) adapted by the author

decline in cereal production and consumption in the late 1990s and early 2000s was caused by the reduced area owing to less government support, but it soon started to recover in 2004 (Li et al. 2013).

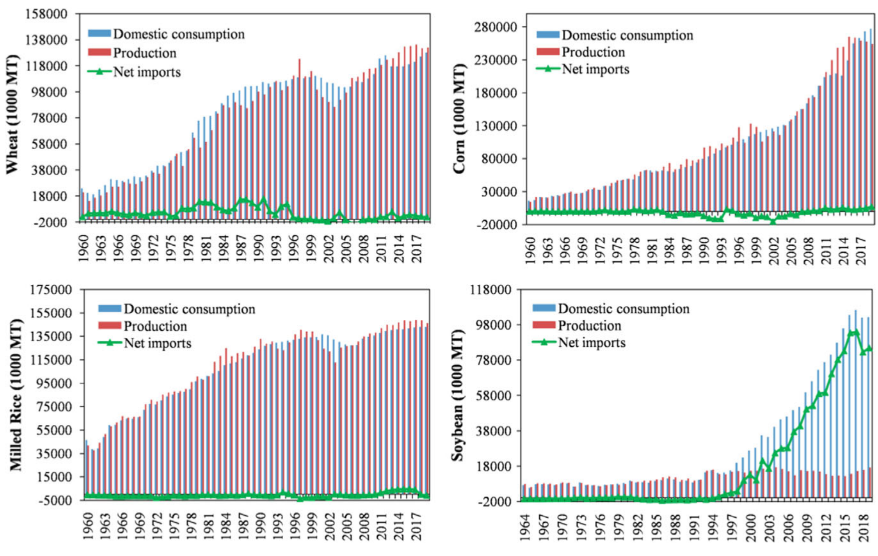

Fig. 11.5 China's wheat, corn, rice and soybean production, domestic consumption and net imports

The increase in cereal production, however, heavily relies on massive inputs of water and fertilizer, leading to severe water pollution and shortages. According to Zhou et al. (2016), annual water consumption for the production of wheat, corn, and rice reached 148 km^3, 204 km^3, and 197 km^3, respectively, in the 2010s compared to 65 km^3, 36 km^3, and 117 km^3, respectively, in the 1960s. Additionally, the blue water related to wheat, corn, and rice accounts for 27%, 8%, and 29% of the total water footprint, respectively.

At the same time, the per capita consumption of animal products (meat, eggs, and milk) has rapidly increased, as has total consumption (Fig. 11.6). The annual consumption of pork and beef increased ~7 times and 24 times from the 1970s to the 2010s, while that of chicken meat increased ~1.5 times from the 2000s to the 2010s. The small amount of overseas imports and even the export of animal products prove that most of the meat products consumed in China come from the domestic market.

Soybeans are used to provide animal feed or protein sources for animals because soybeans are easily available year-round and inexpensive (Dei 2011). Globally, approximately 98% of soybeans are used as animal feed, and only 2% are used directly for human consumption. Figure 11.5 also shows that the need for soybeans as animal feed soared after China joined the World Trade Organization. As a result, China has become the largest soybean consumer and importer in the world. In 2009, China imported over 50% of all soybeans exported globally (Brown-Lima et al. 2010). According to the estimation of Taherzadeh and Caro (2019), by importing soybeans, China imported 2233 km^3 of virtual water in the 1995–2019 period, for an average of 89 km^3 per year, which is more than the annual runoff of the Yellow River.

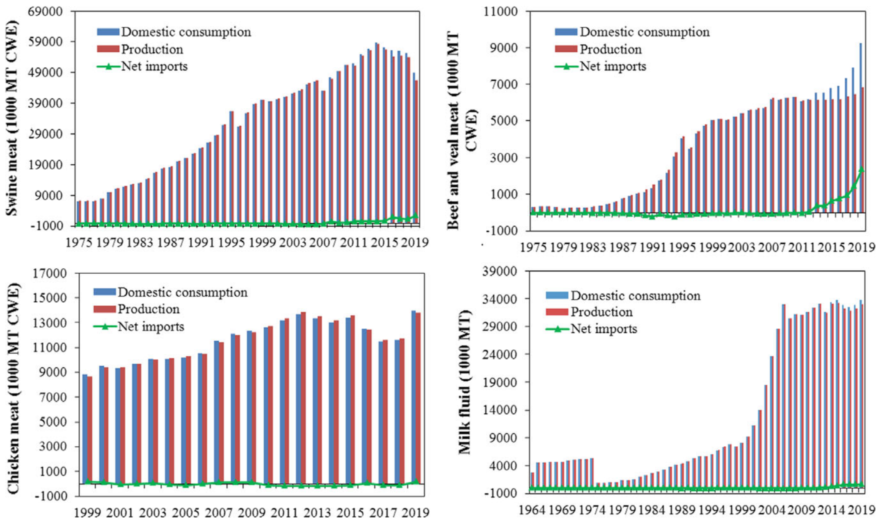

Fig. 11.6 China's production, domestic consumption and net imports of swine meat, beef and veal meat, chicken meat, and milk

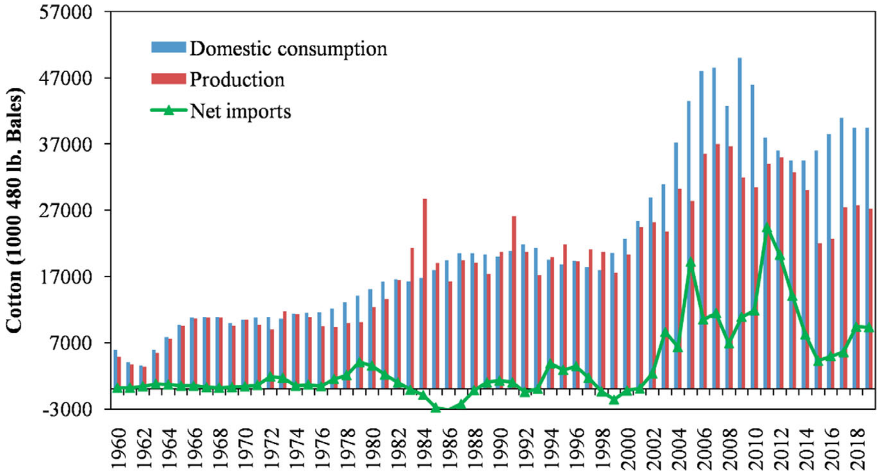

Fig. 11.7 China's cotton production, domestic consumption and net imports (*Source* China Statical Yearbook 2018) adapted by the author

Aside from major crops, China ranks as the largest cotton producer, consumer, and importer globally owing to its textile and clothing industry, which is the largest worldwide (Fig. 11.7). In 2010, more than half of the of textile products consumed worldwide were produced in China (MacDonald et al. 2015). The production of seed cotton, which is a water-intensive crop, reached its peak of 37 million 480 lb bales in 2007, corresponding to ~16 km^3 of water, 5 times higher than the water consumption in the 1960s (Chapagain et al. 2005). Subsequently, seed cotton production slowly decreased to 70% of the peak, as did the imported amount. From 2000 to 2019, China imported 83 km^3 of water through the international trade in cotton (Chapagain et al. 2005).

In recent decades, China's agricultural water consumption has rapidly increased due to population growth and changes in diet composition. Currently, the growth rate of agricultural water consumption has slowed because of the slowdown in population growth and the application of water-saving technologies. In the future, China's agricultural water consumption is expected to decrease to alleviate China's water stresses, although the challenge for food security is obvious.

11.2.3 Energy Production and Consumption

With the world's largest population and a fast-growing economy, China gradually became the top-ranked energy producer and consumer around the world in the twentieth century (EIA 2015). By the 2010s, its energy production and consumption increased by 3 times and 4 times, respectively, from the beginning of the 1980s

(Fig. 11.8). Coal has provided the majority of China's energy consumption, followed by oil, nuclear and renewable energy, and natural gas (Fig. 11.9).

Even though the share of coal in energy consumption decreased from ~75% in the 1990s to 60% in 2018, coal was still the most dominant fuel in China (Fig. 11.9). Since China's reform and opening up in 1978, coal consumption has increased from

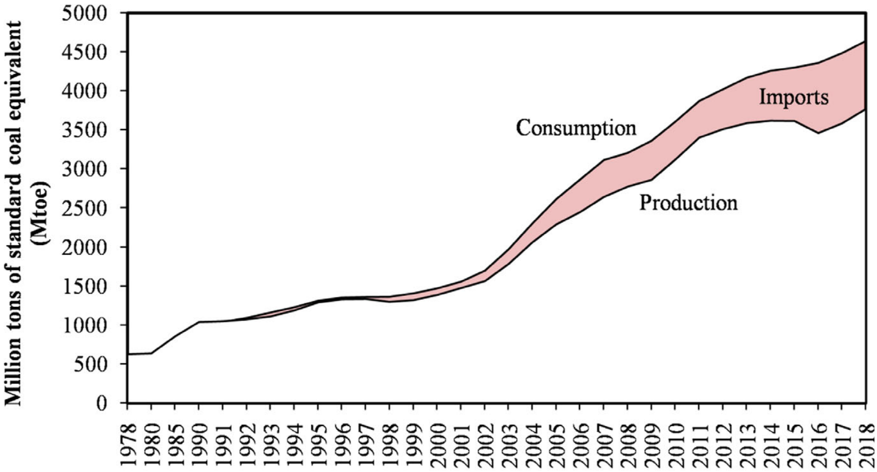

Fig. 11.8 China's energy production and consumption (*Source* China Statical Yearbook 2018) adapted by the author

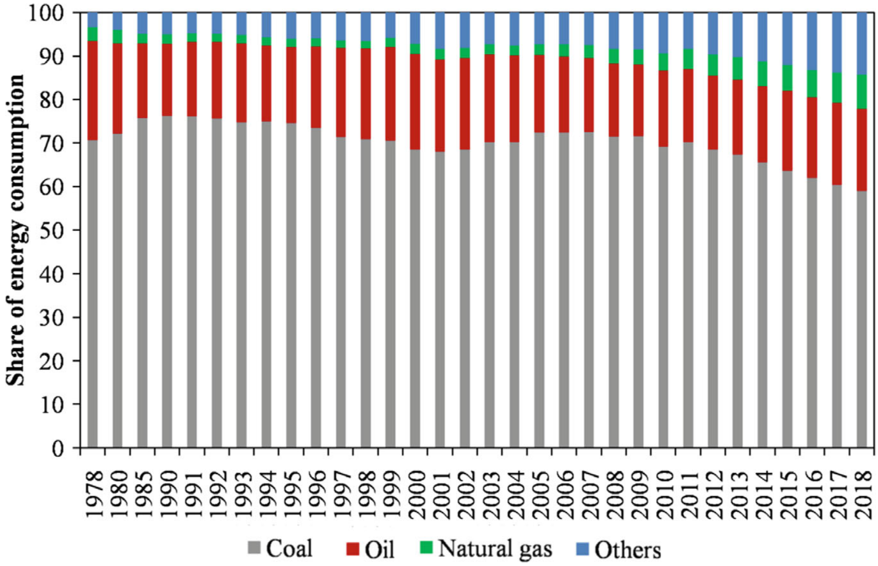

Fig. 11.9 Shares of China energy consumption since 1978

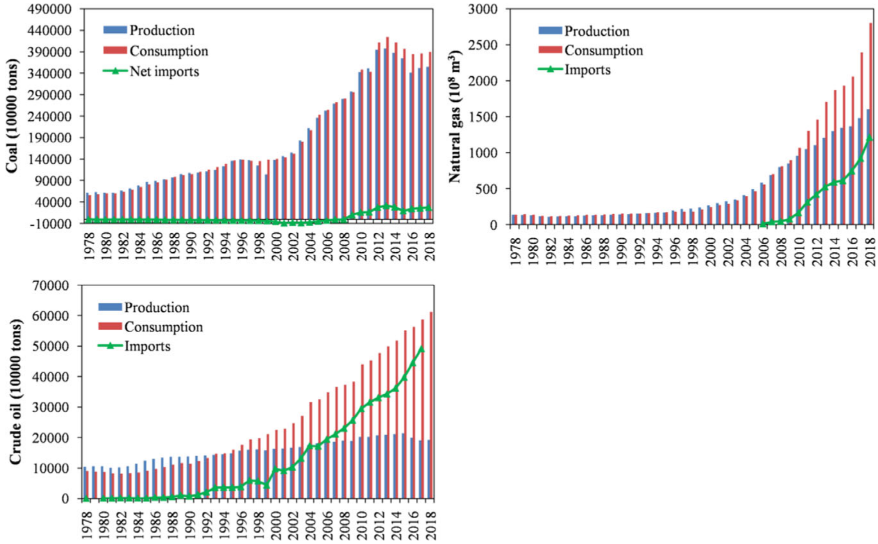

Fig. 11.10 China's production, consumption and net imports of coal, crude oil, and natural gas since 1978 (*Source* National Statistical Bureau 2019b) adapted by the author

585 million tons in 1978 to its peak of 4244 million tons in 2013, with the highest growth rate occurring during the 2002–2012 period (Fig. 11.10). Along with China's policy for controlling air pollution, coal consumption has gradually started to fall. Historically, China was a net coal exporter until 2004. However, since 2009, China has become a net importer of coal (Lam 2005).

Crude oil is one of the most important energy sources for supporting the economy. Since the reform and opening up, China's oil consumption has increased from 90 million tons in 1978 to 613 million tons in 2018 (Fig. 11.10). Because China is not rich in oil resources and the production of crude oil has not kept up with its domestic consumption during the same period, China heavily relies on oil imports, with over 80% of the oil that China consumes coming from overseas. In 1993, China became a net importer of crude oil, and since 2017, it has been the largest oil importer (Dong et al. 2017).

Although China is rich in natural gas, for a long time, natural gas has accounted for only 2% of its domestic energy consumption (Fig. 11.10). Seeking cleaner energy, China has increased the share of gas consumption since 2006. In 2018, the share of gas consumption reached 7.8%, and it is predicted to reach 15% of its total energy consumption in 2035 (Gao and Tian 2019). Meanwhile, the increase in natural gas production has been much slower than the increase in natural gas consumption. As a result, China started to import natural gas in 2006, and it has become the second largest buyer in the world (Fig. 11.10). Similarly, to decrease CO_2 emissions, the share of renewable energy and nuclear energy rapidly rose from 8.5% in 2006 to 18% in 2018.

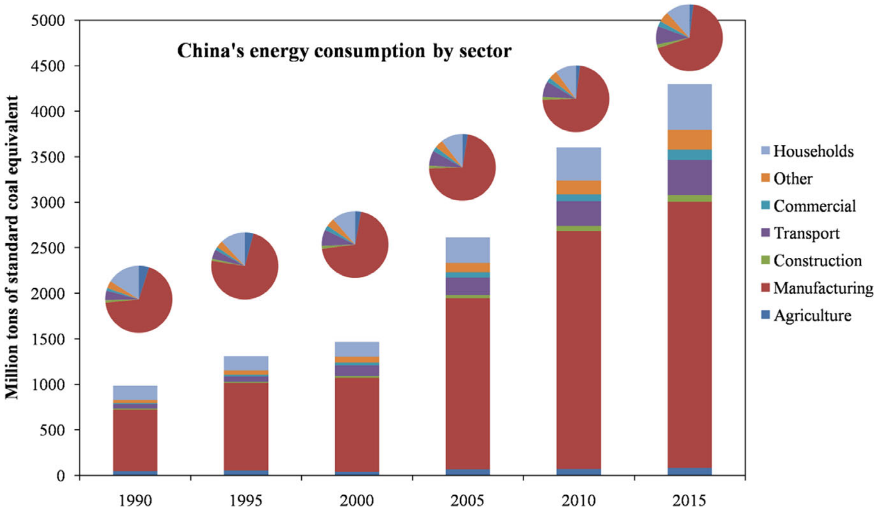

Fig. 11.11 China's energy consumption share by sector from 1990 to 2015 (*Source* National Statistical Bureau 2019b) adapted by the author

Figure 11.11 shows China's gross energy consumption structure in recent decades. Manufacturing is the largest energy consumption sector, consuming 70% of all energy, and it also largely meets the demand of the global market for Chinese-made products. The household sector ranked second and consumed 16% of all energy in 1990 and 11% during the 1995–2015 period. Transport is the third largest energy consumer, and its share gradually increased from 5% in 1990 to 9% in 2015. The share of other sectors has long held steady at 10% from 1990 to 2015. In general, energy for agriculture or food production was low, at 4.9% in 1990 and then only 1.9% in 2017.

During the same period, the energy structure in different sectors notably changed (Fig. 11.12). In 1990, 77% of coal, the primary energy provider, was used in manufacturing, and then, in 2015, the proportion increased to 95%. In contrast, households consumed 16% of all coal in 1990, and that proportion fell to only 2% in 2015, suggesting a quick change towards a clean society. In 1990, most oil (64%) was used in manufacturing, followed by the transport and agriculture sectors. In contrast, in 2015, transportation became the largest oil consumer (37%), suggesting a rapid increase in cars and vehicles for the transportation of goods in China.

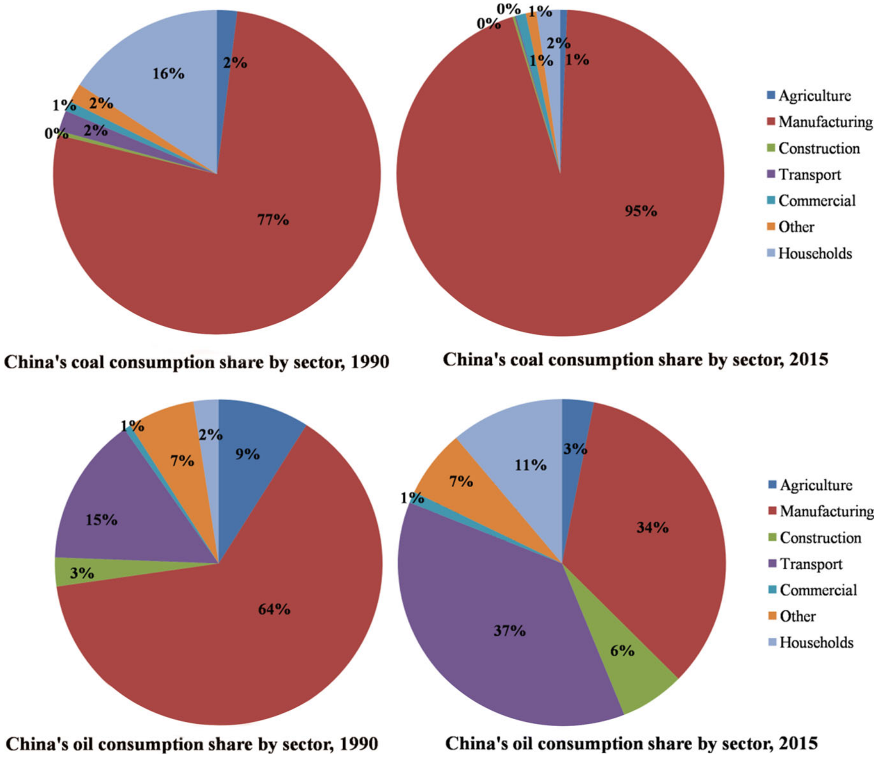

Fig. 11.12 Coal and oil consumption structure in 1990 and 2015

11.3 Water, Energy, and Food in China Through International Trade

11.3.1 China's Food Supply Through Transboundary Trade

Since 1986, China has remained the largest food producer in the world. In 2019, based on China's 117 million ha of cultivated land, its grain production reached 658 million tons, accounting for 24.4% of the global total. In the same year, China's population reached 1.4 billion, accounting for 18.1% of the world population. Thus, food per capita from China's own production reached 470 kg from approximately 324 kg in 1980 and 364 kg in 2000. Economic growth also stimulated Chinese food consumption. To meet its demand for edible oil and animal protein, in 2017, before the trade war between the US and China, soybean imports reached their highest level of 95.5 million tons.

In terms of China's soybean supply, the top three countries are the US, Brazil, and Argentina, accounting for over 90% of all imports. In 2017, 96.6% of imported soybeans came from Brazil (56%), the United States (34%), and Argentina (6.6%) Table 11.1. Table 11.1 also shows the source countries of China's cereal imports. Due

Table 11.1 China's top cereal import countries and their shares in 2017

Cereal	Country	Share
Wheat	US	45%
	Australia	35%
	Canada	14%
Corn	Ukraine	39%
	Burma	36%
	US	19%
Rice	Vietnam	56%
	Thailand	30%
	Cambodia	5.50%
Soybean	Brazil	56%
	US	34%
	Argentina	6.60%

Source Simoes and Hidalgo (2011) adapted by the author

to the national policy for food security, cereal imports, including 4.29 million tons of wheat, 2.83 million tons of corn, and 4.03 million tons of rice, accounted for only 1.7% of China's own cereal production in 2017. Nearly 94% of wheat comes from the United States (45%), Australia (35%), and Canada (14%). Ninety-four percent of corn imports are from Ukraine (39%), Burma (36%), and the United States (19%), while 91.5% of rice comes from China's neighbouring countries, such as Vietnam (56%), Thailand (30%), and Cambodia (5.5%).

11.3.2 China's Energy Suppliers

In 2017, China's energy consumption was equivalent to 4.36 billion tons of coal, of which coal, crude oil, and gas accounted for 60.4%, 18.8%, and 6.4%, respectively (National Information Center of Coal Chemical Industry 2018). A total of 92.9% of China's coal consumption relies on national production, whereas its consumption of natural gas and crude oil is highly reliant on international trade. Unlike food, both crude oil and gas imports show very diverse sources (see Figs. 11.3, 11.14 and 11.15). Taking 2017 as an example, China imported over 420 million tons of crude oil, accounting for 69.5% of its total consumption. Russia accounts for the largest share of China's oil imports (14%), followed by Saudi Arabia (13%), Iraq (8.6%), Oman (7.7%), Iran (7.5%), Brazil (5.1%), and so on (see Fig. 11.13).

In 2017, 39.4% of China's gas consumption relied on imports. Figure 11.14 shows the major suppliers of natural gas. The top ten countries are Turkmenistan (19%), Australia (19%), Qatar (14%), the UAE (9.7%), the US (7.2%), Burma (6.8%), Malaysia (4.5%), Indonesia (3.6%), Papua New Guinea (2.7%), and Uzbekistan (1.8%).

Even though only 7.1% of coal consumption is accounted for by international trade, Fig. 11.15 shows China's major partners for coal imports, including Australia

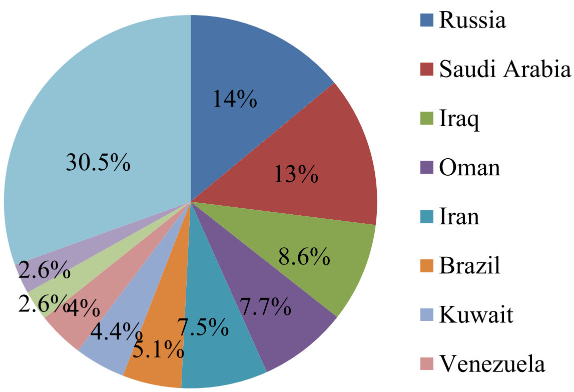

Fig. 11.13 China's top crude oil import countries and their shares in 2017

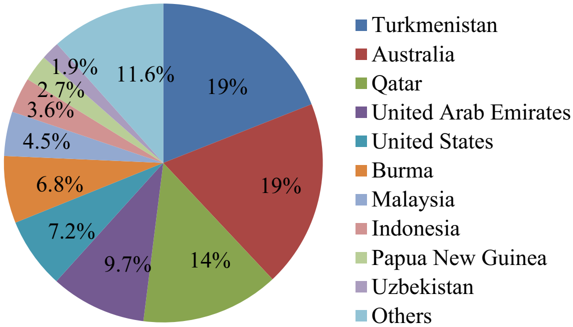

Fig. 11.14 China's top natural gas import countries and their shares in 2017

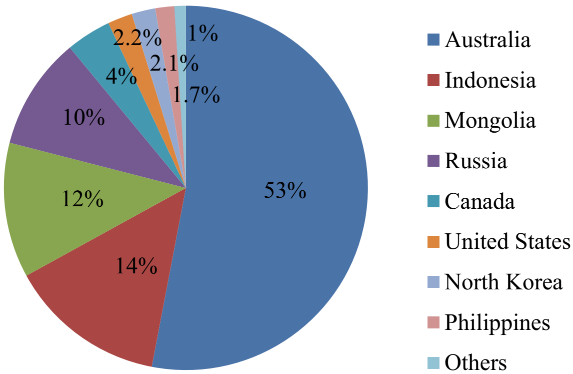

Fig. 11.15 China's top coal supplying countries and their shares in 2017

(53%), Indonesia (14%), Mongolia (12%), Russia (10%), Canada (4%), the United States (2.2%), North Korea (2.1%), and the Philippines (1.7%).

11.3.3 Water or Virtual Water Supply Through Transboundary Trade

Because of China's geological conditions, most of China's rivers flow from west to east and end up at the Pacific Ocean. As discussed earlier, water shortages mainly exist in the northern part, and agriculture is the major driver of water shortages. To solve such problems, China has already constructed many water transfer projects within the country, especially from the water-rich Yangtze River catchment in the south to the water-limited Huai River, Yellow River, and Hai River catchments in the north, and to the so-called three water diversion canals across four mega catchments or mega rivers. Among them, the already finished middle and east routes of the South to North Water Diversion Canals are mostly well known. Each route can potentially transfer nearly 9.5 km^3 of water from the Yangtze River to the North China Plain, especially the Beijing-Tianjin-Hebei area. To date, the middle route has already transferred 29 km^3 of water from the Yangtze River to the 4 northern provinces (Yu 2020). By 2030, both routes are expected to reach a capacity of 15 km^3 of water annually. The west route is also under planning and is expected to transfer 17 km^3 of water to the Yellow River or relevant rivers.

Aside from long-distance water transfer within the country, the virtual water flow through the food trade is regarded as an efficient way to save water. Dalin et al. (2012) showed that China has replaced Japan and become the world's largest beneficiary of virtual water inflow through the food trade, accounting for 13% of global virtual water imports in 2007. According to Dalin et al. (2012), China's virtual water imports in 2007 reached 70 km^3, of which soybean imports accounted for 90% of the virtual water inflow. According to a recent estimation by Wang and Hu (2018), during the 2001–2015 period, China imported 1414.7 km^3 or 94.3 $km^3\ y^{-1}$ of virtual water through its international food trade, especially the soybean trade. Using the food trade to save water resources could still be an effective way to save China's limited water and land resources in the long term, although China's food security at the national level will definitely not be shaken.

11.4 Discussion

11.4.1 China's Future Challenges for Energy and Demand from International Trade

Since the 1990s, with 18.5% of the world population in 2020, China has become a major consumer of food and energy in the global market. As the economy is growing at an annual rate of over 6% at the present level and there are an increasing number of people no longer living in poverty, further demand for external food and energy is likely to occur. China's water, energy, and food security is heavily driven by the economy, population growth, environmental measures, and governmental policy.

For instance, according to a report by BP (BP 2014), as the largest source of energy demand at present, China's energy consumption will continue to increase. According to the prediction, China's energy consumption will increase by 60% until 2035, even though China's internal energy production will likely increase by 46%. China's energy demand from the international energy supply will increase from 15% in 2014 to 23% in 2035, accounting for 26% of the global market, up from 24% in 2014. While for coal the percentage will decrease from 68% in 2014 to 51%, for crude oil and renewable energy the percentage will increase to reduce CO_2 emissions.

In 2014, China announced a reduction in the share of traditional fossil fuel and an increase in the share of renewable energy in the energy supply in the future at the APEC summit. In 2020, Chinese President Xi announced at the 75th Session of the UN General Assembly that China would reach peak in carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060. To achieve such targets, as government actions, China is making various efforts to adjust its economic structure, to upgrade its industry, to optimize its energy structure, and to establish a green low-carbon society. By 2030, China will increase the non-fossil fuel share in all energy to approximately 20% (Yang et al. 2016). The newly released *China renewable energy outlook 2019* set a goal where non-fossil energy will account for 42% by 2035 and 65% by 2050. In the long term, Wang and Sandholt (2019) show that China's demand for fossil fuels will gradually decline, driven by slower economic development, stagnant population growth, and efforts for cleaner energy by 2050.

11.4.2 China's Future Challenges for Food and Demand from the International Market

China's food problem has been one of the greatest concerns of the Chinese government. Through heavy investment in irrigation, newly transformed land, and the development of high standard land, food production growth has been tremendous. For instance, Cui and Shoemaker (2018) showed that total grain output increased 74% from 354 million tons in 1982 to 618 million tons in 2017, surpassing the growth in China's population by approximately 34%. They concluded that China will continue to increase its food production in the foreseeable future. The Chinese government is confident in its national food security.

On the other hand, there have been worries about food shortages in China. For instance, Brown (1995) estimated that due to an increasing demand of urbanization for land, limited water resources, and in increasing population, China will need outside support for food. In 2030, China will need to obtain 200 to 369 million tons of food from the world market. Even though the early warning by Brown (1995) is too pessimistic, China's demand for food calories is probably close to its peak level. The ongoing dietary shift from high-calorie food to animal-based foods, induced by

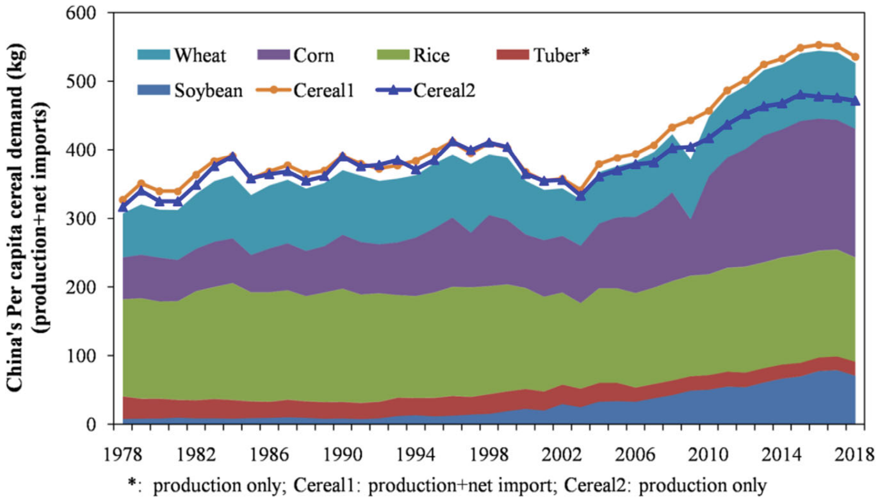

Fig. 11.16 China's per capita cereal demand from 1978 to 2018 (*Source* National Statistical Bureau 2019a; China Statical Yearbook; United States Department of Agriculture) adapted by the author

income growth, is likely to impose considerable pressure on the food supply (Fukase and Martin 2016).

Statistical data show that since China joined the World Trade Organization, China's food balance has changed from being a net exporting country to being a net importing country. Figure 11.16 shows the change in China's total food consumption per capita, including wheat, maize, rice, soybeans, and tubers, such as sweet potatoes and potatoes. It is suggested that with a large amount of soybean imports for meat, milk and eggs or for better food quality, China's food per capita has reached over 500 kg/a. per capita, which is much higher than the national food redline of 400 kg/a. per capita.

According to the China Food White Book 2019 (China State Council 2019a), as a national policy, China is making various efforts to secure its 95% self-sufficiency in grain production. While the supply of high-calorie food such as wheat, rice, corn, and potatoes is likely to be secured from China's own production, the demand for soybeans, as shown in Fig. 11.7, has increased over the last two years although the trade conflicts between China and the US. In the long term, China's demand for food from the international market will depend greatly on the population and the improvement in food nutrition. From a population perspective, according to the China population and labour green book (Zhang 2019), China's population will reach its peak of 1.45 billion, which is only slightly higher than the present level, in 2029 and then start to decline. Meanwhile, it is expected that in 2030, more than 1 billion people will live in cities driven by urbanization or a better life.

From the land perspective, cultivated land is a very valuable but a limited resource. The Chinese government has been making all efforts possible to expand and protect its cultivated land to be over 1.8 billion mu or 150 million ha. Even though urbanization is forcing more fertile land in highly productive regions to be replaced by poorly fertile land, China is planning to increase its high standard agricultural land area from 53 million ha to 67 million ha in 2022 and to an even higher level in 2035 by increasing irrigation guarantees, traffic facilities for machinery support and so on. (China State Council 2019b).

In summary, considering the present increase of China's food production, national policy, and efforts for the security of high-calorie food, as well as the fact that land expansion is difficult and the per unit area yield of soybeans is relatively low compared to other crops (less than 1/3 of wheat, 1/4 of rice, and 1/5 of corn), more soybean or meat products might be required for better food nutrition in China. Alternatively, the Chinese government may like to educate the country's people to adopt a healthy diet involving less meat to decrease the number of obese people in the long term.

11.4.3 China's Future Challenges for Water

China is facing increasingly severe water scarcity, to a large extent caused by the uneven spatial and temporal distribution of rainfall. In general, given its huge investment capability, continuous institutional reform, and strong political water management, China has the ability to achieve water security in the long run (Jiang 2015).

Globally, in 2005, irrigation consumed 60% of all water, while the energy sector consumed 25% of all water (Elcock 2008). China's race for freshwater is less intense because the agricultural sector consumed 60% of all water but the energy sector consumed only 12% of all water in 2010 (Qin et al. 2015). However, the distribution of energy resources is rich in the north, which is exactly the opposite of the distribution of water resources. Among energy sectors, fossil fuel consumes the largest amount of water, 52%, for extraction, followed by 42% for electricity generation (Spang et al. 2014). In 2013, over 70% of coal was mined in three provinces in northern China: Shanxi, Inner Mongolia, and Shaanxi (Wang 2001). Similarly, approximately 80% of crude oil and natural gas production is located in the northeast and north central regions of China (EIA 2015). Thus, the competition for water between energy and food is strong in water-limited regions. Even though the energy sector is always the top priority in terms of water consumption, food is very important. Therefore, how to solve problems related to water is a national challenge.

While it is certain that engineering measures such as long-distance water transfers, the construction of reservoirs, and water-saving measurements will be further taken to alleviate shortages of water for irrigation and domestic and industrial use, a more holistic approach, including ET management or ecosystem management, water markets and prices, water rights and so on, is necessary to reduce water insecurity and to develop a water-suitable socio-economic society. For instance, China has an ambitious plan for green walls or shelter forests in North, Northeast, and Northwest China, although the effect of green cover development on natural climate restoration is still questionable and challenging. Similarly, natural river restoration projects and the growing need for urban landscapes indicate increasing environmental water consumption and competition for water between the environmental sector and other sectors. Qin et al. (2015) analysed water consumption for all energy processes and assessed future water use changes considering potential future policy and technological changes. They found that nuclear power plants will increase freshwater demand, exacerbating inland water stress. Ren et al. (2018) analysed the water-land-food nexus in one of China's food basket regions (Beijing-Tianjin-Hebei) using a nexus framework and found that most virtual water in the water-limited region has been transferred to the south, where water is rich. How more food production can be shifted to the south, even though farmers in the under-developed region have more incentives for food production, will be challenging.

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Chapter 12
Water and Gender: Putting Women at the Centre of the Water-Energy-Food Nexus

Kuanyi Shen

Abstract Women play a central part in the provision, management, and safeguarding of water; however, in East and Southeast Asia, they face inequality in three major ways. That is, they disproportionately suffer from a lack of water and sanitation, have unequal access to land rights and water for productive use, and finally, they have low representation in water governance and management. This negatively influences the safe, productive, and healthy lives of women and girls. To solve these problems, this paper gives three recommendations. First, governments and private sectors should invest in infrastructure—water, sanitation, energy, and transport—to reduce the amount of time that women spend collecting water, reduce violence, and improve their well-being. Second, policies and laws should be developed to promote women's equal rights to land ownership and water access. Third, governments should enable women's meaningful and substantive participation in water management through capacity development and access to information, knowledge, and technology.

Keywords Water · Gender inequality · Women empowerment

12.1 Introduction

The water-energy-food nexus is interconnected with gender. Women are the primary collectors, transporters, users, and managers of domestic water and promoters of home and community-based sanitation activities. They have rich water management knowledge and are always the first to sense changes in the status of water. If the potential of women is neglected and they are discriminated against, the world will lose half of its power to promote healthy human relationships with water. Furthermore, economic output will face huge losses. A McKinsey Global Institute report finds that

K. Shen (✉)
School of International and Public Affairs, Columbia University, 420 W 118th St #1410, New York, NY, USA
e-mail: kuanyi.shen@columbia.edu

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$12 trillion could be added to global GDP by 2025 by advancing women's equality (McKinsey Global Institute 2015).

The water-gender issue has received considerable international policy attention. In 1992, the Dublin principles, endorsed at the International Conference on Water and the Environment, recognized that "Women play a central part in the provision, management and safeguarding of water" (ICWE 1992). In the Johannesburg Plan of Implementation of the 2002 World Summit on Sustainable Development (para 24), governments agreed to "…support capacity-building for water and sanitation infrastructure and services development, ensuring that such infrastructure and services …are gender-sensitive" (UNCED 2002). The International Decade for Action, 'Water for Life' (2005–2015), calls for women's participation and involvement in water-related development efforts (UNGA 2003).

These principles advocate that both women and men need to understand and take real action in terms of legislation, policies, and programme implementation in all areas and at all levels of water management. However, the reality is that gender inequality in water is demonstrated in many respects. There exists a real demand for building capacity in gender mainstreaming into water policies and projects to achieve SDG 5 (achieving gender equality and empowering all women and girls) and SDG 6 (ensuring the availability and sustainable management of water and sanitation for all).

12.2 Gender Inequality in Water

12.2.1 Gender Inequality in Access to Water Supply and Sanitation

Water security has emerged as a gendered phenomenon. Seventy percent of the world's poorest people, with no access to clean water or sanitation, are women and girls (Andajani-Sutjahjo et al. 2015). Currently, 38% of health-care facilities in low- and middle-income countries have no access to safe water (WHO and UNICEF 2015). In East and Southeast Asian countries with available data, less than 40% of schools in Indonesia, Cambodia, and the Philippines have improved sanitation facilities (UNICEF 2019).

Without safe drinking water, adequate sanitation, and hygiene facilities at home and in places of work and education, it is disproportionately harder for women and girls to lead safe, productive, healthy lives. There are three main reasons.

First, women and girls are the major water collectors in eight out of ten households with water off premises (WHO and UNICEF 2017). It is estimated that women in many developing countries walk for an average of approximately six kilometres each day to collect water (UNFPA 2002).

The situation in East and Southeast Asia is similar. In Myanmar and Lao PDR, the share of girls and women who are responsible for collecting water is two to six times greater than the share of boys or men. Mongolia, where boys and men have a greater responsibility for collecting water for the home, is an exception.

The imbalanced responsibility for water collection often means that women must travel long distances and carry heavy loads, in some cases with a high risk of violence. The time required can pull girls out of school and leave women with fewer options to earn an income. Thus, reducing the population with limited water services will have a strong gender impact.

Second, women and girls are more vulnerable to humiliation, harassment, and even assault while walking to and using a toilet or open defecation site. In many schools in East and Southeast Asia, including in Cambodia, Indonesia, Mongolia, and the Philippines, girls report not using latrines, as they are dirty, are not gender-segregated and/or offer insufficient privacy (Sommer et al. 2016). These experiences can negatively influence girls' confidence, self-esteem, and relationships with others.

Third, women bear a greater health care burden in families and have specific hygiene needs during menstruation, pregnancy, and child rearing. When a lack of water and sanitation results in household members falling ill, women assume more of the burden of care and face additional health threats such as trachoma, which is associated with poor hygiene and can cause blindness. During childbirth, clean water and sanitation can mean the difference between life and death for both mothers and babies. Approximately 44 million pregnant women have sanitation-related hookworm infections that pose a considerable health burden in developing societies (UNICEF 2021).

12.2.2 Gender Inequality in Access to Land Rights and Water for Productive Use

Women hold title to less than 2% of the world's private land (Deda and Rubian 2004). In East and Southeast Asian countries with available data, Bangladesh has the highest gender gap, with only 4.6% of women owning land. Even in Thailand, which has the smallest gender gap, women hold only 27.4% of all agricultural land (FAO 2021; ITU 2021) (see Fig. 12.1).

As a result of their limited access to land, women's access to irrigation water for agricultural purposes hangs in the balance. This further decreases their financial independence and bargaining power with males. In Vietnam, women face challenges accessing finance if land is registered only in their husband's name rather than jointly (Hampel-Milagrosa et al. 2010).

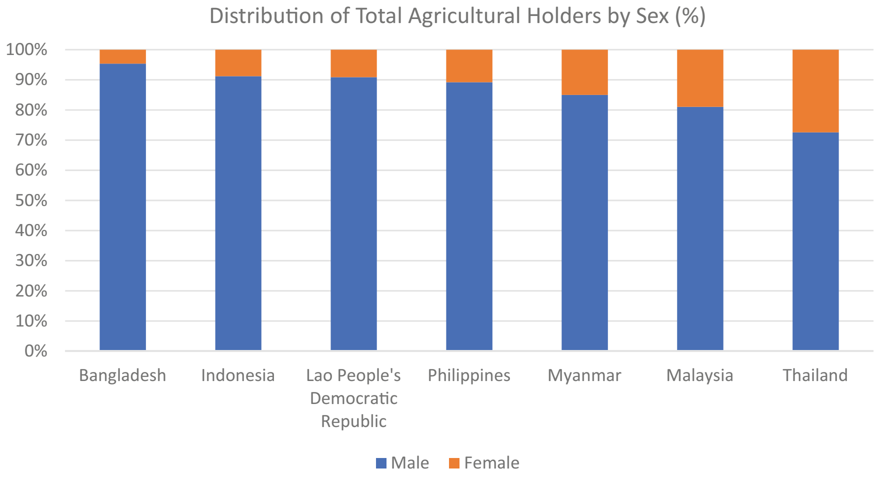

Fig. 12.1 Distribution of total agricultural holders by gender (%) (*Source* FAO 2021; ITU 2021) adapted by the author

12.2.3 Gender Inequality in Public Participation and Decision-Making

Gender discrimination and exclusion exist at all levels of water and sanitation policies, strategies, and programmes. Women are perceived as being less competent, having no technical skills, and being inferior leaders in water governance. Thus, they are rarely adequately represented in ministries responsible for decision-making regarding water resources. The predominance of male engineers, experts, and technocrats further imbalances gender inequalities in accessing public water and services (Ongsakul et al. 2012).

A study of female water professionals revealed that in South Asia, the percentage of technical posts held by women was only 5% and that almost all women interviewed felt that their skills were highly under-utilized (SaciWaters 2009). The gender distribution of participants at international water symposia and conferences shows a marked discrepancy between the number of female and male participants. Only 10 women out of 115 persons attended the Consultative Group meeting of the Global Water Partnership (GWP). The World Water Council has 32 board members, of whom only 3 are women; the International Water Quality Association has no women on the board. These statistics are representative of the gender breakdown of decision-makers in most leading organizations in the 'water world' (Rathgeber 2003). According to a UN report, fewer than half of the countries with data have laws or policies that specifically mention women's participation in rural sanitation or water resource management (UN-Water 2021).

Women seldom join Water User Associations (WUAs) despite policy statements favouring their active membership. (IFAD 2012) This may be because women have fewer opportunities to speak to the public and limited opportunities to access various international communities, as well as the male-dominated atmosphere. Many social norms advocate that public leadership roles are more suitable for men and prevent women from taking up any public role.

Leaving women out of design of projects may result in inadvertently increasing the burden on women. For example, in east Nepal, the tap-stands and tube-wells of improved water services "are located along the roadside where women cannot bathe freely and wash their clothes comfortably for fear of being seen by men. In order to avoid this, women in Hiel village in east Nepal carry water all the way to their homes several times each day, spending significant amounts of time and energy to do this. In three villages women reported waiting until dark to undertake these activities. All these women complained that the surveyors had not involved them in designing the tap-stands or tube-wells" (Regmi and Fawcett 1999).

12.3 Recommendations

12.3.1 Invest in Infrastructure—Water, Sanitation, Energy, and Transport

Fontana and Natali (2008) find that women disproportionately benefit from infrastructure investments. Investments in water and sanitation, transportation, and energy can reduce women's unpaid care burden and increase child health outcomes, giving women more time to engage in paid labour or education (Revenga and Dooley 2020). An example in the Lao PDR indicates that electrification introduced electric water pumps and rice mills, which contributed to reducing women's housework (Korkeakoski 2009). The evidence from the Asian Development Bank points to significant time savings for women and girls when there is improved water supply access (ADB 2015).

Women's needs should be taken into consideration when designing infrastructure. The location of latrines close to the home can reduce violence against women, which may occur when women have to relieve themselves in the open after nightfall. For women's hygiene needs, particular concerns include ensuring privacy and security. In Bangladesh, a school sanitation project with separate facilities for boys and girls helped boost girls' school attendance an average of 11% per year from 1992 to 1999 (Brewster et al. 2006).

12.3.2 Policy Interventions to Close the Gender Gap in Agriculture

Closing the gender gap in agriculture would generate significant gains for the agricultural sector and for society. If women had the same access to productive resources, such as water, as men, they could increase the yields of their farms by 20–30%. This could raise total agricultural output in developing countries by 2.5–4% which in turn could reduce the number of hungry people in the world by 12–17% (Quisumbing et al. 2014).

Policy interventions can also help close the gender gap in agriculture and rural labour markets. Priority areas for reform include eliminating discrimination against women in access to agricultural resources, education, extension, financial services, and labour markets. The laws or customary practices of 102 countries still deny women the same rights to access land as men (OECD 2014). Thus, legislation that can promote inclusive resource ownership needs to be addressed.

12.3.3 Enable the Meaningful and Substantive Participation of Women Through Capacity Development and Access to Information, Knowledge, and Technology

A study of community water and sanitation projects in 88 communities in 15 countries conducted by the International Water and Sanitation Centre (IRC) found that projects that are designed and run with the full participation of women are more sustainable and effective than those that are not. This supports an earlier World Bank study that found that women's participation was strongly associated with water and sanitation project effectiveness (Wijk-Sijbesma 1998).

There is increasing evidence of the ways in which water, sanitation, and hygiene (WASH) offer a strategic entry point to empower women and girls and to increase gender equality (Willetts et al. 2010). Since WASH issues are closely associated with women's traditional roles, WASH programmes and policies can provide fertile ground to promote women's voices, participation, and leadership and, at the same time, shift the attitudes of men and society (Carrard et al. 2013). In Bangladesh, a WASH programme deliberately went beyond the standard aspiration of having at least 50% of WASH management committee roles filled by women: the findings from a review of this programme showed increases in women's skills, confidence in leadership roles, and capacity to advocate on their own behalf with decision-makers (Wilbur and Huggett 2015).

Notably, gender equality is about more than just numbers; it is about 'meaningful' participation. This includes training, financial support, long-term engagement, and working in partnership with organizations such as women's, Indigenous peoples', and disabled peoples' organizations. In many countries, gender representation is still about how many women are involved in processes, with less attention to what happens because of these processes and the ability of both women and men to make their voices heard and to influence processes. Gender equality is demonstrated not only through the number of women in various positions. More attention should be paid to impacts or outcomes.

To empower women to increase their access to information, knowledge, and technology, stronger linkages between gender and water governance disciplines in research and teaching in regional and national universities should be supported. Some universities in the Mekong region have adopted policies to admit more female students into science, technology, engineering, and mathematics (STEM) programmes, including fields such as water engineering (IUCN and Oxfam 2018). Gender issues should also be integrated in interdisciplinary research and teaching (e.g., Can Tho University, Vietnam) or have a separate subject, such as at the National University of Laos and AIT, under IWRM and sustainable hydropower development courses (IUCN and Oxfam 2017).

Other critical actions include engaging gender experts in all stages of a programme's development, supporting women's leadership development through capacity building and ensuring quotas for women in local and national policy-making bodies and governance mechanisms, as well as engagement and collaboration with women's organizations.

12.4 Summary and Conclusions

Even before the COVID-19 pandemic struck, the world was off track to meet Sustainable Development Goal 6—the goal of ensuring water and sanitation for all by 2030. Furthermore, women and girls disproportionately suffer from problems associated with water.

Without safe drinking water, adequate sanitation, and hygiene facilities at home and in places of work and education, women must spend more time collecting water, take a higher risk of being abused and attacked, and suffer as a result of their specific hygiene needs during menstruation, pregnancy, and child rearing.

Women hold title to less than 2% of the world's private land. This means that they face more difficulties in accessing water for productive use, which can make them more financially dependent on their husbands.

Gender discrimination and exclusion exist at all levels of water and sanitation policies, strategies, and programmes. Fewer women than men become engineers, experts, and technocrats in the field of water management. All these inequalities further worsen women's participation in water management and governance, which places women in a more disadvantaged position if their needs are not considered by male leaders.

12.4.1 *What Does Success in the Water-Gender Issue Look Like?*

Women and children will no longer bear the burden of carrying heavy water from far away. Women will no longer be raped or suffer sexual harassment as they travel to the toilet outside of their home. There will be fewer babies dying as a result of mothers giving birth in unhygienic environments. Every girl and woman will have access to appropriate information about sexual and reproductive health and rights and appropriate menstrual hygiene management products and services.

Women will have access to land, water rights, and finance at the same level as men. Women, particularly in developing contexts, will take up more places in the fields of engineering, government, law, and science to support their engagement in the water and sanitation governance sectors. All global forums dedicated to water resource management and WASH will be socially inclusive and provide platforms for women and gender-discriminated people to provide input and influence. Women and gender-discriminated people will hold positions of leadership and power in water—and sanitation-focused organizations.

To achieve those positive changes, three recommendations are given. First, more infrastructure should be built to provide accessible clean water and hygiene facilities, with women's needs taken into consideration when designing the infrastructure. Second, new policies and laws should be developed that eliminate gender discrimination and recognize that women's rights are equal to men's. Third, women should be empowered, and their full participation in water project design and implementation should be encouraged.

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Chapter 13
Regional Partnership to Achieve Water Security: The Role of the UNESCO Water Family in Asia and the Pacific

Hans Dencker Thulstrup

Abstract In response to the growing need to cope with very large water challenges, the role of intergovernmental organisations and the regional partnerships they facilitate have become increasingly crucial to achieve water security, particularly in Asia and the Pacific, which is highly vulnerable to water insecurity and climate change. This chapter introduces the role of intergovernmental and scientific regional partnerships and collaborative mechanisms for water security and sustainability from the perspective of the UNESCO Intergovernmental Hydrological Programme (IHP). It takes stock of the IHP through a brief review of the programme's history and a cross-section of current activities and trends observed in Asia and the Pacific. In this way, a trajectory is traced from the programme's beginnings as an effort focused on the consolidation of hydrology as a scientific discipline into a broad platform designed to deliver "science for society" in pursuit of the 2030 Agenda and the Sustainable Development Goals. Finally, the chapter discusses how the emergence of the extended IHP network, known as the UNESCO Water Family, has played a role in ensuring the continued growth in scope and reach of the IHP during a period of financial constraints and has provided an indication of a more diverse, complex, and decentralized delivery mechanism that likely plays a key role in IHP's future.

Keywords Water security · Regional partnership · UNESCO IHP · Asia and the Pacific · Intergovernmental hydrological programme

13.1 Introduction

Water flows all around us, giving life to the environment that sustains us and underpinning all human activity. In recognition hereof, the United Nations 2030 Agenda for Sustainable Development designated Sustainable Development Goal 6 (SDG 6)

H. D. Thulstrup (✉)
The United Nations Educational, Scientific and Cultural Organization, Regional Sciences Bureau for Asia and the Pacific Jakarta, Jakarta, Indonesia
e-mail: h.thulstrup@unesco.org

E. Lee et al. (eds.), *The Water, Energy, and Food Security Nexus in Asia and the Pacific*, Water Security in a New World,
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to ensure the availability and sustainability of water and sanitation for all. Water is the key driver of economic and social development, while at the same time providing a basic function in maintaining the integrity of the natural environment. This is of particular importance for many countries in Asia and the Pacific, whose economies are heavily dependent on natural resources, in particular increasingly scarce freshwater.

Reflecting the threat of growing water insecurity, our daily life is already affected—from water scarcity to pollution to more frequent exposure to water-related disasters such as floods and droughts. In Asia and the Pacific, approximately 300 million people have no access to safely managed water services such as drinking water and 1.2 billion people lack adequate sanitation (Asian Development Bank 2020). Given the role of water in the water, energy, food, and ecosystem (WEFE) nexus, the vulnerability of water resources in the region will have impacts on ecosystem health as well as energy and food insecurity.

In response to the growing needs of the region to cope with such enormous challenges, the role of international organisations and regional partnerships—among governments, academia, water managers, and other practitioners—is crucial if Asia and the Pacific are to achieve water security. Regional partnerships allow for the sharing of strategies and information for sustainable water resource management, foster integrated involvement and contributions by multiple countries and stakeholders, and share the benefits from transboundary water resources.

As a specialized agency of the United Nations with a specific mandate for science, UNESCO provides a platform for sharing ideas and setting standards, catalyses international cooperation in science, promotes dialogue between scientists and policymakers, and builds capacity in science. The Intergovernmental Hydrological Programme (IHP) of UNESCO is the only intergovernmental programme of the United Nations system devoted to water research and management and related education and capacity development. Throughout its history, IHP has remained among the most influential platforms in water science through its facilitation of international cooperation, networking and knowledge-sharing, support of sound policies and governance, as well as for raising awareness of scientific issues among policymakers and the public.

This chapter introduces the role of intergovernmental and regional partnerships and cooperative frameworks in water security. Focus has been given to the major achievements of the IHP Regional Steering Committee (RSC) in Asia and the Pacific, a key facilitator of water cooperation for three decades. Regional efforts and partnerships such as those outlined below have the potential to help us protect vulnerable water systems, mitigate the impact of water-related hazards such as floods and droughts, safeguard access to water functions and services, and manage water resources in an integrated and equitable manner. In so doing, an extensive reference is made to the author's chapter "Capacity for Water Security: Water Education in UNESCO's International Hydrological Programme" (Thulstrup 2019), published by UNESCO and the International Centre for Water Security and Sustainable Management as part of its Global Water Security Issues (GWSI) Series.

13.2 IHP: A Brief Introduction

UNESCO's IHP was founded in 1975 as an intergovernmental water science programme and has since been implemented in a series of multiyear phases, each with a different overarching area of focus. The 9th phase of IHP (IHP-IX) is implemented from 2022 until 2029 under the title "Science for a Water Secure World in a Changing Environment." With action envisioned across five distinct priority areas, IHP-IX (2022–2029) advocates an interdisciplinary, integrated approach to water management, drawing on and integrating social dimensions of water resources. The five priorities are:

1. Scientific research and innovation
2. Water education in the fourth industrial revolution, including sustainability
3. Bridging the data-knowledge gap
4. Integrated water resource management under conditions of global change
5. Water governance based on science for mitigation, adaptation, and resilience

As the theme headings make clear, IHP places the hydrological sciences within a wider, societal context that requires science practitioners, educators, communicators, planners, and decision-makers to work across disciplinary and sectoral boundaries to advance water security at all levels and, in this way, to make a tangible contribution towards the United Nations 2030 Agenda and the Sustainable Development Goals. This association with the 2030 Agenda is particularly significant given that IHP-IX coincides with the final years of the 2030 Agenda and the Goals.

Within this overall context, the IHP-IX Strategic Plan makes specific reference to the water-energy-food-ecosystem nexus:

> The water, energy, food, and ecosystem (WEFE) nexus is a key element to consider to achieve sustainable development. Therefore, the understanding of the nexus and its integrative approaches should be incorporated in educational programs at all levels, formal and informal. IHP-IX will use the opportunity of linking with the Man and Biosphere programme (MAB), the International Geoscience and Geopark Programme the Local and Indigenous Knowledge Systems (LINKS) programme and with UNESCO's Education Sector and UNEP (UN Environment Programme) efforts on "Education for Sustainable Consumption" to undertake actions to advance water education and capacity development activities, for a sustainable future. (UNESCO 2021)

The IHP-IX Strategic Plan, in this manner, assigns particular significance to the WEFE nexus as a key concept for incorporation into educational programmes at all levels. The integrated approach advocated by IHP-IX, and by which the WEFE nexus is assigned such a central role, is the present-day result of a long evolution in IHP's purpose and orientation.

IHP was launched at the close of the International Hydrological Decade (IHD) 1965–1974. That decade, in turn, arose from cooperation that emerged during the early years of the United Nations in the 1950s involving UNESCO, other UN agencies such as FAO and WMO, and professional nongovernmental organisations in the relatively new field of hydrology. While this cooperation had focused in particular on the needs of arid and semiarid areas, issues relating to water science and water management were increasingly recognized as deserving of more explicit and focused attention (Thulstrup 2019).

As outlined above, IHP's work today stresses inter- and multidisciplinarity. Focus is placed on the interaction between hydrological scientists and actors in other fields of science and other sectors of society. This approach stands in contrast to the programme's early years, which were much more focused on interactions between scientists within the hydrological sciences based in different countries and across political, geographical, and economic divides. Michel Batisse describes the situation at the start of the IHD as follows:

> […] in most countries, whether rich or poor, hydrologists were practically inexistent. The field had only been approached at a few universities and engineering schools in industrialised countries and then only as a minor appendix to hydraulics or geology, almost never as a completely separate subject. A few scattered individuals had become competent hydrologists, but they were a relative handful and few of them had actually been trained as hydrologists (Batisse 2005).

While the current wide-reaching approach of the IHP has evolved considerably over the years, it is not to be considered an endpoint. A number of challenges remain for the programme. Key among these is the need to ensure engagement far beyond the hydrological sciences themselves, connecting the water sciences with decision-makers, media, local communities, managers, and students of all ages.

This ongoing trajectory and the shift in focus it represents is at once a considerable achievement for the IHP and a significant challenge: if the potential of the water sciences towards water security and sustainability are to be fully realized, significant work remains to be done, in particular relating to the articulation between science and society (Thulstrup 2019).

13.3 The UNESCO Water Family: An International Network for Global Water Security

As a specialized agency of the United Nations, UNESCO engages with its members through national commissions established by member state governments. According to UNESCO's constitution, its member states "[…] shall make such arrangements as suit its particular conditions for the purpose of associating its principal bodies interested in educational, scientific and cultural matters with the work of the Organization, preferably by the formation of a National Commission broadly representative of the government and such bodies" (UNESCO 1945). UNESCO National Commissions were from the founding of the organisation intended to represent interests from across UNESCO's mandate and are not limited to membership from government entities. National Commission members are typically drawn from both government and civil society entities across the fields of education, the sciences and humanities, culture, and communication.

With the gradual expansion of UNESCO's engagement across this broad range of issues during the first decades of the organisation, intergovernmental programmes such as IHP were established, adding their own governance and national counterpart structures. In the case of IHP, member states were encouraged to establish IHP National Committees, which in turn "form the backbone of the IHP and are fundamental to ensuring the widest possible participation of Member States in the international programme. These Committees are constituted and run under the authority of national governments and play a critical role in the implementation of the IHP" (Thulstrup 2019).

UNESCO's National Commission structure and continuous engagement with the scientific research community have helped shape the manner in which IHP and other intergovernmental programmes have evolved. In particular, the close interplay between these programmes and academic institutions, such as national research councils, laboratories and universities, has helped extend the reach of the IHP and its sister programmes beyond the conventional range of intergovernmental work.

This process has been instrumental to the emergence of a range of member state-funded and hosted structures formally recognized by UNESCO and dedicated to contributing to the organisation's objectives and priorities. While these structures have taken several forms over the past decades—and addressed a wide range of topics across the sciences—two principal modalities are today recognized by UNESCO: UNESCO Institutes and Centres (either Category 1 or 2) and UNESCO Chairs and UNITWIN Networks.

Although they operate with significant autonomy, Category 1 Centres and Institutes are an integral part of the UNESCO programme, supporting research and institutional capacity in Member States. In contrast, Category 2 Centres and institutes are established and funded by member states to contribute to the achievement of UNESCO's objectives. They are not legally part of the organisation but are associated with it through formal agreements between UNESCO and the member state hosting the institute or centre. Another mechanism through which UNESCO associates university chairs and networks with its programmes and activities is the UNITWIN/UNESCO Chairs programme, which grants UNESCO-affiliated status to activities and networks within academic institutions contributing to UNESCO's objectives in accordance with a specific set of guidelines (Thulstrup 2019).

While UNESCO Centres and Chairs have been established across UNESCO's areas of work, the field of water science has been particularly prolific. Water-related Category 2 Centres were among the first to be established, starting with the International Research and Training Centre on Sedimentation in Beijing, China, established in 1983. Today, UNESCO recognises more Category 2 Centres in fields related to the water sciences than any other thematic area, from traditional knowledge on water-to-water security, water and disasters, tropical hydrology, and particular UNESCO-associated innovations such as ecohydrology.

The multifaceted engagement by this expanding pool of expertise working at different levels in support of UNESCO's water science objectives has helped give prominence to the concept of the "UNESCO Water Family". The UNESCO Water Family refers to the combination of the UNESCO Secretariat at the Organization's headquarters and in the field, acting in combination with the many institutes, centres, chairs, committees, commissions, and other bodies contributing to UNESCO's water sciences work. The work of the UNESCO Water Family members are an essential complement to that of the UNESCO Secretariat, as expressed in the documents of the 22nd session of the IHP Council:

> UNESCO works to build the scientific knowledge base to help countries in the sustainable management of their water resources. This is done through its UNESCO Water Family comprising the International Hydrological Programme (IHP), the World Water Assessment Programme (WWAP), the UNESCO-IHE Institute for Water Education, water Centres under the auspices of UNESCO and water-related Chairs and UNITWIN Networks. UNESCO's Water Family operates as a global network that works together to implement the organisation's strategic goals. (UNESCO 2016 in Thulstrup 2019)

The UNESCO Water Family represents a significant extension of UNESCO's reach and engagement with society through water science research, education, and networking. As noted above, the modality of working with a range of government and civil society groups is not unusual for UNESCO. However, the Water Family is unique in terms of the sheer number of institutes, centres, and chairs that are formally affiliated with the IHP and its objectives.

13.4 Regional Partnership for Water in Asia and the Pacific: The Regional Steering Committee (RSC)

Over the past three decades, the IHP in Asia and the Pacific has been closely affiliated with the gradual development and consolidation of the IHP Regional Steering Committee for Asia and the Pacific (RSC).

Initially established in 1995, the RSC was conceived as a mechanism through which a uniquely regional hydrological science platform designed for and by the water science community in Asia and the Pacific could be encouraged and promoted. The founders of the Committee felt that an opportunity for the development of an independent and viable water sciences community in the region was being undermined by the practice of looking towards North America or Europe for new and emerging research and innovation in their field. The RSC was anticipated as a mechanism through which a regional exchange could be built among the countries of the region, thereby creating an international hub within the region.

At the RSC's 25th anniversary meeting held in Manila, the Philippines in 2017, two of the Committee's founding members, Prof. Kunioshi Takeuchi of Japan and Prof. Soontak Lee of the Republic of Korea, recalled the background for its establishment. Takeuchi noted that prior to 1990, no hydrologist lobby had been established in Asia and the Pacific, communication among hydrologists in the region was scarce, knowledge of hydrological conditions in neighbouring countries was limited, and the region had not produced global leadership in hydrology and water resources. Lee noted that "in the region of Asia and the Pacific, there are significant differences and varieties of hydrological characteristics through a vast range of areas. Therefore, it is obviously needed to have some cooperative activities to understand the hydrology and water resources of the region" (UNESCO Jakarta Office 2017).

The initial impetus towards the formation of the RSC came from Japan. First conceived by a working group under the Japanese IHP National Committee, the establishment of the RSC was proposed in an invitation letter issued by the UNESCO Office in Jakarta to UNESCO member states in Southeast Asia, as well as Australia and New Zealand. The geographical focus on Southeast Asia was related to the geographical coverage of the UNESCO Office in Jakarta at the time of the RSC's establishment, providing an initial geographical limitation that was to be retained throughout much of the group's early history.

The RSC intended to provide a "regional forum for professionals and practitioners of hydrology and water resources in the region to gather periodically, exchange and discuss each other's experiences, problems and possible solutions and promote scientific cooperation for better management of water in the region" (UNESCO Jakarta Office 2017). The Committee's regional focus—its emphasis on creating a hydrological discourse uniquely for and by Asia and the Pacific—was underpinned by a set of shared conditions that were far more than of a purely technical nature. Addressing the 2017 session in Manila, Takeuchi asked the question "What is the Asia and the Pacific region to us?" and provided the following answer: "The coexisting community sharing common nature, culture, problems, potentials and fate. Climate, geology, society, history, culture, urban problems, disaster, rice, air pollution, economy. Solve local problems jointly. Unique insights from regional peculiarity for global society. Regional responsibility for the globe".

In other words, the RSC was anticipated as a body that would take its point of departure in the region's natural and cultural diversity, draw strengths and "unique insights" from the region and deliver hydrological sciences and associated services for Asia and the Pacific capable of solving "local problems jointly" avoiding the need to look outside the region to address issues within. In this regard, it is worth noting the high level of ambition expressed during the initial years of the RSC, captured in the final two phrases of Takeuchi's statement: "Unique insights from regional peculiarity for global society. Regional responsibility for the globe." As these phrases indicate, the RSC was created with a view towards eventually contributing with impact at the global level.

The first meeting of the RSC was held in Yokohama, Japan in 1993. Since then, the RSC has convened annually—the only exception being 2020, when restrictions imposed in response to the COVID-19 pandemic necessitated the postponement of the meeting. The 28th meeting of the RSC was held as a hybrid event in November 2021, hosted in Hanoi, Vietnam with in-person attendance by the Vietnamese delegates and virtual participation by the rest of the region, including a virtual field visit.

In his overview of the RSC's work and achievements, Lee summarized the achievements of the first 25 years of the RSC (UNESCO Jakarta Office 2017):

- It has organised its annual RSC meetings with associated International Symposia/Conferences held in rotation among the 19-member countries.

- It has produced approximately 800 scientific papers—a massive quantity—that have been presented in conferences and symposia throughout its history.
- It has organised more than 30 training courses (IHP Nagoya training courses and others).
- From 1995 to 2004, five volumes of the catalogue of rivers for Asia and the Pacific were produced and published, which included 114 basins in 13 different countries; the material for a sixth volume was assembled and is available online.
- It has developed regional networks such as APFRIEND and APHELP, which organised several workshops and symposia and published different reports.
- It has integrated the participation of other countries in the region, such as the Pacific Island countries, Myanmar, and Timor-Leste (1st participation in the 19th RSC meeting, October 2011) (UNESCO Jakarta Office 2017).

In the years following the 25th-anniversary meeting, the RSC developed a new mechanism for sharing and co-developing hydrological tools to address key regional challenges derived from the IHP thematic focus areas. Under the title "Catalogue of Hydrologic Analysis", the resulting publication series is an extension of the "Catalogue of Rivers" referenced above, focusing, however, on the practical application of hydrological analysis tools in regional contexts. Two volumes of this series have been published to date: one on the topic of flood hazard mapping and one on dam reservoir operations for addressing water-related disasters, water scarcity, and quality.

While the hydrological sciences in Asia and the Pacific are likely to have made significant progress over the past decades even without the support of the RSC, the presence and active engagement of the Committee has been instrumental in fostering a number of activities and achievements by the UNESCO Water Family in the region, all associated—closely or tangentially—with the work of the RSC itself. The following section highlights some of these activities in further detail.

13.5 Major Achievement and Initiatives of the UNESCO Water Family: Examples from Asia and the Pacific

Over the course of the past decade and a half, the most prolific UNESCO-affiliated contributor to regional and global water cooperation has been the International Centre for Water Hazard and Risk Management (ICHARM), hosted by the Public Works Research Institute (PWRI) in Tsukuba, Japan. ICHARM began operations in 2006, and immediately after its establishment started a Master's programme drawing students from water management and research agencies in developing countries in Asia and the Pacific and around the world. With particular emphasis on water hazards and risk, the programme has produced over 130 MSc graduates to date, a significant achievement among UNESCO Category 2 Centres.

Building on this, ICHARM has also established a PhD programme. In partnership with Japan's National Graduate Institute for Policy Studies as the degree-conferring institution, most ICHARM graduates receive scholarships provided by the Government of Japan through the Japan International Cooperation Agency (JICA). Topics are determined collaboratively with each student, generally in relation to major water-related disaster management challenges faced by the student's home institution. This allows the students to acquire new skills and apply them when they return home after completing the programme (Thulstrup 2019).

As indicated above, the delivery of full master's and PhD courses remains relatively rare among UNESCO Water Family member institutions. A more common modality for water education offered by UNESCO-affiliated bodies is short-term intensive training curriculum. Among the most prolific and lasting courses of this kind is a series of IHP Training Courses organized annually for more than a quarter of a century by the universities of Kyoto and Nagoya in partnership with UNESCO Office Jakarta and with the support of the Government of Japan through various funding mechanisms. The recurring organisation of this training course over such a long period of time demonstrates the continuing demand for water education opportunities across the region. The list below highlights course titles over a ten-year period in reverse chronological order, demonstrating the manner in which topics have evolved with the different phases of the IHP as well as in response to the urgent and emerging issues in the region.

- 2017: 27th course: Integrated Basin Management under Changing Climate
- 2016: 26th course: Coastal Vulnerability and Freshwater Discharge
- 2015: 25th course: Risk Management of Water-related Disasters under Changing Climate
- 2014: 24th course: Forest Hydrology Conservation of Forest, Soil, and Water Resources
- 2013: 23rd course: Ecohydrology for River Basin Management under Climate Change
- 2012: 22nd course: Precipitation Measurement from Space and its Applications
- 2011: 21st course: Introduction to River Basin Assessment under Climate Change
- 2010: 20th course: Groundwater as a Key for Adaptation to Changing Climate and Society
- 2009: 19th course: Water Resources and Water-Related Disasters under Climate Change

As the titles suggests, a number of key priorities under IHP and other UNESCO science programmes are addressed by the courses, from water-related disasters to groundwater, from space-based technologies to ecohydrology and from forest hydrology to climate change. The latter has been the most consistently applied topics in the last decade of courses (Thulstrup 2019).

The series also illustrates the continuing development of the organisational network that makes up the UNESCO Water Family. While all the courses listed were organized by the two host universities, the course for 2018 was organized in the context of a new UNESCO water-related chair established by Kyoto University under the acronym WENDI—a new, multidisciplinary chair dedicated to "water, energy and disaster management for sustainable development."

The establishment of a chair on such an integrated platform—with clear reference to the significance of the WEFE nexus for sustainability and with an added reference to disasters, drawing on multiple departments across the university—is symptomatic of the increasingly multi- and transdisciplinary nature of IHP, through which the hydrological sciences are applied to address real-world issues in nexus-type interaction with other fields of inquiry. Kyoto University's intentions are outlined in WENDI's mission statement, which reads:

> WENDI aims to promote multi-disciplinary and holistic approach for research implementation, knowledge transfer and capacity building in the fields of water, energy, and disaster management and linkages to other sectors (food, forestry, biodiversity, climate change and data science). This is done by developing a comprehensive and trans-disciplinary Education for Sustainable Development (ESD) programme for graduate school level to establish 'KU-Model of ESD' and by providing unique international collaborative research using existing UNESCO-Sites including Geoparks, Biosphere Reserves and Cultural, Natural and Mixed World Heritage Sites as the application field.

In line with the approach advocated in the IHP-IX Strategic Plan (see Sect. 13.2), WENDI promotes a multidisciplinary and holistic approach to research and education, provided through a transdisciplinary ESD programme focusing on UNESCO-designated sites with both cultural and natural heritage. Its programmes are delivered through a mechanism that explicitly draws upon UNESCO programmes and capacities from across the organisation's mandates—from culture to education to the natural and social sciences—focusing on sites that have been designated and recognized under UNESCO's global intergovernmental site-based programmes: the World Heritage Convention, the Man and the Biosphere Programme and the UNESCO Global Geosciences and Geoparks programme.

While Japan—as a major global and regional donor to UNESCO's science programmes—might perhaps be expected to play a leading role in developing international water science cooperation, other parts of the region have also proactively established UNESCO-affiliated centres and chairs. In Southeast Asia, the Asia–Pacific Centre for Ecohydrology (Indonesia) and the Humid Tropics Centre Kuala Lumpur (Malaysia) have conducted a range of water education activities in recent years.

The Asia–Pacific Centre for Ecohydrology (APCE), hosted by the Indonesian National Research and Innovation Agency (Badan Riset dan Inovasi Nasional–BRIN) in Cibinong near the capital Jakarta, has recently emerged as an organiser of international short-term training courses focusing on the emerging transdisciplinary field of ecohydrology—itself a theme under IHP-VIII and a concept promoted through IHP since its inception. Established in 2011 with the ambition of becoming an internationally recognized centre for urban and rural ecohydrology, APCE's mandate includes research, training and knowledge exchange, information system development, and public awareness.

APCE's first large-scale international undertaking was a major international conference on ecohydrology. Organized in 2014 along with a series of thematic activities, the event received financial support from the Government of Indonesia through a UNESCO Office Jakarta project to achieve water security in Indonesia and raise the regional capacity in the field of ecohydrology.

During 2018, APCE led the organisation of two international training courses. First, a regional training course for Asia and the Pacific on coastal ecohydrology was held in August in the city of Yogyakarta as a joint undertaking with Portugal's International Centre for Coastal Ecohydrology (ICCE)—also a UNESCO Category 2 Centre—with financial and logistical support from UNESCO. The event combined lectures, field investigations, laboratory work, and presentation sessions. Its organisation shows an example of the increasing interaction between UNESCO Category 2 Centres located in different geographical regions but thematically connected.

Joint organisation and close interaction between members of the UNESCO Water Family contribute to enhancing the competence of both the direct beneficiaries of the training—the participants—and the contributing Category 2 Centres, which are provided with the opportunity to exchange scientific and organisational knowledge as well as experience. For a relatively young Centre such as APCE, such exposure represents an important growth opportunity. It also serves as an illustration of the benefits of belonging to the UNESCO Water Family, in this case, the development of professional exchange and cooperation between the regions on the basis of a common thematic purpose, formulated and advanced by the IHP.

In November 2018, the APCE hosted a second water education event, under the International Initiative on Water Quality (IIWQ). As part of a series of global training events with parallel training courses organized in Africa, the Arab States, Latin America, and the Caribbean, the course brought together water managers, government officials, and researchers from all over the region. Throughout this event, APCE contributed to the global goals of a UNESCO-implemented project funded by the Swedish International Development Cooperation Agency (SIDA). This event demonstrated a growing ability and capacity of APCE to host and lead international events in its field of competence and to contribute through regional action towards a set of global priorities, an opportunity given to the Centre through partnerships with UNESCO and IHP.

The Humid Tropics Hydrology and Water Resources Centre for Southeast Asia and the Pacific in Kuala Lumpur, Malaysia (called HTCKL) was established in 1996 and recognized as a UNESCO Category 2 Centre in 1999. Hosted by the Malaysian Department of Irrigation and Drainage, HTCKL pursues four main goals related to research, networking, education, and publication.

As another example of the UNESCO Water Family's activities to address the WEFE Nexus, in 2017 HTCKL published a three-volume compendium under the title "Water Management Curricula using Ecohydrology and Integrated Water Resources Management" as a contribution to the IHP 8th phase and with the purpose of contributing to the understanding of the interfaces and interconnections within the water-energy-food nexus and, consequently, contributing to a further improvement of Integrated Water Resources Management (IWRM) practices.

In cooperation with UNESCO Office Jakarta and with financial support from the Government of Malaysia, the three volumes investigated the application of ecohydrology as a tool for implementing IWRM in various contexts and established an operational connection between two concepts advocated through IHP's water education programmes. The curricula were developed under coordination by HTCKL and UNESCO Office Jakarta in partnership with a range of Malaysian universities.

In this manner, the development of water education curricula has enabled HTCKL and its host institution to serve as a bridge between national academic network and UNESCO's global water science priorities. The publication of the compendium was followed up a subsequent UNESCO Office Jakarta initiative supported by the Government of Malaysia through which the three volumes were adapted to the African context through the participation of members of both African and Asian water families, including major African partners such as the Regional Centre for Integrated River Basin Management (RC-IRBM) in Nigeria. This work resulted in the preparation of a new, revised African edition of the compendium scheduled for publication by UNESCO in 2022. The publication of this edition is an example of the potential of interregional cooperation within the UNESCO Water Family to further expand its scope and potential.

The establishment of the International Centre for Water Security and Sustainable Management (i-WSSM) in the Republic of Korea in 2017 added a significant contribution to the UNESCO Water Family. Based on the accumulated technology and scientific experience of the *K*-water Institute and the wider Korean water sector, *i*-WSSM has served as a bridge to solve a wider range of water security problems in different contexts by utilizing Korean knowledge and experience. *i*-WSSM plans to further develop its position as an international research and education centre focusing on supporting water security strategies for sustainable development with a strong profile in key priority areas, including water and gender. *i*-WSSM's focus on sustainable development explicitly aligns sustainable development goals and the 2030 agenda, adopted in parallel with the centre's establishment.

Since its inauguration in June 2017, *i*-WSSM has built an increasingly active profile by providing technical support for a major UNESCO Africa-Asia water security project supported by the Government of the Republic of Korea and launching a dedicated programme to address water security concerns in small island developing states (SIDS) that are particularly impacted by climate change and variability with resulting water security challenges. *i*-WSSM's SIDS activities focus specifically on the development of capacity to solve water security problems in the field through tailored education and training interventions. *i*-WSSM serves as a key partner for ongoing projects to support groundwater monitoring and management in Dili, the capital of East Timor, implemented in close cooperation with UNESCO office Jakarta (Thulstrup 2019).

13.6 Conclusion

This paper has outlined the role of IHP in fostering international partnerships and cooperation in Asia and the Pacific through a brief review of the programme's history and a cross-section of current activities and trends observed in the region. In so doing, a trajectory has been traced from the programme's beginnings as an effort to consolidate hydrology as a scientific discipline into a wider platform to deliver "science for society" in pursuit of the Sustainable Development Goals and the 2030 Agenda. The emergence of the UNESCO Water Family has served to ensure the continued growth in scope of the IHP during a period of financial constraints and has provided an indication of a more diverse, complex, and distributed delivery mechanism that could play a key role in IHP's future.

While the core direction of the IHP is established and disseminated by the IHP Intergovernmental Council, its Bureau and the IHP Secretariat, it is the agencies and individuals constituting the IHP Water Family—from Category 2 Centres to Chairs to academic and civil society partners—who will increasingly serve as the interface between IHP and its growing, broadening constituency. This enhanced participation is required for IHP-IX's expectations to be fully realized, which will eventually require improved capabilities among all members of the Water Family to ensure that the scientific and technical standards are maintained.

To enable this reinforcement, further integration and consolidation of the IHP Secretariat's communication and networking efforts will be required. As IHP begins its 9th phase, the programme has the opportunity to reach a larger audience than ever before. This will enable a strong and feasible contribution towards the Sustainable Development Goals and the 2030 Agenda.

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Chapter 14
The Nexus as an Entry Point for Achieving Long-Term Security, Sustainability, and Peace

Yujeong Kim and Sara Castro-Hallgren

Abstract This chapter examines the interconnected relationship between sustainable development, security and peace, and the water-energy-food (WEF) nexus, underscoring that the key to understanding it lies in systems thinking and a focus on resilience. Security and peace can be achieved only by meeting the 17 Sustainable Development Goals (SDGs), and vice versa, and the WEF Nexus is presented as a practical solution under this approach. The chapter recommends a shift from the traditional focus on security in addressing the WEF nexus to resource efficiency and, ultimately, resilience in the face of increasing risk due to climate change and anthropogenic impacts on the earth system. The chapter also highlights some examples of efforts made to enhance the synergies between multiple SDGs in the context of the WEF nexus in the East and Southeast Asian region through improved multi-level governance. The 2030 Agenda encompasses all areas of the WEF nexus, including the importance of realizing synergies and working through an integrated approach. The analysis of the impacts of the recent COVID-19 pandemic on the water, energy, and food sectors clearly demonstrates the importance of greater multi-level governance to achieve the SDGs. Strengthening public governance for WEF nexus implementation at the country level may benefit from, at minimum, regional multi-lateral agreements where countries commit to adopting a nexus approach to achieving resilience in the water, energy, and food systems.

Keywords Sustainable development goals · Resource security · Systems approaches · Multi-level governance · Resilience · Public governance

The views expressed in this publication are those of the authors and do not necessarily reflect the views of the United Nations.

Y. Kim (✉) · S. Castro-Hallgren
United Nations Office for Sustainable Development, Incheon, Republic of Korea
e-mail: yujeong.kim@un.org

S. Castro-Hallgren
e-mail: sara.castrohallgren@un.org

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Sustainable development cannot be realized without peace and security; and peace and security will be at risk without sustainable development.

The 2030 Agenda for Sustainable Development (A/RES/70/1)

14.1 WEF Nexus and Sustainable Development

Published 23 years ago, the seminal 1987 Brundtland Commission Report, 'Our Common Future', underscored the need for institutional change for sustainable development, noting that the "integrated nature of the global environment and development challenges pose problems for institutions…The real world of interlocked economic and ecological systems will not change; the policies and institutions concerned must" (WCED 1987). The need for institutional change still holds true today five years after the adoption of the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) by United Nations member states—a voluntary agenda in which public institutions assume the primary responsibility for its implementation (UNGA 2015).

Defining a narrative for the water-energy-food (WEF) nexus in the context of sustainable development depends on a greater understanding of the nonlinear behaviour of complex systems (Hynes et al. 2020). Systems are a sum of parts 'coherently organized and interconnected', producing a pattern of behaviours to fulfil a specific purpose (Meadows 2008). Water, energy, and food do not exist in a vacuum; rather, they are all parts of our earth system, where human decisions cause complex feedback loops at global and local scales (Field and Michalak 2015). Therefore, placing the WEF nexus in the context of earth system governance is essential, especially if the focus is on long-term security and peace.

The current governance practices and decision-making, which are not sustainable for the water, energy, and food systems, will largely lead to system collapse if drastic changes are not made. Unsustainable production and consumption behaviours in the WEF systems not only impact resource security but also affect the possibility of achieving sustainable development in the near term to the long term. The WEF nexus cuts across the sub-systems of the broader earth system composed of the (1) atmosphere, (2) biosphere, (3) cryosphere, (4) geosphere, and (5) hydrosphere (NASA 2021). As a result, some of the WEF production and consumption practices in the East and Southeast Asian region may disrupt essential cycles, such as the water (hydrologic) cycle that connects the earth system with impacts across the region (Blondel 2012).

Interdependence between humans and natural systems is a central tenet of the 2030 Agenda for Sustainable Development, which aims to transform our world (UNGA 2015). Adopted by United Nations member states in 2015, this universal agenda and its 17 Sustainable Development Goals have promoted the importance of viewing sustainable development as a nexus itself where water, energy, and food, as well as peace, security, and more, are central to the 'future we want' in 2030.

The 17 goals, 169 targets, and 232 indicators provide the basis for implementing interdisciplinary and crosscutting approaches such as the WEF nexus, placing the approach within what UN member states have defined as essential puzzle pieces of sustainable development. These puzzle pieces are also summarized under the pillars of the 2030 Agenda, the ‘five Ps’—people, planet, prosperity, peace, and partnership (Box 1). The 2030 Agenda itself and its five pillars are evidence of a paradigm shift in sustainable development from the original three pillars, i.e., the economic, social, and environmental pillars, to a systems approach recognizing interconnections to realize sustainable development.

Box 1: The Five Ps of the 2030 Agenda for Sustainable Development Represent a Paradigm Shift in Sustainable Development from Three to Five Pillars

The 2015 United Nations resolution that adopted the 2030 Agenda and its Sustainable Development Goals defines the five pillars for sustainable development as follows and reaffirms that “The interlinkages and integrated nature of the Sustainable Development Goals are of crucial importance in ensuring that the purpose of the new Agenda is realized.”

People: We are determined to end poverty and hunger, in all their forms and dimensions, and to ensure that all human beings can fulfil their potential in dignity and equality and in a healthy environment.

Planet: We are determined to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations.

Prosperity: We are determined to ensure that all human beings can enjoy prosperous and fulfilling lives and that economic, social and technological progress occurs in harmony with nature.

Peace: We are determined to foster peaceful, just and inclusive societies which are free from fear and violence. *There can be no sustainable development without peace and no peace without sustainable development*.

Partnership: We are determined to mobilize the means required to implement this Agenda through a revitalised Global Partnership for Sustainable Development, based on a spirit of strengthened global solidarity, focused in particular on the needs of the poorest and most vulnerable and with the participation of all countries, all stakeholders and all people.

Source United Nations General Assembly (UNGA) (2015)

The 2030 Agenda's Sustainable Development Goals are based on a systems-thinking approach, where one can draw interconnections, co-benefits, and trade-offs across the goals and targets. The WEF nexus similarly requires a systems-thinking approach. Various methodologies and approaches for identifying co-benefits or synergies, while navigating trade-offs, have been adopted in the nexus literature (Fader et al. 2018). This is precisely because of the interdependence between the production and consumption of water, energy, and food within the earth system. The WEF nexus is therefore subject to ecological constraints as a result of unsustainable patterns of human production and consumption.

For decades, it has been clear that there are limits to growth, including global ecological constraints and therefore, resource constraints that, when exceeded, can lead to crises and conflict as systems overshoot and collapse (Meadows et al. 2004). These predictable trends are the clarion call for sustainable development and the WEF nexus to be applied to public governance and policymaking. The security and resilience of humanity on earth depend on this fact.

14.2 Peace and Security for Sustainable Development

The 2030 Agenda reminds us that *sustainable* development is dependent upon peace and security, including resource security, requiring an integrated approach to public governance and policymaking. Peace is indispensable in this new paradigm for sustainable development, and the preamble of the UN resolution notes, "There can be no sustainable development without peace and no peace without sustainable development" (UNGA 2015).

As the notion of human security has evolved since its introduction by the United Nations Development Programme (UNDP 1994), the concept of security covers various aspects of human lives, including the economy, politics, food, health, and the environment. As noted in United Nations General Assembly resolution 66/290 adopted in 2012, the human security approach requires "identifying and addressing widespread and cross-cutting challenges to the survival, livelihood and dignity of their people."

The WEF nexus is an inextricable part of both human security and the universal and interdependent 2030 Agenda, which covers areas of resource security, sustainable resource management, and more to achieve sustainable development. Therefore, we cannot look at peace and security without focusing on resource security in the context of sustainable development, as WEF nexus research has already explored (Simpson and Jewitt 2019).

Applying the nexus approach in the context of sustainable development in the Asia–Pacific region is not new, given the increased regional competition for resources amid fast-paced development patterns and growing environmental impacts. The environmental carrying capacity of the Asia–Pacific region, especially East Asia and across ASEAN nations, has declined, as production and consumption patterns have increased along with economic growth, paving the way for a greater focus on resource security (UNESCAP 2005). Within this picture, countries have sought to ensure resource security through geopolitical moves to secure resource rights from land grabbing to hydropower investments, and these affect regional tensions and resource competition.

Earlier research by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) predicted that "geopolitical flashpoints" associated with the WEF nexus would be in Southeast Asia as a result of the "impact of China's dams" along the world's 9th largest river, the Mekong River (UNESCAP 2013).Today, over 100 dams are located across the Mekong River Basin from China into the Lao People's Democratic Republic, Thailand, and Vietnam, impacting the water, energy, and food needs of millions of riparian communities. Multiple regional countries have been involved in these hydropower projects, which inevitably both positively and negatively affect the water, energy, and food resources of the region (Matthews and Motta 2013).

In the case of the Mekong River Basin, the WEF nexus is central to planning for water, energy, and food resilience among all who depend on and benefit from this fragile ecosystem. Multilateral engagement moving from a military or geopolitical view of resource security to a focus on resilience is essential to achieve sustainable development in the region (Simpson and Jewitt 2019; Keskinen et al. 2019). This is even more important given the 2030 Agenda's focus on long-term or intergenerational access to resources, where intergenerational equity is pivotal for sustainable development. While regional powers may focus on short-term resource security, the intergenerational focus requires a shift towards an efficient management of resources to secure their long-term resilience.

14.3 From Resource Security to Resource Efficiency and Resilience

> In the context of these global governance frameworks for sustainable development, **resilience** is defined as "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions".
>
> The Sendai Framework for Disaster Risk Reduction. United Nations, 2015.

Public governance of the water, energy, and food systems must shift from the security perspective to resource efficiency and, ultimately, resilience. Such a shift entails moving planning and policy discussions from the concepts of water, energy, or food *security* to *resilience* (Fig. 14.1) and balancing feedback loops and interactions across the earth system (Simpson and Jewitt 2019; Meadows et al. 2004; Keskinen et al. 2019).

Water, energy, and food are present across the SDGs, as Box 2 summarizes below. However, the focus changes across the goals, with some emphasizing security and

Fig. 14.1 Water, energy, and food systems: from security to resilience

scarcity and others emphasizing sustainable management and resource efficiency practices. Goal 2 focuses on food security, for example, while SDG 6 addresses water scarcity and basic access, SDG 7 addresses more advanced concepts of energy efficiency, and SDGs 8 and 12 address resource efficiency and resource consumption and production patterns. Efficiency is especially examined not only in the context of SDG 7 to achieve 'energy efficiency' but also in the context of SDG targets focused on technology and sustainable agriculture or water systems. If one looks at the interdependence of climate change and ecosystems with food production or energy, then there is a clear focus on SDGs 13, 14, and 15. However, these do not emphasize crucial public governance and intergovernmental policymaking that underpin the water, energy, and food systems. The importance of 'effective, accountable, and inclusive' public institutions and governance is rooted in SDG 16 and policy coherence under SDG 17. Therefore, the concepts of resource security, efficiency, and public governance for the WEF nexus cut across the SDGs.

Seminal works on systems thinking have noted that "systems need to be managed not only for productivity or stability, but they also need to be managed for resilience" (Meadows 2008). This concept of system resilience has been adopted and incorporated into global multi-lateral agreements such as the Sendai Framework on Disaster Risk Reduction, which is also part of the 2030 Agenda. The Sendai Framework for Disaster Risk Reduction is a global multilateral agreement to mitigate risk and achieve resilience that also cuts across the goals noted in Box 2, from SDGs 1, 11, 13, and more. These aspects of security, efficiency and, ultimately, resilience denote a shift in how governments govern natural resources and ultimately plan around the WEF nexus.

Ecological constraints limit exponential economic growth and resource use not only in the Asia–Pacific region but also globally. As resource constraints have multiplied, WEF resources have kept up through gains in technological efficiency, but they will inevitably be limited by planetary boundaries if the focus on resilience does not become the norm (Meadows et al. 2004).

As the environmental carrying capacity of the Asia–Pacific region continues to decline, the WEF nexus can play a role in strengthening resilience. However, the implementation of the WEF nexus in planning and policymaking will require greater data on evolving resource use from a socio-ecological systems perspective (Taniguchi et al. 2017). Climate change will further affect the carrying capacity of ecosystems, requiring risk-informed approaches to natural resource management and resultant socio-economic effects through multi-lateral cooperation (Woodworth-Jefcoats et al. 2016). Risk-informed planning is essential to ensure resilient systems for WEF and sustainable development, but to do so, policymakers must view the nexus in the context of sustainable development as a whole (Independent Group of Scientists Appointed by the Secretary-General 2019; UNISDR 2015).

14.4 Impact of the COVID-19 Pandemic and the WEF Nexus

As the UN marks its 75th anniversary, the world is also grappling with the global COVID-19 pandemic, which is impacting the WEF systems at all levels. The COVID-19 pandemic is reversing the gains made in all the sustainable development goals, exposing the weaknesses of not achieving the 2030 Agenda and exponentially increasing vulnerability.

Achieving SDG 6 is crucial to prevent infection and contain the spread of COVID-19, and there are positive signs that governments are increasingly focusing on extending access to water and sanitation (UNDESA 2015a). However, in recent data collected through national surveys, the majority of countries noted that while policies and plans are in place for hygiene, they often lack sufficient human and financial resources to implement the plans (WHO 2020).

Food security targets in the context of SDG 2 were not on track before the COVID-19 pandemic, with global hunger increasing by 10 million people in one year and by nearly 60 million in the previous five years (UN 2020a). Data show that 8.9% of the global population experiences hunger and that 381 million people, the bulk of the world's undernourished population, are still found in Asia (UN 2020a). Current estimates indicate that the pandemic will push over 60 million more into extreme poverty, lead to famine of "historic proportions," and leave 1.6 billion people without livelihoods, even further reducing progress in regard to SDG 2 (UN News 2020a). SDG 2 aims for more resilience in food systems, and without great attention, achieving this goal by 2030 will become impossible.

SDG 7 on access to affordable and clean energy also confronts negative impacts, despite the need for energy as an essential resource for combatting the pandemic. Due to the economic impacts of COVID-19, the world is seeing a 20% reduction in energy investment, the largest decline ever recorded (UN 2020b). In addition, as household incomes decline, it can be expected that financing for the transition to renewable energy and investments in energy access will decline across the developing world.

Prior to the COVID-19 pandemic, the pace of progress to achieve the SDGs was not fast enough (UN 2020c). Public institutions are now focusing even less on the persistent problems of climate change and environmental degradation, lagging behind on nearly all environmental goals that are crucial for more sustainable management and resilience of the WEF systems (Lade et al. 2019; WRI 2020). During the pandemic, many have pointed to a temporary reduction in carbon emissions due to lockdowns and reduced economic activities, but in some cases, the pandemic has also led to reduced environmental management, which will inevitably impact water quality, for example. In addition, the United Nations Security Council has noted that the pandemic "is likely to endanger the maintenance of international peace and security," adopting a resolution calling for a global ceasefire and urging countries to redouble their efforts for peace (UN News 2020b).

These destabilizing impacts notwithstanding, the COVID-19 crisis provides an opportunity for a 'great reset' (World Economic Forum 2020). The United Nations underscores the importance of multilateralism to recover from the impacts of the COVID-19 pandemic and emphasizes that humans are reaching tipping points as the earth system declines at "an unprecedented rate" (UNDESA 2020). Crises can and have presented windows of opportunity to reform policies in water and agriculture, for example, precisely because in times of crisis, stakeholders can recognize the urgency of addressing vulnerability and preventing future risk (Gruère 2019).

The decade remaining between now and 2030 was recognized by heads of state as a "Decade of Action" to achieve the SDGs, but now, it could be a decade of only recovering from COVID-19 unless solutions are found to rapidly accelerate progress (IISD 2020). Nexus-based approaches and solutions can provide this by ensuring that public policies identify leverage points for system change. These nexus-based solutions can accelerate sustainable development and move the water, energy, and food systems from recovery to resilience.

At the opening of the 75th United Nations General Assembly, leaders from East Asian and Southeast Asian nations remarked on the importance of achieving sustainable development and identifying solutions that can accelerate progress (General Assembly of the United Nations 2020). These statements reaffirm the national commitment among regional leaders to recover from the pandemic with more secure, efficient, and resilient systems that will be more resistant to future shocks.

Earth system governance refers to interrelated institutions, rules, and norms from the global level to the local level of decision-making and requires multilateralism to ensure transformation for sustainable development (Biermann et al. 2010)

Multi-level governance refers to systems of public governance where there is a devolution of power and authority from the national level to the local level, an increase in the quantity of actors engaged in decision-making, requiring greater coordination and engagement across government (Di Gregorio et al. 2019)

14.5 Strengthening Public Governance for the WEF Nexus

Never before has the concept of strengthening global to local governance for the WEF nexus been so important to turn the COVID-19 crisis into an opportunity for change. As part of this effort to accelerate progress, the United Nations has launched the SDG 6 Global Acceleration Framework (UN Water 2020), which aims to ensure rapid results at scale as part of the Decade of Action to achieve the SDGs by 2030 and to ensure water and sanitation for all. The framework notes that at the local level, outdated infrastructure and governance slow the achievement of SDG 6 along with a clear lack of capacity and finance among local governments and water and sanitation providers. Similar efforts are needed but with a focus on the nexus approach, as opposed to individual sectors or resources. Multi-level governance models can equip national governments with the necessary framework for cross-sectoral and nexus-based decision-making. As anthropogenic impacts on earth systems increase the resilience of the water, energy and food systems, there are global to local knock-on effects that require cross-sectoral and transboundary coordination (Burch et al. 2019).

Earth system governance is similar to the concept of multi-level governance in that it also focuses on the global to local levels of decision-making for a more effective steering of progress from meta- or nexus approaches to local results (Meuleman 2019). Governments must integrate the WEF nexus in the context of earth system governance, which addresses institutions and processes at the global to local levels of decision-making and requires multilateralism (Biermann et al. 2010).

The 2030 Agenda encompasses all areas of WEF, including the importance of realizing synergies and working through an integrated approach. At present, there are no other global or regional multi-lateral agreements on the WEF nexus (Endo et al. 2017). Strengthening public governance for WEF nexus implementation at the country level may benefit from, at minimum, regional multi-lateral agreements where countries commit to adopting a nexus approach to achieving resilience in the water, energy, and food systems.

14.5.1 Sub-regional Approaches to Strengthening Public Governance

At sub-regional levels, the Association of Southeast Asian Nations (ASEAN) and East Asian nations have taken varying approaches to address water, energy, and food, especially in the context of resource security and sustainable development. For the Southeast Asian region, agreements contributing to the WEF nexus have included multiple accords, protocols, action plans, and legal instruments on the areas under the nexus.

In the area of food security, as early as 1980, ASEAN member states adopted the Agreement on ASEAN Food Security Reserve, which is a legal instrument focused on strengthening food security among member states in the context of 'economic resilience'. The agreement established "a food security reserve among ASEAN Member Countries based on the principle of collective self-reliance to contribute to the strengthening of the respective national economic resilience, as well as to ASEAN economic resilience and ASEAN solidarity" and included early-warning systems and other areas to ensure more risk-informed governance for shifting from food security to collective resilience (ASEAN Secretariat 1979). In the area of water, there is the ASEAN Strategic Plan of Action on Water Resource Management (ASEAN Secretariat 2005), where the ASCC Blueprint 2025 is intended to serve as the guiding mandate for the work of the ASEAN Working Group on Water Resource Management (ASEAN Secretariat 2020). Regarding energy, already in 1986, ASEAN countries established the Agreement on ASEAN Energy Cooperation (ASEAN Secretariat 1986). More recently, there have been even efforts to strengthen energy standards across products and sectors by harmonizing ASEAN energy efficiency standards across lighting, air conditioners, and more along with national policy roadmaps in the energy efficiency area (United for Efficiency 2020). However, there is no ASEAN integrated agreement or cooperation framework on the WEF as a nexus, although the 2012 ASEAN Declaration on Environmental Sustainability includes water, energy and food resources as integrated priorities, among others, under the sustainability banner (ASEAN Secretariat 2012).

For East Asian nations, the picture is similar. There is no agreement referring exactly to the WEF nexus; East Asian countries are contributing to the nexus by jointly responding through a regional framework. However, the North-East Asian Subregional Programme for Environmental Cooperation (NEASPEC), which was established in 1993 by six member states (China, the Democratic People's Republic of Korea, Japan, Mongolia, the Republic of Korea, and the Russian Federation) to address the pressing issues in the region, such as transboundary air pollution, biodiversity and nature conservation, marine protected areas, low carbon cities, and desertification and land degradation (NEASPEC 20th Senior Officials Meeting 2016). The Tripartite Environment Ministers' Meeting (TEMM) of China, Japan, and the Republic of Korea also serves as a venue for promoting cooperation on the WEF nexus among the three countries by focusing on air quality improvement, climate change, marine and water environment management, and zero waste cities, among others, as laid out in the Joint Communique for the 21st TEMM in 2019 (Trilateral Cooperation Secretariat 2019).

Research on the East Asian region shows that it is also necessary to focus on integrating the WEF nexus into regional trade policies for greater resilience, with new methodologies to examine East Asian 'WEF footprints', including through trade in goods (White et al. 2017). This research shows that countries have overcome resource constraints in water, for example, by importing "virtual water" through products and, therefore, externalizing environmental impacts through intra-regional trade, exposing a need for government policymaking to also include WEF footprints in regional trade accounting (White et al. 2017). This approach would indeed require greater multi-lateralism and legally binding approaches to be adopted among East Asian governments, with a look at WEF footprints, including through regional trade, environmental management, and resilience.

14.5.2 Strengthening Public Governance for WEF at the National Level

A further challenge is implementing the nexus approach at the national levels of public governance. Each country occupies its national sphere of public governance or policy space. Echoing this need for sovereignty, SDG target 17.15 calls on the global community to "Respect each country's policy space and leadership to establish and implement policies for poverty eradication and sustainable development" (UNDESA 2015c). Effectively implementing multilateral agreements and approaches, voluntary as they are, requires this understanding of national governance contexts and respect for the variety of policy spaces to operationalize the WEF nexus (Glass and Newig 2019).

Countries often have varying systems of government, institutional development, and levels of decentralization (administrative, political, or fiscal), which affect the implementation of global agendas (Bardhan and Mookherjee 2006). Nevertheless, studies show that to achieve sustainable development and effectively implement crosscutting and integrated approaches such as the SDGs and WEF, democratic institutions create the most 'conducive environment' by ensuring accountability, transparency, and responsiveness in public institutions and policymaking (Glass and Newig 2019). This is echoed by SDG 16 with targets on concepts essential for public governance to implement the 2030 Agenda, including the rule of law and 'effective, accountable and inclusive institutions' (UNDESA 2015b).

At the national level, strengthening integrated public governance for the WEF nexus also meets the challenges of coordination and coherence across government. The following table shows the complexity of roles and responsibilities across government agencies in the WEF nexus. The table is by no means exhaustive but depicts an initial glance at national-level entities primarily mandated to set policy and regulate the WEF systems.

Table 14.1 showcases the diversity of government structures for the WEF systems in East Asian and ASEAN countries at the time this chapter was drafted. Countries may place high priority on energy governance and less so on food systems, for example, or more so on water resources and less on energy. Where Singapore has a 'multi-ministry task force' such as the Singapore Food Agency governing food production, it has no ministry of agriculture. According to the data collected in the table, other nations take a different approach, with multiple ministries addressing agriculture and food production and even additional ministries addressing agrarian reform.

This initial analysis of government structures for the WEF nexus in East Asian and ASEAN countries does not cover the types of governments, although this is a key factor in how resources are governed. Policy coherence depends on the government's ability to coordinate across structures horizontally and vertically from the national to local levels for the actual governance of resources. Another major factor the table does not cover is the level of decentralization in countries. Effectively decentralized government functions are essential in the successful implementation of the WEF nexus, especially in terms of ensuring improved local governance for these crucial resources.

Governments will differ and change, especially as leadership changes through transitions of power. Ensuring that the WEF systems are governed for resilience will require a centrally coordinated approach across all horizontal and vertical levels of government. Mappings of country government structures and responsibilities need

Table 14.1 Government structures for the WEF systems in East Asian and ASEAN countries

Country	Water	Energy	Food
1. Brunei (Shams and Napiah 2019)	Ministry of Development; Ministry of Primary Resources and Tourism	Ministry of Energy	Ministry of Primary Resources and Tourism
2. Cambodia (Open Development Cambodia 2015)	Ministry of Water Resources and Meteorology; Tonle Sap Authority; Ministry of Mines and Energy (urban water resources); Ministry of Rural Development (rural water resources); Ministry of Public Works and Transport; Ministry of Environment	Ministry of Mines and Energy, Electricity Authority of Cambodia	Ministry of Agriculture, Forestry and Fisheries; Ministry of Land Management, Urban Planning and Construction
3. China (Chen et al. 2019)	Ministry of Water Resources; Ministry of Land and Resources (MLR) (underground water pollution)	Communist Party of China National Energy Committee; State Council and National Development and Reform Commission and its National Energy Administration; Ministry of Natural Resources (e.g., natural gas fracking); Ministry of Water Resources (e.g., hydropower)	Ministry of Agriculture; Ministry of Land and Resources
4. Democratic People's Republic of Korea, North Korea (UNICEF Democratic People's Republic of Korea 2018)	Ministry of Urban Management; Ministry of Fisheries	Ministry of the Electricity and Coal Industry	Ministry of Agriculture

(continued)

Table 14.1 (continued)

Country	Water	Energy	Food
5. Indonesia (Cabinet Secretariat of the Republic of Indonesia 2019)	Ministry of Home Affairs; Ministry of Health; Minister of Public Works and Public Housing; Ministry of Villages; Development of Disadvantaged Regions and Transmigration; Ministry of National Development Planning/Head of the National Development Planning Agency	Ministry of Energy and Minerals; Ministry of Industry; Ministry of Public Works and Public Housing; Ministry of Villages, Development of Disadvantaged Regions and Transmigration; Ministry of National Development Planning/Head of the National Development Planning Agency	Ministry of Agriculture; Ministry of Fisheries and Marine Affairs; Ministry of Agrarian Affairs and Spatial Planning/National Land Agency; Ministry of Villages, Development of Disadvantaged Regions, and Transmigration
6. Japan (e-Gov Japan 2014)	Ministry of the Environment; Ministry of Land, Infrastructure, Transport and Tourism	Ministry of Economy, Trade and Industry	Ministry of Agriculture, Forestry and Fisheries; Ministry of Land, Infrastructure, Transport and Tourism
7. Lao PDR (The Committee for External Relations of the Central Committee of Lao's People Revolution Party 2017)	Ministry of Natural Resources and Environment; Ministry of Public Works and Transport; Ministry of Planning and Investment	Ministry of Energy and Mines; Ministry of Public Works and Transport; Ministry of Planning and Investment	Ministry of Agriculture and Forestry; Ministry of Planning and Investment; Ministry of Natural Resources and Environment
8. Malaysia (The Malaysia Administrative Modernisation and Management Planning Unit 2019)	Ministry of Environment and Water; Ministry of Rural Development; Ministry of Housing and Local Government; Ministry of Works	Ministry of Energy and Natural Resources; Ministry of Rural Development; Ministry of Housing and Local Government; Ministry of Science; Technology and Innovation; Ministry of Works	Ministry of Agriculture and Food Industry; Ministry of Plantation Industries and Commodities
9. Mongolia (Baljmaa 2020; Ministry of Nature, Environment and Tourism 2017)	Ministry of Environment and Tourism	Ministry of Energy	Ministry of Food, Agriculture and Light Industry

(continued)

Table 14.1 (continued)

Country	Water	Energy	Food
10. Myanmar (Myanmar President Office 2019)	Ministry of Agriculture, Livestock and Irrigation; Ministry of Natural Resources and Environmental Conservation; Ministry of Planning, Finance and Industry	Ministry of Electricity and Energy; Ministry of Planning, Finance and Industry	Ministry of Agriculture, Livestock and Irrigation; Ministry of Natural Resources and Environmental Conservation; Ministry of Planning, Finance and Industry
11. Republic of Korea, South Korea (Department Global Communication and Contents Division 2012)	Ministry of Environment	Ministry of Trade, Industry and Energy	Ministry of Agriculture, Food and Rural Affairs
12. Singapore (Government of Singapore 2019)	Ministry of Sustainability and the Environment; Ministry of Trade and Industry; Ministry of National Development	Ministry of Trade and Industry; National Environment Agency	Singapore Food Agency (multi-ministry task force)
13. Thailand (The Government Public Relations Department 2020)	Ministry of Natural Resources and Environment; National Water Resource Committee, Office of National Water Resources	Ministry of Energy; Ministry of Industry	Ministry of Natural Resources and Environment; Ministry of Agriculture and Cooperatives; Ministry of Natural Resources and Environment
14. The Philippines (Official Gazette of Republic of the Philippines 2018)	Department of Environment and Natural Resources; Department of Public Works and Highways; Department of the Interior and Local Government; Housing and Urban Development Coordinating Council; National Economic and Development Authority	Department of Energy; Department of Public Works and Highways; Department of the Interior and Local Government; Housing and Urban Development Coordinating Council; Department of Trade and Industry; National Economic and Development Authority	Department of Agrarian Reform; Department of Agriculture; Department of Trade and Industry; National Economic and Development Authority

(continued)

Table 14.1 (continued)

Country	Water	Energy	Food
15. Vietnam (Vietnam Government Portal 2020)	Ministry of Natural Resources and Environment; Ministry of Construction; Ministry of Agriculture and Rural Development; Ministry of Planning and Investment; Ministry of Industrial and Trade	Ministry of Industry and Trade; Ministry of Planning and Investment	Ministry of Agriculture and Rural Development; Ministry of Industry and Trade; Ministry of Planning and Investment

to be continuously monitored and coordinated at the regional level to ensure that the nexus approach is feasible, given the variation in government structures across the region. Improved data are needed on the public governance systems surrounding WEF resources, including on the science-policy interface for these resources given their transboundary importance. Bridging the gap in regional understanding and current knowledge of resources is required to ensure multi-level governance and coordination for WEF systems.

14.6 Useful WEF Nexus Approaches to Enhance Sustainable Development

This section introduces examples of projects and policies already implemented or planned for implementation in the region, which can accelerate the achievement of the SDGs, particularly from the WEF nexus perspective.

14.6.1 Maximizing Synergies: Solar Electrification Programme (Indonesia)

The case of a solar electrification programme in East Nusa Tenggara in Indonesia, submitted to the UN as an SDG good practice, is an example that shows how the energy, water, and food sectors are closely linked. Investing in one goal, access to sustainable energy (SDG 7) in this case, can contribute to multiple SDGs, including water security (SDG 6) and food security (SDG 2) (United Nations—The Partnerships for SDGs 2018).

In this case, a remote rural village in eastern Indonesia, which relied on moonlight and kerosene lamps after sunset, was transformed into an electrified village with the help of non-governmental organizations, educational institutions, and the government. Under the leadership of the women in the village who completed a training course on solar power generation, the villagers successfully installed and operated solar panels in the community. Now, the villagers enjoy bright lights at night and an improved quality of life (SDG 7.1 ensure universal access to affordable, reliable, and modern energy services).

One of the factors behind the project's success lies in the active participation of beneficiaries, the community members. The residents identified their own needs for and roles in village development, fully understood the programme, and established and implemented their own funding plans for battery replacement. A sense of ownership by beneficiaries ensured the sustainability of the programme.

As fishing became possible at night, fish yields increased (SDG 2.3 double the agricultural productivity and the incomes of small-scale food producers; SDG 2.1 end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round). A solar-powered water pump system provided access to clean water (SDG 6.1 achieve universal and equitable access to safe and affordable drinking water for all).

The growth in the production of woven cloths and reduced costs for kerosene for their lamps led to higher incomes (SDG 8 decent work and economic growth, and SDG 1 poverty eradication). The accessibility of health services improved (SDG 3 good health and well-being), and students and youth were able to spend more time studying (SDG 4 quality education). Some of the female members in the community were empowered with capabilities and confidence through skills development (SDG 5 gender equality). Finally, the whole project was implemented through multi-stakeholder collaboration (SDG 17 partnerships for the goals).

There are complex links that exist between sustainable energy projects and the food and water sector, and the WEF nexus approach to project design or evaluation could potentially help to improve energy development interventions at the local level (Terrapon-Pfaff et al. 2018). While this case focused on energy access, it is worth noting that water (SDG 6) has the most potential synergies with other SDGs, and supporting targets related to SDG 6 will make it easier to achieve other goals (Fader et al. 2018).

14.6.2 Improving Resource Efficiency: Hydrothermal Energy Complex (Republic of Korea)

The nexus approach can leverage existing single-sector infrastructure with supplementary investments to achieve synergies between competing sectors and maximize benefits (IUCN 2019), as seen in the following case.

The Ministry of Environment of the Republic of Korea announced plans to foster hydrothermal energy as the flagship project of the Green New Deal in June 2020 (Ministry of Environment 2020). Hydrothermal energy can be used for heating and cooling by using physical characteristics that are colder than the atmosphere in summer and warmer in winter. Its use can eliminate cooling towers for heat-producing buildings and reduce energy use (SDG 7) and greenhouse gas emissions (SDG 13).

The plan introduces a pilot project to build the Gangwon Hydrothermal Energy Convergence Cluster in Chuncheon, Gangwon Province, by 2027 utilizing the Soyang Dam. The country intends to verify the effectiveness of hydrothermal energy projects by using dam water, which has not yet been widely used as a renewable energy source, and to establish opportunities to expand hydrothermal energy use. This pilot project aims to reduce energy use by aggregating energy-intensive facilities such as data centres, smart farms, enterprises, and residential complexes around the Soyang Dam, and it uses hydrothermal energy from the dam water for cooling. At a certain depth, dam water remains cool throughout the year, making it suitable for cooling clustered facilities such as data centres. After the data centres increase water temperatures, the water with elevated temperature is reused in smart farms and business and residential complexes, heating these facilities and then being discharged back to the dam.

All of the water intake volume is returned to the stream or dam; thus, there is no loss of water, and only heat energy is utilized without introducing pollutants. Hydrothermal energy saves on energy costs compared to fossil fuels and lowers greenhouse gas emissions, contributing to the fight against climate change. Another advantage is that this kind of project can revitalize the local economy by creating jobs and higher incomes (SDG 8) from value adding agricultural products.

As seen in this plan, co-locating water, energy, and agricultural infrastructure makes it possible to minimize transportation costs and lower energy and water requirements. It also shows the potential of using existing infrastructure to overcome resource scarcity and increase resource efficiency.

Box 2: Gangwon-do Water Thermal Energy Convergence Cluster in the Republic of Korea

By 2027, the Soyang River Dam will be used to the create Gangwon-do Water Thermal Energy Convergence Cluster in Chuncheon, Gangwon-do (supply scale: 16,500RT). The Soyang River Dam, which is 198 m deep, holds 2.9 billion tons of fresh water that maintains 5–6 °C yearly. A total of 250,000 m^3 of raw water (approximately 7 °C) is supplied daily to an integrated control centre.

- Area: 785,000 m^2.
- Project Cost: 302.7 billion won.
- K-Cloud Park (world's first eco-friendly data centre complex powered by water thermal energy): 210,000 tons is supplied to data centres. The electricity cost can be reduced by up to 75.7% compared to data centres in the area of Seoul. 200 MW floating PV (photovoltaic plant) is also planned.

- Smart Farm High-Tech Agricultural Complex: 40,000 m^3 of water warmed in data centres (approximately 12 °C) is reused as a heating source for smart farms, houses and buildings. For cooling, 40,000 m^3 of raw water as a cooling source is supplied directly from the Soyang River.
- Specialized Industrial Complex for Water businesses: Specialized industrial complex buildings provide a new business ecology of integration and co-work.
- Eco-friendly Housing Complex: After the reuse of water for heating, water that is cooled again (approximately 7 °C) is supplied to data centres.

14.6.3 Innovating with Up-to-Date Technology: Digital Farming (Japan)

Agriculture is by far the largest consumer of water resources (World Bank 2020). New digital technologies can enable more production with less resource inputs, increasing resource efficiency and sustainable agricultural practices, in line with SDGs 2, 8, and 12.

Goedde et al. (2020) suggest that smart farming practices with advanced connectivity, such as smart monitoring with connected sensors, drone surveillance, and the use of artificial intelligence, could further increase productivity and streamline the use of inputs, including water, and will ultimately enhance the sustainability of the sector. The article argues that the potential impacts of these technologies are higher in Asia than in North America, where productivity is already considerably optimized.

To increase yield and address concerns about agricultural sustainability, the Japanese government has been developing and encouraging digital agricultural technologies (The Government of Japan 2021). By collecting and analysing farming practices and environmental data using the Internet of Things (IoT) and artificial intelligence (AI), farmers can increase productivity while using water and fertilizer efficiently. For example, in a highly digitized strawberry farm, computers control temperature and humidity to maintain the best cultivation conditions and to provide water at the right time, while in a rice farm, electronic sensors measure water levels and monitor the condition of rice in the paddies (Kaneko 2017).

Precision farming based on advanced technology is expected to reduce the use of water and chemicals such as fertilizers and pesticides and the energy required for irrigation, heating, and cooling. Moreover, agricultural practices equipped with the latest technology improve the young generation's perception of this traditional sector. It offers the potential to attract a new generation of young 'smart farmers' to rural areas to re-invigorate rural and agro-economies that can also feed growing populations.

14.6.4 Climate, Land-Use, Energy, and Water Systems (CLEWS) Modelling

As climate change increases the unpredictability of resource changes, new modelling tools can be used to assess how consumption and production across the WEF nexus affect climate change and how resource use will contribute to climate change. Climate, land-use, energy, and water systems (CLEWS) models are tools for simultaneously incorporating a WEF nexus approach into the public governance and policymaking process. With agreed-upon policy goals, countries in the region can adopt the stepwise approach suggested to build a CLEWS model: (1) system profiling (identifying hotspots/data collection); (2) model development; (3) model execution; (4) analysis of the results; and (5) informing policymaking (CLEWS 2017).

For countries to adopt regional or sub-regional approaches for the WEF nexus and to ensure that doing so is consistent with sustainable development and resilience, CLEWS models can provide a common approach for governments to use. Through the modelling tools, policymakers can assess pressure points or leverage points, as well as the interactions and interdependencies in areas of climate, land use, energy, and water, to ensure more evidence-based decision-making on the SDGs. CLEWS models have been applied in multiple countries, sectors and more to assess competition for water resources, agricultural transformation, taxes on fossil fuels and water consumption impacts and to compare climate scenarios alongside trade-offs (CLEWS 2020). Line ministries and other key stakeholders related to CLEWS and, therefore, also the WEF nexus can be equally engaged in the implementation of the approach to ensure a multi-level governance approach and more data-driven and evidence-based decisions.

14.7 Conclusions and Recommendations

Water, energy, and food are basic necessities of human life. The competition over these resources can lead to various forms of conflict at the regional, national, and local levels, threatening security and peace. As stated in the 2030 Agenda for Sustainable Development adopted in 2015, peace and security are interdependent with sustainable development. Peace is one of the 5 Ps of the 2030 Agenda and has its own goal under SDG 16 alongside effective government institutions to sustain peace and good governance. Water, energy, and food are also key components of sustainable development, as in SDGs 2, 6, and 7, but they remain interdependent and interlinked with all other SDGs. The interdependence of the water, energy, and food systems across the 2030 Agenda is due to human reliance on earth systems, and as a result, peace and security around natural resource governance should be understood from a macroscopic view of the earth system as a whole.

In East and Southeast Asia, long-term peace and security are possible only when water, energy, and food governance and policymaking shift from a focus on security to resilience. This focus on resilience and transboundary cooperation to achieve it is the key to realizing sustainable development. Multi-level governance and regional cooperation for the resilience of WEF systems are essential to avoid conflict in the current situation where the impact of climate change increases resource uncertainty and risk. The direction of public governance should shift from managing WEF resource security to improving resource efficiency and, ultimately, resilience.

The recent COVID-19 pandemic threatens the maintenance of international peace and security and increases the risk of not achieving the 2030 Agenda, with short- and long-term effects on all aspects of society, including the water, energy, and food sectors. Paradoxically, however, we should take this crisis as an opportunity to adopt innovative approaches that can accelerate cooperation and policymaking around the WEF nexus. Efforts should be made to ensure that the 'Decade of Action' until 2030 is a decade of green and resilient recovery, more than just a return to business-as-usual before the crisis.

The cases introduced at the end of this chapter suggest that WEF nexus-related efforts can be made in all countries regardless of the degree of development. A project focused on one of the sectors of energy, water, or food can create synergies in other sectors through improved planning and contribute to accelerated progress on the SDGs and resilience in the water, energy and food systems. These efforts may be led not only by the government but also by various entities, such as civil society, private enterprises and academia.

In this respect, strengthening governance focusing on the nexus approach is critical. At the sub-regional level, it is worth considering a multilateral agreement that addresses the WEF nexus to encourage nexus approaches in national policymaking. At the national level, given the various government entities leading WEF resource policymaking and overlapping mandates, improving coordination through multi-level governance is essential. The long-term sustainable development of the WEF systems can be guaranteed when regional cooperation, multi-level governance, and evidence-based policies adopting a nexus approach are implemented in all countries in the East and Southeast Asian region.

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Chapter 15
Addressing Nexus Challenges—Innovative Approaches to Urban Nexus Security

Thammarat Koottatep and Ida Bagus Hendra Gupta

Abstract Thirty percent of the world's population lives in East and Southeast Asia, of which close to 60% lives in urban areas. The Global Competitiveness Report 2018 recognized that the increasing economic dynamism of the region has contributed to rapid industrialization, a rise in living standards, and a drastic reduction in extreme poverty. The report further stated that the region was one of the fastest growing regions in the world in 2017, including China's significant contribution to the region's rapid economic growth. Such rapid growth leads to a massive consumption of natural resources, resulting in unprecedented environmental problems such as pollution, resource depletion, and waste disposal. If one considers the urban setting to be a starting point for dealing with the water–energy–food (WEF) nexus, it offers immense challenges and opportunities for innovative solutions. Innovative approaches, both existing and new technology, are required to safeguard the most critical resources. This chapter examines approaches and technologies that can contribute to overcoming nexus challenges in East and Southeast Asia.

Keywords Innovative · Technology · Urban · WEF · Nexus · East and Southeast Asia

15.1 Introduction

The nexus approach linking water, energy, and food (WEF) security seeks to achieve resource efficiency and sustainability through holistic approaches that fully encompass the interconnection between different nexus elements. The East and Southeast Asian regions present an enormous diversity in terms of the availability of water,

T. Koottatep
Asian Institute of Technology, Bangkok, Thailand
e-mail: thamarat@ait.ac.th

I. B. H. Gupta (✉)
Bremen Overseas Research and Development Association, Bremen, Germany
e-mail: hendra@borda-sea.org

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energy, and land resources that contribute to production systems. Nevertheless, the region possesses great potential for improvement. One of the greatest challenges in achieving efficiency in the production systems of the region is how to ensure that the demands for water, energy, and food are properly valued and that these resources are secured with sufficient access to all.

In the context of water and food production, it is important to note that East and Southeast Asia is a major rice production region of the world. It has long been recognized for possessing knowledge resources in rice production that allow it to adapt to the varying natural landscape and geography of the region. For example, a terraced system, a rice planting technique that is applied on sloping terrain, continues to be practised in the Philippines (known as *Zanjeras*), Indonesia (*Subak*), and Thailand (*Muang-fai*). In contrast, farmers in Bali, Indonesia, have built diversion weirs in rivers or canals to irrigate their paddy fields without worrying about the flow of water through the fields (Yekti 2017). Despite such ancient and innovative methods of agriculture and rice production, challenges remain in ensuring food security, providing access to clean water and sanitation, and meeting the energy demands of poor individuals. Furthermore, many countries in the region are trapped in natural resource conflicts that are further compounded by bad governance systems and limited technology.

The nexus approach recognizes that the pressures of population growth, urbanization, and globalization will increase the demand for water, energy, and food resources, which are closely linked to each other. The negative nexus between WEF production systems has created stresses that threaten the sustainability of the ecosystem, of which humans are a part. At the same time, the increasing demands for these resources have also created opportunities to achieve synergies that can contribute to increased efficiency. Half of the world's population now lives in cities, and decision-makers face challenges in formulating policies and taking actions to create a sustainable urban environment by managing waste, improving resource efficiency, and securing clean water, energy, and food for all. Fortunately, with continuous advances in science, technology, and innovation (STI), various technologies are available to, for example, convert waste into energy, promote urban farming and decentralized water systems, and better treat wastewater so that it can safely be disposed of in the urban environment. The deployment of technology can be achieved with good collaboration between decision-makers, civil society, and private sectors, including the use of innovative financing tools. A sustainable future can occur when good planning lays the foundation and inbuilt resilience guards against future risk. Smart cities that deploy the best technology for the job and innovative financing tools are good examples (UNESCAP 2019).

This chapter reviews the population growth, urbanization, and food production in the East and Southeast Asian regions in light of the STI that is necessary to manage waste and recover resources in urban contexts. We introduce some interesting approaches and innovative technologies for resource recovery, such as the conversion of urban waste into energy, in view of the urban nexus. This chapter argues that decision-makers will have to incorporate investments in STI. The large-scale application of existing and recent technologies will determine the progress made in addressing the nexus challenges in urban settings.

15.2 Population Growth and Urbanization in East and Southeast Asia

The East and Southeast Asian regions are home to 30% of the world's population. In 2019, 2.3 billion people lived in East and Southeast Asia (UNDESA 2019). The population of the region nearly tripled from 1950 (842 million) to 2019, and the population of Southeast Asia reached 662 million in 2019, four times higher than the population in 1950 (165 million) (Fig. 15.1). The median value of the projected population of the region will reach nearly 2 billion in 2100 (UNDESA 2019). China and Indonesia are the most populated countries of the two regions. Brunei Darussalam and Mongolia recorded the highest population growth since 1950, with population growth in the two countries being nine and four times higher in 2019, respectively.

East and Southeast Asia are rapidly urbanizing. The World Urbanization Prospects (2018) estimated that 65% of East Asia's population and 50% of Southeast Asia's population resided in urban areas in 2020 (UNDESA 2018). It also predicted that whereas only 17.9% and 15.6% of the total population in East Asia and Southeast Asia, respectively, lived in urban areas in 1950, by 2050, approximately 81.4% of the total population in East Asia and 66% of the total population in Southeast Asia will be living in urban areas. Table 15.1 shows the historical and projected percentages of the urban population in East and Southeast Asia. The urban growth rates between 1950 and 2018 were positive in all countries in the region. Under such rapid urbanization, the urban-centralized nexus linked to WEF security can offer enormous opportunities

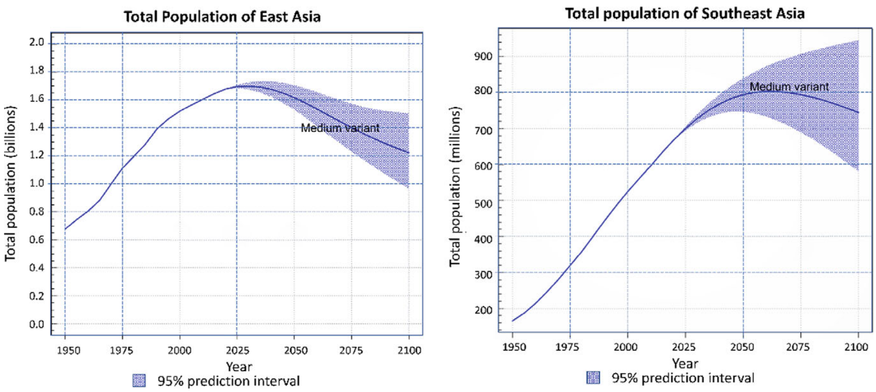

Fig. 15.1 Total population of East Asia and Southeast Asia (*Source* UNDESA 2019) adapted by the author

Table 15.1 Historical and projected percentage of the urban population in East and Southeast Asia

No	Region and country	1950	1975	2000	2020	2025	2050
	East Asia	*17.9*	*25.5*	*42.0*	*64.8*	*69.2*	*81.4*
1	China	11.8	17.4	35.9	61.4	66.5	80.0
2	Democratic People's Republic of Korea	31.0	56.7	59.4	62.4	63.8	74.2
3	Japan	53.4	75.7	78.6	91.8	92.2	94.7
4	Mongolia	20.0	48.7	57.1	68.7	69.5	77.7
5	Republic of Korea	21.4	48.0	79.6	81.4	81.6	86.4
	Southeast Asia	*15.6*	*23.2*	*37.9*	*50.0*	*52.8*	*66.0*
1	Brunei Darussalam	26.8	64.2	71.2	78.3	79.7	85.7
2	Cambodia	10.2	4.5	18.6	24.2	26.5	41.2
3	Indonesia	12.4	19.3	42.0	56.6	59.8	72.8
4	Lao People's Democratic Republic	7.2	11.1	22.0	36.3	39.6	55.7
5	Malaysia	20.4	37.7	62.0	77.2	79.7	87.3
6	Myanmar	16.2	23.9	27.0	31.1	32.8	47.1
7	Philippines	27.1	35.6	46.1	47.4	49.0	61.8
8	Singapore	99.4	100.0	100.0	100.0	100.0	100.0
9	Thailand	16.5	23.8	31.4	51.4	55.0	69.5
10	Vietnam	11.6	18.8	24.4	37.3	40.9	57.3

Source UNDESA (2018) adapted by the author

for the sustainability of the region if the right policies and technologies are in place. Indeed, urban living has the potential to use resources more efficiently, create more sustainable land use, and protect the biodiversity of the natural ecosystem in all regions whether urban or non-urban.

15.3 STI in East and Southeast Asia

The development of technology offers opportunities to overcome the environmental challenges that arise in the region, such as population, urbanization, food production, and environmental pressures such as waste production and wastewater disposal. The development of STI differs based on the country context and focus. China, Japan, the Republic of Korea, and Singapore incorporated STI within their development focus earlier than other countries in the region. Policies on STI in these countries have been recognized as playing a significant role in their socio-economic transformation (UNESCAP 2018).

The ratio of gross domestic expenditure on research and development (GERD) to gross domestic product (GDP) varies between countries in the region. GERD as a percentage of GDP is the total intramural expenditure on R&D performed in the national territory during a specific reference period expressed as a percentage of the GDP of the national territory (UNESCO 2021). Table 15.2 compares the countries' 5-yearly GERD ratio to GDP from 1995 to 2015. The investment can be categorized as countries with a high investment GERD-to-GDP ratio that is beyond 2%, including China, Japan, the Republic of Korea, and Singapore. Countries with a GERD expenditure-to-GDP ratio below 1% are Cambodia, Indonesia, Myanmar, Mongolia, the Philippines, Thailand, and Vietnam. Malaysia is located in between the two categories. The Republic of Korea has the highest ratio of GERD to GDP in the region, recording impressive growth of 2.26% in 1996 to 4.22% in 2015. Japan and the Republic of Korea invested 2.69% and 2.26%, respectively, of their GDP in STI in 1996, when most countries invested less than 1%. Countries such as Mongolia, Cambodia, Indonesia, Thailand, and Vietnam have a GERD-to-GDP ratio below 1%. No data or only partial data were available for Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Myanmar, the Philippines, Timor-Leste, and Vietnam.

Table 15.3 shows the GERD share by the business sector. Business sectors were involved in technology innovation in Japan and the Republic of Korea as early as 1940, when the government developed a policy to develop the capabilities of local industries (UNESCAP 2018). In 1996, the business sectors in the two countries contributed more than 70% of the total investment funds for STI. China's business

Table 15.2 GERD as a percentage of GDP in East and Southeast Asia

Region and countries	GERD as a percentage of GDP				
	1996	2000	2005	2010	2015
East Asia					
China	0.56	0.89	1.31	1.71	2.07
Democratic People's Republic of Korea					
Japan	2.69	2.91	3.18	3.14	3.28
Mongolia	–	0.19	0.24	0.24	0.15
Republic of Korea	2.26	2.18	2.63	3.47	4.22
Southeast Asia					
Brunei Darussalam	–	–	–	–	–
Cambodia	–	–	–	–	0.12
Indonesia	–	0.07	–	–	–
Lao People's Democratic Republic	–	–	–	–	–
Malaysia	0.22	0.47	–	1.04	1.30
Myanmar	–	0.11	–	–	–
Philippines	–	–	0.11	–	0.16
Singapore	1.32	1.82	2.15	1.98	2.26
Thailand	0.12	0.24	0.22		0.62
Vietnam	–	–	–	–	0.44

Source UNESCO (2021) adapted by the author

Table 15.3 GERD funded percentage by business sector

Region and countries	1996	2000	2005	2010	2015
East Asia					
China		58	67	72	75
Japan	73	72	76	76	78
Mongolia			10	7	7
Republic of Korea	75	72	75	72	75
Southeast Asia					
Brunei Darussalam					
Cambodia	–	–	–	–	19
Indonesia	–	26	–	–	–
Lao People's Democratic Republic	–	–	–	–	–
Malaysia	–	–		60	50
Myanmar	–	–	–	–	–
Philippines	–	–	63	–	38
Singapore	58	55	59	53	–
Thailand	18	–	49	–	66
Timor-Leste	–	–	–	–	–
Vietnam	–	–	–	–	58

Source UNESCO (2021) adapted by the author

sectors are catching up, contributing 72% of the total investment funds in 2010. The business sectors of Malaysia, Singapore, Thailand, the Philippines, and Vietnam contributed 50–70% of the total investment funds. Singapore has initiated the development of STI since 1965 and has maintained the contribution of business sectors to STI investment, ranging from 50 to 60% within the past two decades.

15.4 Opportunities and Challenges of the Nexus in Cities

Urban areas play a critical role in strategies to protect people and ecosystems. The World Cities Report 2020 stated that cities give rise to a set of complex problems around challenges such as health, education, mobility, logistics, food security, consumption, waste, poverty, and inequality (UN Habitat 2020). These issues make cities prime stages for developing innovative solutions to global challenges.

15.4.1 Food Waste and Energy in Urban Settings

Urbanization and population growth have increased the opportunities and challenges to secure food and nutrition for all. The rapid expansion of urban areas raises critical concerns regarding issues such as the generation of food waste. Food waste is defined as the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services, and consumers (FAO 2019). The UNEP further refined the definition of food waste as food and the associated inedible parts removed from the human food supply chain in the following sectors: retail, food services, and households (UNEP 2021). The Food Waste Index Report 2021 estimated that approximately 931 million tonnes of food waste were generated in 2019, 61% of which came from households, 26% from food services and 13% from retail (UNEP 2021). The disposal and treatment of wasted food are an enormous challenge considering the mix of wastes in its content.

Organic and agricultural waste resources produced in urban areas can be used to generate energy and fertilizers (Dubbeling et al. 2016). During this process, technology plays an important role in treating urban food waste. State-of-art studies on food waste treatment and disposal strategies in Asian countries revolve around five major options: animal feeding, composting (aerobic digestion), anaerobic digestion and fermentation, incineration, and landfilling. The disposal of organic waste such as food waste along with municipal solid waste decreases the recycling rate and increases the landfilling rate. Hence, source segregation and treatment are the way forward for the sustainable waste management of these organic wastes (Visvanathan and Mohanakrishnan 2018). Given the enormous amount of food waste, the conversion of food waste into energy through innovative STI possesses a great potential to achieve urban nexus security and to provide a circular economy model of urban food waste (Fig. 15.2).

Example 1: Conversion of Community-Based Food Waste into Energy and Fertilizer Production

The Asian Institute of Technology in Thailand has developed Internet-of-Things (IoT) based decentralized community-scale anaerobic digestion for waste treatment and resource recovery at the campus. Anaerobic digestion is one of the most appropriate (and preferred) options for the management of food waste in Asia, and thus, the policy drivers of the region have paid increasing attention to using waste to produce energy. Small-to-medium-scale decentralized systems for anaerobic digestion have received increasing attention as the way forward over large-scale centralized systems, since they are easier to operate and require less space (Joshi and Visvanathan 2019). This technology treats food waste by digesting solids and turning them into electricity. The inclusion of sensors that capture the composition of biogas presents an opportunity to monitor the performance of the treatment plant, which then allows an operator to make an informed decision. The food waste to energy project is an example of decentralized community-managed waste management. The AIT campus, with an area of 133 ha, produces approximately 1680 kg of waste every day, of which 60% is food waste. The community food waste contains a mixture of raw, cooked, and overripe food, with no formal method of segregation for disposal. Segregation of waste is required to remove plastic bags, bones, and other non-degradable solid material before disposal of waste to the digester. The waste is then pulverized before being fed to the digester. After the digesting period, the treatment produces biogas and a nutrient-rich bio-fertilizer. The research demonstrates that feeding an estimated 1000 kg of food waste daily to the digester can produce 100 m^3 of biogas, an equivalent of 60 L of kerosene, 167 kg of firewood, or 73 kg of charcoal. The digester also generates 187 kWh of power, which can light 1000 15 W LED bulbs (Asian Institute of Technology 2020).

Example 2: South Korea's Urban Farm and Food Waste Recycling

South Korea's fundamental action to recycle food waste demonstrates a nice example of WEF nexus interconnection. At present, South Korea recycles 95% of its food waste, compared to only 2% in 1995. A foul odour and a large amount of leachate from the collection and treatment process triggered

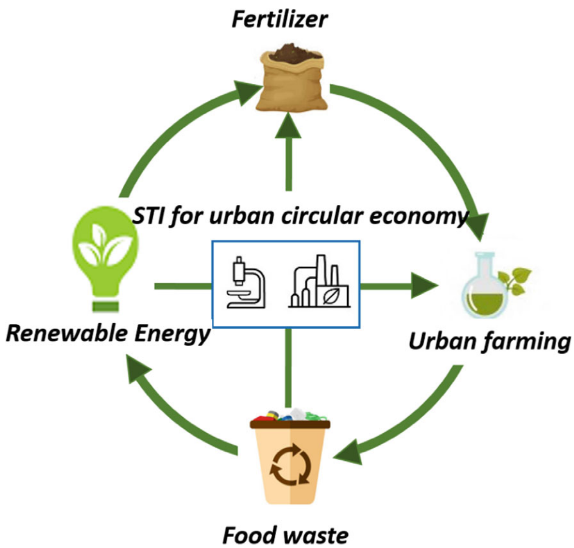

Fig. 15.2 Conceptual diagram of the urban circular model: conversion of food waste into urban resources

the government to address the issue. The government imposed a volume-based user fee system in 1995 and 1997 and released a notice of intent to ban food waste in landfills by 2005 (UNDP 2019). Furthermore, from 1998 to 2004, the government supported municipalities both financially and technically in establishing collection systems and constructing food waste treatment. The government encouraged private companies to participate in the treatment of food waste. In 2005, the government banned the dumping of food waste in landfills and stopped dumping leftover water squeezed from food waste into the ocean in 2013. The government introduced compulsory food waste recycling using special biodegradable bags in 2013. Automated bins equipped with scales and radio frequency identification (RFID) that weigh food waste as it is deposited and that charge residents using an ID card were installed. In Seoul, there are 6000 automated bins installed across the capital city. There are 240 food waste treatment facilities operating nationwide, of which 140 of the facilities are operated by private companies. The waste collected is then drained at the processing plant to remove moisture. The liquid part is then used to create biogas and bio-oil, while dry waste is processed into animal feed and fertilizer that support the country's rapidly growing urban farm movement. The urban farms or community gardens in Seoul currently account for 170 ha, a six-fold increase over the past seven years.

15.4.2 Resource Recovery from Wastewater and Waste in Urban Settings

Our best chance for a sustainable future is determined by the way we manage cities. Therefore, it is important to learn about the relationship between ecosystems and urban expansion and to address the challenge of improving environmental security, for example, the quality of water. Historically, water has determined the locations of settlements. Water is the centre of the nexus interplay and is non-substitutable. In cities, wastewater and solid waste are often disposed of in water bodies such as lakes, ponds, canals, or rivers, and thus, the quality of water is considerably related to the urbanization level.

The proportion of the population using improved sanitation facilities in 2012 stood at 66% and 71% in East Asia and Southeast Asia, respectively (Asian Development Bank 2014). The ADB further stated that the urban coverage of improved sanitation was 75% and 80% for East Asia and Southeast Asia, respectively. Developed countries such as Japan, the Republic of Korea, and Singapore have reached almost 100% coverage of improved sanitation facilities in urban and rural areas. Malaysia (96%) and Thailand (93%) are two Southeast Asian countries that nearly reach full coverage of improved sanitation.

Waste management and sanitation in East and Southeast Asia vary depending on the country. Wastewater treatments can be categorized by the number of household connections, including individual residential systems, decentralized systems, community-scale systems, and centralized systems or city-wide systems. Cities in China, Japan, the Republic of Korea, Malaysia, and Singapore have treated wastewater from domestic, commercial, and industrial sources using centralized treatment plants, in which nearly all households are connected to sewerage. Other countries, such as Indonesia and the Philippines, have applied centralized treatments in major cities and are striving to achieve household connections for all. Fast-growing city centres such as Luang Prabang and Vientiane (Lao PDR), Bangkok (Thailand), Hanoi (Vietnam), and Kunming (China) have applied a conventional approach (i.e., flush and forget) for the provision of environmental sanitation and improved urban infrastructure (Koottatep 2010).

Most urban areas manage waste and wastewater in a linear model. The conventional linear practice first treats waste and wastewater and then disposes of them to landfills and a receiving body, respectively. Recently however, scientists and policymakers have focused on the potential to recover resources such as energy and nutrients from wastewater and solid waste (a circular model). Indeed, solid waste contains a mixture of materials, including organic waste, implying that these wastes could yield compost and biogas with proper techniques, such as composting and anaerobic digestion.

The treatment of waste should be seen not only as an approach to safely dispose of wastes, but also as a way to benefit from water reuse, energy generation, and the use of biosolids as fertilizers (Fig. 15.3). Organic wastes such as excreta, wastewater, and animal wastes contain energy that may be recovered by physical, chemical, and biological techniques, as well as the combination of different techniques (Polpasert and Koottatep 2017). Various wastewater and solid waste treatment technologies for recovering resources from wastewater are available on the market. Energy or biogas can be recovered or produced through anaerobic digestion treatments. Nutrients such as phosphorous and nitrogen can be recovered through crystallization processes. Faecal sludge and food waste can be composted to produce energy and fertilizer for agricultural purposes. Resource recovery will increase the value of the area by improving the quality of the environment and surface water, the reuse of treated water, and a supply of organic fertilizers to farmers. Considering that cities produce a massive amount of organic waste every day, the recovery of material from waste and wastewater through innovative STI can not only significantly reduce the amount of waste disposed of, but also guide us to achieve WEF nexus security and healthy urban settlements for all.

Example 3: Plastic Recovery and Cogeneration in Rayong, Thailand

Rayong municipality is an industrial zone on the eastern coast of Thailand. The municipality is 180 km away from Bangkok and has an area of 3552 km^2,

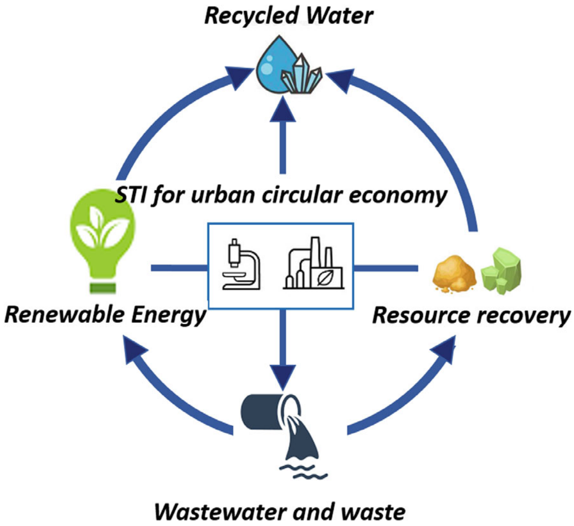

Fig. 15.3 Conceptual diagram of the urban circular model: conversion of waste and wastewater into urban resources

covering eight administrative districts. In 2006, the city population was estimated to reach approximately 60,000. Having evolved as a commercial city, Rayong produced 60.3 tons/day of solid waste between 1995 and 1997. In 2004, Rayong installed a solid waste treatment facility designed to treat 70 tons of waste daily or 25,550 tons annually. The facility applies treatments to stabilize waste, generate electricity, and produce soil conditioner (Polpasert and Koottatep 2017). The plant is projected to annually generate 2.2 million cubic metres of biogas, 5100 MWh of electricity, and produce 5600 tons of soil conditioner. The recovered methane (CH_4) from the anaerobic digestion process that was used in electricity generation resulted in a greenhouse gas (GHG) reduction of approximately 0.34 Gg CH_4 per year, equivalent to 7.15 Gg CO_2 equivalent of total GHG emissions per year (Jutidamrongphan 2018).

Rayong is a pilot province of the public–private partnership plastic project in Thailand, and it intends to develop an effective waste management system with the support of both public and private agencies, local administrative organizations, and civil society by incorporating the circular economy concept. The project was initiated to engage the public in recycling plastic waste and to introduce a circular economy model. Thailand is one of the top 10 plastic debris contributors to the ocean along with other countries such as China, Indonesia, the Philippines, Vietnam, Sri Lanka, Egypt, Malaysia, Nigeria, and Bangladesh. The collaboration between private and public institutions is expected to contribute to reducing the amount of plastic waste found in Thailand's sea by at least 50% by 2027 (GC Circular Living 2019).

Example 4: Resource Recovery from Domestic Urban Wastewater in Japan

Japan addressed the sanitation issues in urban areas at the beginning of the twentieth century due to the spread of infectious water-borne diseases that caused casualties (Japan Sewage Works Association 2017). The report further stated that measures were taken to contain and remove wastewater and stormwater from residential areas. However, water pollution remained a problem for the country. In the 1970s, the government of Japan decided to conserve water quality and to massively invest in and install new wastewater treatments and expand the capacities of existing treatments. Gradually, the government of Japan improved the policies and laws on wastewater treatment and the use of by-products. In 1996, a new law was published to encourage the recycling and use of sludge generated from wastewater treatments. Currently, Japan has built a total of 460,000 km of sewer lines and 2200 treatment plants that serve 80% of the population. The rivers are cleaner now than they were in the 1970s and 1980s due to full connection. However, eutrophication or excessive algal blooming remains a challenge. Tokyo Bay, Nagoya Bay, Osaka Bay, Lake Biwa, and Lake Kasumigaura are the most affected by excessive algae growth. Cases of red tide, blue tide, and others have been reported to appear in these stagnant coastal and freshwater bodies. Japan has responded by introducing novel approaches to optimize the operation and remove nutrients with the conventional activated sludge process. Furthermore, the country is shifting from treating wastewater for safe disposal to resource recovery. Clean water, organic and inorganic fertilizer, biochar, and energy in the forms of heat, fuel, and electricity are produced by and recovered from the collection and treatment of wastewater. Reused water is used for landscape and river maintenance and snow melting. The local governments of Tokyo and Fukuoka, where severe water shortages are predicted, published laws that require developers to use recycled water, either treated wastewater or harvested rainwater, for flushing toilets and landscape irrigation. Japan has focused on recycling sludge to biochar and ash supporting the production of cement, concrete products, fertilizer, soil stabilizing agents, and asphalt filler. The recovery of phosphorus is a priority since it is becoming a scarce resource. The government focuses on energy recovery such as air conditioning through exchanging heat with effluent and raw sewage, the refinement of biogas for vehicles' fuel and the supply district gas network.

15.5 Recommendation

The experiences of East and Southeast Asian countries have shown that the use of technology supported by policies helps governments and other agencies improve and adapt to the situation in handling urban wastes and seeking an efficient use of WEF resources. Despite its significance, we learn that investment in STI still lags in most Southeast Asian countries. To fill these gaps, government-led investment should trigger the participation of the private and business sectors. Governments have the power and leverage to develop policies and new markets to accelerate innovation and the deployment of technology. The investment ratio for STI is observed to gradually increase in some Southeast Asian countries where the private or business sector has accounted for a substantial part of investment over the past 10 years. Against this backdrop, we urge urban decision-makers to:

1. Adopt and adapt timely resource recovery technology to scale up use and gain universal benefits.
2. Manage the innovation of technology in an integrated manner to solve current and potential issues.
3. Regionally cooperate in execution involving decision-makers, civil society, business sectors, and research institutions.

The availability of funds may be the limiting factor. Therefore, a proper strategy for application and adoption needs to be deployed for efficiency and results. The application of frontline technology for consolidating data is crucial. It will help decision-makers assess the situation, project the future, and make informed decisions or renew strategies to improve the quality of the environment.

15.6 Conclusion

In 2011, the World Economic Forum pointed to WEF nexus as a major source of uncertainty for the global economy. Since then, the nexus approach has been recognized globally as a tool for integrated resource management and governance across sectors and scales. The guiding principles of the nexus approach aim to increase resource use efficiency, provide additional benefits, and secure the human rights to water, energy, and food. Furthermore, the nexus approach encourages national and local governments to set integrated cross-sectoral policies. For example, cities should pursue energy-generating solid waste treatments rather than transporting waste to centralized landfills, which consumes a substantial amount of fuel.

We have shown that population growth and urbanization in East and Southeast Asia have significantly increased the resource demand of the region. For example, the demand for food/rice in the region has significantly increased along with the population growth, which has greatly shaped the patterns of water consumption and land resources in the region. The increasing population in urban areas has raised the demand for resources to support urban lifestyles and the need to better manage the converged consumption and waste generation. Such demands influence policy as well, acknowledging that current food security policies that focus on self-sufficiency through production-oriented and trade-restrictive policies have important drawbacks in achieving efficient resource allocation, for example, in irrigation and other agricultural infrastructure (OECD 2017).

We have also discussed that the concentration of population in urban areas has created challenges with the environment and wellbeing. The proportion of the urban population living in slums was reduced from 39% in 2000 to 27% in 2018, with nearly 369 million people still living in such slums in East and Southeast Asia (UN Habitat 2020). Environmental challenges in this region are imminent. In East and Southeast Asia, few cities have invested in centralized wastewater treatment, leaving house owners who are not part of the centralized system to dispose of their wastewater through ground infiltration or directly into the environment, such as into canals and rivers. Sadly, many water utilities source their freshwater from rivers. Food waste and other solid waste are collected and transported to disposal areas. Most cities maintain open dump practices, and therefore, only a fraction of the solid waste ends up in a landfill, let alone a sanitary landfill. Currently, water, wastewater, and solid waste treatment and discharge consume a substantial amount of energy and financial resources with a limited scale of replication.

Taking urban areas as a starting point for dealing with the WEF nexus offers an enormous potential considering the concentration of the population. In this article, we emphasize that the principles of waste reuse and recovery offer a more sustainable approach. For example, biogas generation from solid waste, wastewater, and food waste provides renewable energy, nutrient recovery that supports farming, and waste material recovery that allows remanufacturing.

The transformation of policies that aim to integrate technology within the ecological/ecosystem context is essential. The integrated approach should enable key actors or stakeholders to effectively employ interventions that are appropriate for handling sustainable management and the use of natural and environmental resources with minimal adverse impacts (Koottatep 2010). It is frequently argued that outdated urban governance and management practices, in which resources are managed in isolation by their respective sectoral departments, have resulted in wasteful fragmentation and a disconnect of infrastructure and governance mechanisms at the city and metropolitan level (Lehmann 2018). Water, energy, and food issues are interrelated; therefore, the nexus approach will guide stakeholders in addressing interconnections, interdependencies, and the redefinition of policies. The nexus approach guides stakeholders to integrate management and governance across sectors and scales to perform resource use efficiently. Governments are accountable for determining an integrated approach that pushes investment in infrastructure and human capital, recognizing the role of technology in efficient resource use. Within this context, the drive to innovate and apply technology necessitates the involvement of private sectors where innovation and application take place.

There are great opportunities to be realized if the nexus is addressed coherently across all scales through multi-level governance with differentiating (but clearly defined) responsibilities (Hoff 2011). The nexus approach aims to stimulate intersectoral and inter-governmental relationships that create new partnerships and eliminate policy barriers. It encourages collaborations among key actors or stakeholders beyond administrative borders, bearing in mind that resources such as water are a cross-border issue. The execution will of city leaders to choose the right battle, select the right technology, and cooperate regionally will determine our situation in the next decade.

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Chapter 16
Healthy Citizens, Peaceful Societies and a Healthier Planet

Lawrence Surendra, Benno Böer, and Eunhee Lee

Abstract In this chapter, we attempt to connect the dots to the discussion that precedes this volume and refer to some relevant water, energy, and food (WEF) nexus contexts that are not adequately covered in this volume, such as issues of privatization and overconsumption. This chapter is presented from a perspective of what needs to be done in the context of the problems analysed in relation to WEF. In relation to WEF security, future scenarios and solutions are discussed focusing on technical innovations, such as remote sensing and artificial intelligence (AI). The chapter concludes with the message that not only competence, technology, and skills but also attitudinal changes and shifts are essential for sustainable futures. The collaborative synergies among education, political will, and technical innovation under the framework of WEF nexus security will be essential to achieve healthy citizens, peaceful societies, and a healthier planet.

Keywords WEF nexus · Water privatization · Overconsumption · Multidisciplinary approach · Technical innovation

16.1 Introduction

In this concluding chapter, we attempt to connect the dots to the discussions that precede this volume. At the time of going to press, COP 26 has taken place at

L. Surendra (✉)
The Sustainability Platform Asia (TSP Asia), Bangalore, India
e-mail: lsrendra@gmail.com

B. Böer
The United Nations Educational, Scientific and Cultural Organisation, New Delhi Cluster Office, New Delhi, India
e-mail: b.boer@unesco.org

E. Lee
Korea Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, South Korea
e-mail: eunheelee@kigam.re.kr

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Glasgow and the world and especially young people there waited eagerly to see whether governments and corporations will truly act in the interest of future generations through genuine actions and not mere slogans, rhetoric, empty promises, and "greenwash". Only actions can make the only planet we have recover its health from the ravages of the Anthropocene age we are currently in (Monastersky 2015). Furthermore, we are still witnessing the consequences of the unprecedented global health crisis that the COVID-19 pandemic has set in motion. A recent study by Tollefson stated, "As humans diminish biodiversity by cutting down forests and building more infrastructure, they're increasing the risk of disease pandemics such as COVID-19" (Tollefson 2020).

In 2015, world leaders adopted the 2030 Agenda for Sustainable Development (Sustainable Development Goals; SDGs) with a vision for more peaceful and inclusive societies. However, the UN Secretary-General has also warned that conflict and instability in many parts of the world are impeding progress towards these goals. The UN Secretary General's Report to the 2019 session of the High-Level Political Forum (HLPF), a year before the COVID-19 pandemic struck the world, noted the following (United Nations Economic and Social Council 2019):

> It is cause for great concern that the extreme poverty rate is projected to be 6% in 2030, missing the global target to eradicate extreme poverty; hunger is on the rise for the third consecutive year and little progress is being made in countering overweight and obesity among children under the age of 5; biodiversity is being lost at an alarming rate, with roughly one million species already facing extinction, many within decades; greenhouse gas emissions continue to increase; the required level of sustainable development financing and other means of implementation are not yet available; and institutions are not strong or effective enough to respond adequately to these massive interrelated and cross-border challenges.
>
> Direct economic losses from disasters have increased by more than 150% over the past 20 years, with losses disproportionately borne by vulnerable developing countries. Without a surge in mitigation, global warming will continue at a rapid pace, amplifying the challenges of adaptation and entrenching a sense of vulnerability and insecurity among large population groups.
>
> Rising income and wealth inequality risk undermine efforts to achieve the Sustainable Development Goals. They threaten to erode social cohesion, entrench insecurity and dampen productivity growth. Rising intolerance in many parts of the world threatens fundamental human rights and human progress. The nexus among inequality, injustice, insecurity and lack of sufficient trust in governments and institutions can further hinder the necessary conditions for advancing sustainable development.

What we are currently witnessing in the world is the inextricably close links and feedback loops from a systems perspective between a healthy citizenry contributing to peaceful societies and the healing of our dying planet by seeking sustainability and resilience in natural resource systems. In this regard, the WEF nexus has wide implications and far-reaching consequences. Contributions in this volume, for example, explore these connections between health, gender, equality and sustainability and peace (see Chaps. 12 and 14).

With this backdrop, this volume has sought to provide a comprehensive overview of the WEF nexus, with a regional focus on East and Southeast Asia. The integration of East and Southeast Asia, although mainly from the economic perspective, has proceeded over the decades through different regional and subregional organizational arrangements, such as the ASEAN, ASEAN Regional Forum, Economic Research Institute for ASEAN and East Asia (ERIA), Mekong River Commission (MRC) and other dialogue partner formats part of ASEAN, such as ASEAN Plus Three. Contributing to an international vision and cooperation is the presence of major UN institutions, including the FAO, ILO, IOM, UNDP, UNEP, UN ESCAP, UNESCO, UNICEF, UNDRR, UNOSSC, UNU, WHO (and others), and multilateral banks, such as the Asian Development Bank (ADB), Asian Infrastructure Investment Bank (AIIB), and the Islamic Development Bank.

Processes of global trade integration in more recent times, in combination with population dynamics, have led to greater regional and subregional economic integration, which in turn has contributed to integrated resource mobilization and the consumption and management of natural resources on a regional scale. Therefore, a regional-scale analysis of resource security has become critical to sustainably manage the limited crucial resources, including WEF. Although the attempt at a regional-scale analysis in this volume is insufficient to capture the complex interactions between water, energy, and food security, we hope that the issues covered provide a good picture of East and Southeast Asia with regard to the nexus.

In this concluding chapter, we refer to some relevant nexus contexts that are not covered in this volume and take up other issues that the preceding chapters in this volume may not have adequately addressed. However, it must be cautioned that this chapter is an attempt not to fill in all the gaps, but to point to some of the missing issues. More importantly, this concluding chapter is presented from a perspective of what needs to be done in the context of the problems analysed. Before we start doing any of the latter, let us first try to unravel some of the conceptual issues around the notions of WEF security and the nexus *problematique*.

16.2 Water

16.2.1 Conceptual Issues in Framing Water as a Natural Resource

Water, like the air we breathe, is absolutely essential to human survival. However, we take for granted that the mere invocation of the term ‘water’ covers water in all its forms as a natural resource, especially its management and governance, as a resource essential to human survival. ‘Water’, however, is a critical natural resource that has posed difficulties in being confined to any single conceptual vessel of natural resource conservation and management discourse. For example, in the realm of classical economics, it has a dichotomous existence of being both a private good and a public good, although universally it is treated as a common good. This duality of its understanding in economics is also the basis of many complications around how water as a resource should be managed and is being managed globally.

There also exists confusion around the notion of “commons”, which is used in the case of water to refer to common property resources (CPRs), such as mangroves, lakes, wetlands, and water bodies. These confusions largely emerged from the influential but complex work of biologist Garett Hardin, ‘The Tragedy of the Commons’ (Hardin 1968). Hardin’s work basically tried to address the population and resource problem, but his arguments extended to discussions relating to what we have referred to as common property resources or ‘commons’ in general and issues around assigning ‘property rights’ to natural resources that are either a community resource or belonged to no one. Assigning private property rights to a resource that does not belong to anyone was argued to make the management of a resource more effective and efficient. Whether such approaches fulfilled the needs of equity in a community’s access and use of resources was another issue that made ‘the tragedy of the commons’ perspective on the management of natural resources complicated in both theory and practice. Ostrom, in her brilliant work, ‘Governing the Commons’ (Ostrom 1990), pointed out the fallacies in the ‘tragedy of the commons’ arguments, sorted out the confusions regarding such an understanding of ‘the commons,’ and laid clear roadmaps for the management of common property resources. Her work is very relevant and useful in examining issues around the management of water sources, which this volume has also addressed.

Extending this property rights argument or attaching the property rights notion to other notions from the microeconomic theory of ‘firm economics’ has led to processes promoting the privatization of resources as one way of management. Notwithstanding all of the above, we also have to recognize, especially in the context of water, the rich variety of nonproperty-based institutions that exist for the management of natural resources. Often, the tendency to treat the institution of the market (Polanyi 2001) as the only social institution of human creativity that can solve mankind’s problems has further complicated the management of natural resources in general, but especially and increasingly scarce and critical resources, such as water. Many workable solutions that exist for managing natural resources involve a combination of market and other institutions, both collective and community-based, and produced hybrid institutions and models, especially in the East and Southeast Asian region, which shows great cultural and environmental diversity.

The second critical dimension related to water is that most discussions related to water (especially with the emergence of controversies related to water privatization in different countries and contexts) are centred around supply-side issues. There is not much discussion that is in tune with the diversity of water sources that we depend on for our water needs. Surface water sources, particularly river water and its transboundary nature, have attracted much attention because of the debates and controversies surrounding the sharing of river water resources. Groundwater, the most used and abused source of water, which can also be a transboundary resource and a common property resource in some cases, does not receive the same focus (UNECE 2001; UNESCO 2004, 2010; Puri and Aureli 2005; Lee et al. 2018). Groundwater is often the “magic source” that makes up for all quantitative and seasonal deficits in the water supply for human needs. Groundwater remains the world's largest source of fresh water. Yet, groundwater is a source that is rapidly depleted, and its depletion affects both water quality and quantity and remains the least factored in terms of water governance issues. A "mining" perspective that governs mineral resources also unfortunately prevails in relation to groundwater.

However, it seems that groundwater is slowly being acknowledged in scholarly and other discourses around water. Currently, it is recognized as one of the five most serious threats to our natural world (Greenfield and Weston 2021). Groundwater provides nearly half of the water used for agricultural irrigation and most of the drinking water for billions of people. In one of the largest studies performed on groundwater, published in Science, in April 2021, Jasechko and Perrone examined data from approximately 39 million wells in 40 countries worldwide to investigate their vulnerability to declining water levels (Jasechko and Perrone 2021).

In addition to adopting market-based perspectives and discourses on water and water sources, discussions related to water have also turned to "traditional knowledge" perspectives and looked at water storage and harvesting in terms of traditional tanks and constructed wetlands for flood control, water storage, groundwater recharge, and rainwater harvesting. Additionally, countries such as Singapore have benefitted from the use of cutting-edge technology using sensors and membrane technology (Khoo 2017). However, it must be noted that traditional technologies, methods, and sources of water harvesting and storage often involve and possess a history of community-based water conservation and management. These solutions are mainly inspired and supported by nature and mimic natural processes to contribute to the improved management of water, providing us with the basis for the nature-based solution (NBS) (WWAP 2018). In NBS, useful and valuable work and discussions have also emerged and led to innovative contributions on 'governing the commons' (Ostrom 1990). Though, in terms of water governance, the issue of use (managing the resource) and regeneration or ecological recovery from a conservation perspective tends to become mixed. There seems to be a need to focus on both conservation and management and regeneration or ecohydrological recovery, especially in regard to water.

16.2.2 Fractured Governance: Conflicts Over Water and the Politics of Water Governance

Several chapters in this volume discuss the issues of "fractured governance" in relation to water. In the overall context of nexus, the paper in this volume by Kim and Castro-Hallgren (see Chap. 14) examines how the interconnected nexus dimensions of water, energy, and food are cut up between different line ministries in East and Southeast Asia. For water alone, often more than one ministry or government department deals with matters related to water, which leads to either the neglect of some critical aspects or duplication, resulting in incoherent systems for managing water sustainably. Further, policy discussions on water governance institutions tend to be mixed with the earlier generation of water management practices by traditional institutions, followed by the next-generation practices of regulatory institutions/statutory bodies/local authorities and newer market-driven institutions, such as corporations, and sometimes the emergence of new private entities from once public institutions. However, these are not just issues of the administration and bureaucratic management of a critical resource, such as water; they have far-reaching implications for the sustainable conservation and management of water as a critical resource and from a nexus perspective.

At a deeper and more fundamental level, water as a critical resource is part of many levels of conflicts, both local and between nations in terms of its use and access. Competing access to water between rural areas (for safe drinking water and agriculture in terms of livelihoods and food security) and other sectors (be it for hydroelectric power generation leading to the damming of transboundary rivers within national borders, for industrial use, or for the growing urban populations, who also tend to be politically powerful) is leading to serious situations of international and community-level conflicts. As a result, the term 'water wars' has been gaining greater currency in discussions related to water.

Adding fuel to this already conflict-ridden situation is the entry of private corporate sources eager to profit from what is seen as the next frontier of private infrastructural investment, namely, water and sanitation. The value of the global water and wastewater market was estimated to be 263.07 billion USD in 2020. The market is projected to reach a value of almost 500 billion USD by 2028 (Fortune Business Insights 2021). In this global water market, the bottled water industry has shown remarkable growth. In addition, there are large water consumers in the liquor and soft drink industry that consume billions of litres of water every year. Large companies are also expected to greatly benefit from the growing privatization and markets in water, making them powerful advocates of water privatization and increasing their ideological stakes in making water a commodity globally. This enormously increases the private corporate interest in water privatization and the resulting pressure on governments, especially in East and Southeast Asia, to shift water from being a public good to a private good, not only in the management of the water supply but also in its overall governance as a critical natural resource. This is also the reason why increasing water privatization is gaining ground in discourses on water governance.

These policy shifts from a state and public goods perspective towards free markets also had a corresponding influence on international and policy development debates in relation to water in the 1990s. The 1992 Dublin Principles from the *Dublin Conference on Water* provided space for the increased role of markets in the supply and management of water. Water privatization since then has increasingly become a controversial issue. The number of projects that involved private sector participation in water and sewerage projects in developing countries correspondingly increased from zero in 1990, to a peak of 35 in 1999, and down to 17 in 2001, attracting a peak investment of 9.3 billion in 1997 down to 2.3 billion in 2001. These ups and downs in the role of private companies in water were also related to community struggles to take back community control of water sources (Schneider 2017). Several countries legislated the ban of water privatization (Barlow 2007). It also came to be reflected in the UNDP's annual flagship report in 2006, titled *Power, Poverty and the Global Water Crisis* (UNDP 2006). The report stated,

> Throughout history, water has confronted humanity with some of its greatest challenges. Water is a source of life and a natural resource that sustains our environments and supports livelihoods – but it is also a source of risk and vulnerability. In the early 21st Century, prospects for human development are threatened by a deepening global water crisis. Debunking the myth that the crisis is the result of scarcity, this report argues poverty, power and inequality are at the heart of the problem.

However, it must be noted that the controversy generated by water privatization has also generated responses emphasizing access to water and sanitation as a human right. The United Nations International Covenant on Economic, Social and Cultural Rights now requires countries that have ratified the Covenant to "… *take the necessary steps towards the progressive achievement of the right of everyone to an adequate standard of living, including access to water and sanitation.*" More recently, in October 2021, the UN Human Rights Council adopted a landmark resolution recognizing that everyone everywhere has the human right to live in a clean, healthy, and sustainable environment. This definitely includes the right of access to a clean and reliable supply of water as a fundamental human right (United Nations 2021).

While privatization of water seems to loom as a threat to the concept of water as a public good and in terms of ensuring water to the poor, low-income users, and rural areas, the issues facing water governance are far more complex than merely the issue of water privatization. The private sector is clearly not the answer to ensure that people have adequate and equitable access to safe water and sanitation. In addition, given that water is a public resource, many governments, as mentioned above, are realizing that they will face opposition to any radical moves towards complete privatization. Likewise, multilateral agencies are unable to push through openly free market approaches as part of their neo-liberal agendas in relation to managing water and sanitation. In such a context, both governments and multilateral agencies are currently adopting hybrid approaches of treating water as both a public and a private good while pursuing more subtle and less visible strategies in making water a private good. Efforts are being made (and need to be made) to treat and retrieve wastewater, both grey and black. As mentioned above, countries such as Singapore are at the forefront of such efforts, and such recycled water is called 'new water'. Resident welfare associations in apartment complexes in many countries are increasingly taking over the management of the water they use and not only reducing water wastage by the use of smart metres but also recycling grey and black water for reuse for toilet flushing water and gardening. These efforts need to be multiplied in urban areas by introducing relevant laws and regulations and learning from the example of countries such as Singapore (Khoo 2017).

In addition to issues of privatization, other issues relating to the community management of water resources exist. All of this means that there is a great urgency for activist researchers, grassroots groups, and public policy activists in the region to develop a more accurate understanding of what is happening in relation to water as a crucial resource that is central in relation to ensuring food security and livelihoods and achieving poverty eradication. Additionally, there is little cross-border exchange of information and research in terms of what is taking place in relation to the management of water as a resource in the different countries of East and Southeast Asia. Hopefully, publications such as this will motivate more people, especially young people, to take up water and its multidimensional issues, especially those connected from a nexus perspective, for campaigns and public policy advocacy. From such a rationale, this book also hopes to serve as a base for developing campaigns, advocacy, and public policy research and interventions in relation to the conservation of water sources, preventing wastage, and ensuring equity with reference to water as a resource in East and Southeast Asia.

16.3 Energy

Closely linked to water is the question of energy. Water and energy cannot be separated. Connecting water and energy from a nexus perspective, we need to note that while water and its conservation, management, and governance do receive much attention, discussions on energy- and water-related issues are more diffuse. Water as a resource is also a source of energy, as in the case of hydroelectric dams (as well as for marine water resources as a source for kinetic energy, tidal energy, and desalinization plants coupled with electricity generation). In cases where water is a source, such as groundwater, it remains as stock and has to be converted to a usable resource by pumping it out of the ground. Its conversion from stock to source is done by the intervention of energy to pump the water out. Equity issues in particular cannot be addressed if the link between energy (electricity) and water is not made. Water therefore cannot be adequately examined without also examining energy/electricity-related issues. These links are very germane to East and Southeast Asia and especially in countries that seemed to have hitched their star to the path of rapid economic growth and are rapidly privatizing electricity-generating institutions.

It is therefore important to examine the water–energy linkage through the lens of energy and equity and not water and equity alone.

In addition to the water–energy duality that we have to deal with, the search for sustainable and renewable sources of energy as alternatives to fossil fuels, especially in the context of climate change, makes the relationship between the two even more complex. Many of the contributions in this volume address these complexities. While hydropower is seen as a major alternative to fossil fuels, in the context of both droughts and floods, whose frequencies have been increasing as a result of climate change, hydropower's reliability as a perennial and reliable source of power is being challenged as the risks associated with hydropower are pointed out. Furthermore, generating hydroelectric power, especially from transboundary rivers, has given rise to a new set of problems.

New energy sources, such as solar power, wind power, and energy plantations, as renewable sources of energy are competing for the sustainable energy space. All of these new energy sources also pose new threats to food security by taking away large areas of cultivable land for energy production. Wind power turbines are also seen as affecting bird life, especially large migratory birds (Parvaiz 2021). Although there are currently attempts to locate solar and wind power on the high seas, what damage to birds and marine life they may cause remains to be seen. Energy plantations pose a direct threat to food security. The irony in the search for energy alternatives and renewable energy is that a vast amount of the electricity generated is wasted.

Looking at the COP 26, taking place in Glasgow while this chapter is being written, it should not be forgotten that not enough has been done in the last 50 years since the global energy crisis in the 1970s. As an example, the historical plot of the estimated car fuel efficiency showed that the car fuel economy (usually represented as distance (km) per litre of fuel consumed) decreased, particularly during the period between 1985 and 2005, although it has considerably increased since 2005 (EPA 2016). This clearly demonstrates that private sectors as well as policymakers, academia and practitioners should make more efforts to produce more energy-efficient systems through technical innovations and laws and regulations.

16.4 Food

16.4.1 Security for the Seeds and Plants

Moving to the third and most critical link in the WEF nexus, food, we have to keep in mind that plant biodiversity is critical for the availability of food for human consumption and livestock production. This is a critical issue that needs to be flagged in a book looking at the WEF nexus, although we will not be able to go into it in much detail here. The FAO estimates that 75% of crop diversity was lost between 1900 and 2000. A recent study predicts that as much as 22% of the wild relatives of important food crops of peanut, potato, and beans will disappear by 2055 because of a changing climate (FAO 2010).

16.4.2 Food Security Versus Overconsumption

Another important issue we have to consider in looking at food security is the two sides to it, "underconsumption" and "overconsumption". The contribution to food security in this volume by Choiruzzad (see Chap. 4) provides a detailed presentation of the situation. According to the chapter, malnutrition in terms of undernutrition leading to wasting and stunting in children still exists in East and Southeast Asia, while at the same time, the "malnutrition of excess" also exists. Food security has also transformed to overconsumption and obesity, with countries in the region accounting for the largest number of obese people, especially mega economies such as China, although the percentage of the population remains low. This also changes the nature of the problems to be addressed in these two regions from solving complex conservation, sustainable use and management issues in relation to water and energy to addressing critical lifestyle issues that affect food consumption and equal energy and water use.

In the context of food and energy, we generally look at the links between food production and energy use and consumption in a macro sense, a dimension that all papers in this volume have also covered. Another dimension in the food–energy link is individual food consumption. From a food security point of view and in the crossover from achieving food security to actually facing an overconsumption scenario, one of the issues is consuming more energy (kilocalories) than the energy expended to maintain life and carry out our daily activities. Weight gain happens in a situation of energy surplus, where more energy is consumed but less energy is expended. The situation of overweight and obesity has been caused by an increase in the availability and intake of kilocalories, while less is expended. This is another energy scenario that needs correction for healthier populations and a more sustainable and healthier planet. To achieve this, fundamental lifestyle and attitudes to food and consumption have to change.

Compared to the global data on rates of growth and percentage of the population who are obese, although most countries in this region are better off compared to global figures, the absolute numbers are still high, a point that is mentioned in a paper in this volume (for more details, see Chap. 6), which observed that the highest number of obese people in the world are in China. The ADB looked at this issue and noted the following (Helble and Francisco 2017):

> In Southeast Asia, Indonesia and Thailand are showing alarming trends. The rate of overweight and obesity in Indonesia was around 15% in 1990 but this has escalated to 26% in 2013. A similar picture can be seen in Thailand where it rose from 21% in 1990 to 36% in 2013. Similarly, we observe a rapid increase in cases of overweight and obesity in Cambodia and the Philippines. Vietnam has seen a similar increase – although it has one of the lowest overweight and obesity rates in the region, it rose from 6% in 1990 to 13% in 2013.

> Overall, in Asia, male adults in Malaysia and Singapore are among the most overweight, with a prevalence of 43.8% and 44.3%, respectively. For female adults, Malaysia (48.6%) and Maldives (54.0%) have the higher prevalence. A telling example for the fast increase of obesity in the region is Malaysia where in 1996 only 21.0% of the population was recorded as overweight, but by 2015 this has more than doubled to 47.7% of all adults.

An even more serious issue is that of child obesity, a very curious phenomenon that makes the number of children suffering from malnutrition due to overeating equal to the number of children suffering from malnutrition and stunting due to lack of adequate food and nutrition, especially in their younger years. ADB recommends (Helble and Francisco 2017),

> Overweight and obesity are public health problems that can basically be tackled on two fronts: nutritional intake and physical activity. Improving nutritional intake can be more difficult than may be expected. Food choices are a mix of cultural, societal factors and market related factors, mainly in terms of availability and price. One approach is to ensure that school food is healthy and provides students with an example of healthy food choices. Influencing the food choice of children is the approach that has been focused on in various countries. Another

> approach is to regulate marketing of unhealthy foods. Aggressive television marketing has been identified as playing an important role in influencing the food choices of consumers, including those of children. Several countries have therefore imposed restrictions on the marketing of certain foods to children. Introducing food labels that allow consumers to make better-informed decisions is another option. Taxes on unhealthy foods, such as sugar, can help to steer the consumer towards more healthy food; however, taxes alone might not be enough.

From a nexus perspective, the issues of overconsumption show great disparities within the Southeast Asian region, for example, between more affluent countries, such as Malaysia, Brunei, Thailand, and Singapore, and poor countries, such as Lao PDR and Myanmar. The direct and indirect health costs of overconsumption leading to overweight and obesity are quite high, as the ADB study on this subject points out (Helble and Francisco 2017). It should be added that a more balanced consumption of food, with more plant products and less meat and poultry products, significantly reduces the very high amount of water and energy needed for meat production (for the production of calories), and it reduces the land area needed for livestock fodder, and in turn, significantly increases the land area for the production of plant-based food, and perhaps biofuel.

In discussing meat consumption, let us make a couple of caveats. First, we need to distinguish between industrial meat or factory-produced meat and meat that is produced by small livestock owners, farmers, and indigenous communities. We also need to note that for many indigenous communities and communities living in mountainous regions with little access to modern transport and other infrastructure, meat from animal sources is the only source of stored protein. In terms of the industrial production of meats, red meats, especially beef and pork, have very disastrous effects on health and the environment and a negative ecological footprint. A World Watch Institute study in 2005 (Nirenberg 2005) noted the following:

> Today, confined animal feeding operations (CAFOs), or factory farms, account for more than 40 percent of world meat production, up from 30 percent in 1990. Once limited to North America and Europe, they are now the fastest growing form of meat production worldwide. The greatest rise in industrial animal operations is occurring near urban areas of Asia, Africa, and Latin America, where high population densities and weak public health, occupational, and environmental standards are exacerbating the impacts of these farms.

16.5 Water, Sanitation, and Waste: Closing the Sanitation Loop and Managing Urban Waste

The other system link to the WEF nexus is water and sanitation. Linked to the overconsumption of food is the fact that human beings are on the horns of a dilemma that we do not recognize. We generate great amounts of waste and place great loads on the sewage system. To increase food production and the growing demands of agriculture, we need increasing amounts of fertilizer, especially phosphorous, the demand for which continues to grow (Rosemarin et al. 2008). In addition, in not closing the sanitation cycle, we are losing vast amounts of nutrients, especially phosphorous.

Similar to the oil crisis when terms such as ‘peak oil’ were used, we are facing a ‘peak phosphorous’ situation in terms of the crisis of a shortage of phosphorus for agricultural growth and food production. Ironically however, we waste away phosphorous, which is part of human excreta, a human waste from food consumption. We thereby refuse to acknowledge the dilemma we face of not extracting wealth from our own waste. Moreover, the amount of food wastage has reached an unacceptable level. According to Forbes, “global food waste is well on the way to becoming a billion tonne problem.” Quoting a UNEP 2021 study, the Forbes infographic estimates the waste of food in China to be 64 kg per capita, the highest in the world, and India at 50 kg per capita (India ranks 101 on the 2021 Global Hunger Index out of 116 countries) and the US at 59 kg are not far behind (McCarthy 2021). Needless to say, many millions of people could be fed with these large amounts of wasted food.

Let us look at the consequences of the inadequate provision of sanitation facilities globally. According to data provided by the WHO and UNICEF, inadequate sanitation contributed to approximately 830,000 deaths and over 49 million disability-adjusted life years (DALYs) in 2016, caused by diarrheal diseases and many other diseases and conditions, including soil-transmitted helminth infections, malnutrition, trachoma, schistosomiasis, lymphatic filariasis, and diseases linked to inadequate wastewater management practices (UNICEF and WHO 2020). Globally, 1.8 billion people worldwide are at risk of developing cholera, dysentery, typhoid, and polio because of faeces-contaminated drinking water (UNICEF and WHO 2015).

With rapid population growth and changes in lifestyle, a rapid increase in total wastewater often makes centralized sewage systems unaffordable. Source separation allows for containment and the development of new sustainable alternatives that can be dry or waterborne depending on the local conditions. Global statistics show that approximately 44% of household wastewater is not safely treated (UN Water 2021), and more than 80% of wastewater is released to the ecosystem without proper treatment (WWAP 2017).

Urgent attention needs to be given to alternatives to centralized sewage systems and sludge recovery. Decentralized wastewater treatment systems (DEWATS) and new technologies for ecologically sustainable sewage treatment plants using biomimicry, as well as laws and regulations, are changed to implement such solutions (UN ESCAP 2018). Cities that pose the greatest challenge in terms of implementing nexus solutions need to completely change the overall management of water, sanitation provisioning, and urban organic wastes.

Examples of urban organic waste recycling practices include the use of fresh waste from vegetable markets, restaurants, and hotels, as well as food processing industries as feed for urban livestock (Allison et al. 1998); the direct application of solid waste on and into the soil; the mining of old waste dumps for fertilizers (Lardinois and van de Klundert 1993); the application of animal manure, e.g., poultry/pig manure and cow dung; the application of human excreta or biosolids to the soil (Cofie et al. 2005); and the organized composting of solid waste or the co-composting of solid waste with animal manure or human excreta. New technologies have emerged for converting waste to energy, and these technologies need to be implemented as part of dealing with the wastes generated by human activity and consumption (Cofie et al. 2006).

Closing the sanitation loop, alternative decentralized ways of dealing with sewage and implementing nutrient recovery through fecal sludge management and ecologically sustainable sewage treatment as well as recycling urban wastes, especially by conversion to energy, will also make an important contribution to climate adaptation.

16.6 Addressing Some Remaining Issues

Before we conclude this section, let us look at some of the issues that remain to be addressed from the country cases. There are some commonalties in terms of poor countries, such as Cambodia, Lao PDR, Myanmar, and the Philippines, which face many challenges in the context of climate change and water and energy challenges. These countries have borne the brunt of disasters caused by cyclones and floods. They also face serious deficits in provisioning for water and sanitation. Water and sanitation also need to be examined within a nexus perspective, and we will return to this aspect after a summary of food security issues.

Malaysia, although it is a rich country, remains vulnerable to floods, landslides, haze, and water pollution, similar to other Southeast Asian countries. Disasters related to flooding are on the rise in Malaysia and have already caused many landslides, with great losses to the economy, while droughts have also been part of the climatic cycles. In the case of Brunei, it is unique not only because it is a wealthy country rich in oil and natural gas reserves, but also because 72% of the country is covered with peat swamps, lowland forests, and mangroves that are key to global climate control.

Singapore is equally unique. Despite its small size in terms of total area (640 km^2), the country has made remarkable economic progress as an entrepot of global trade. Situated in a coastal zone in Southeast Asia, the country remains vulnerable to global climatic change and its impacts; thus, the government has put much effort into recovering ecological and natural resources and greening the country. It is interesting to note that Lee Kuan Yew, the first Prime Minister of Singapore, took great interest in the greening of Singapore, cleaning its waterways which has contributed to nature returning. Increased bird, animal, and other species diversity in both Singapore's water bodies and terrestrial habitats clearly demonstrates the importance of the political will (Yew 2000).

These ecologically rejuvenated areas of Singapore are currently tourist attractions. Yew, in his book (Yew 2000), devotes an entire chapter titled, 'Greening of Singapore', and writes:

> One compelling reason to have a clean Singapore is our need to collect as much as possible of our rainfall of 95 inches.

He also mentions how ASEAN leaders decided to green their cities and says the following:

> Our neighbours have tried to out-green and out-bloom each other. It was immensely better that we competed to be the greenest and cleanest in Asia. I can think of many areas where competition could be harmful, even deadly.

Finally, in closing this coverage on nexus issues in this closing chapter and in the context of a post-pandemic world, it is worth restating what was said in the opening chapter (see Chap. 1).

> Current methods to investigate the impact of pandemics on social systems and resource security are inadequate (Calder et al. 2021). Although some interesting studies have shown the causal relation between COVID-19 and WEF security, there have thus far been few holistic analyses on the cross-sectoral impacts of pandemics (Al-Saidi and Hussein 2021). The stress on the WEF sector during the pandemic has clearly shown that water, energy, and food supply all depend on labour and capital inputs; thus, future studies on this topic should be devoted to determining the interlinkage among the connections of the WEF-human health economy in an integrated manner (Calder et al. 2021).
>
> Finally, the COVID-19 crisis offers an opportunity for reflection on management and governance responses across the WEF nexus sectors. The gaps revealed during the crisis have raised awareness among global communities on the significance of sustainable resource production systems and the need for risk-based perspectives in policy-making and decision-making. A quantitative risk trade-off framework and synthesized analysis tools could improve decision-making and resilient WEF planning (Calder et al. 2021).

To this end, we can add the connections between lifestyles, consumerism, and overconsumption, that is, putting both nations and the planet at risk. Not seeing the interconnection in a systems perspective between the overall health of the population and resource issues related to water, energy, and food is endangering human life and nature.

16.7 Conclusion: Looking Beyond

> It's been nine days since a full-bodied drop of water emerged out of the taps. The water carriers, the poor men who ferry water across town, collecting water from faraway jhoras (a water source) and lugging them in containers hanging from their heads, have disappeared. Like the water in this town. There are rumours that schools and colleges will be closed from next week – the buildings stink from a distance, the toilets have no water, students have stopped carrying water bottles to school because water is now drunk only after meals, at home – and, if the situation doesn't get better, possibly not in offices too. There's been an unofficial rationing on the sale of bottled drinking water: No more than four bottles per family. The fifth only if one has a medical certificate to prove that there's an ailing person in the family (Roy 2019).

In looking to the future and beyond the situations we are in relation to WEF security that this book deals with in terms of problems, challenges, and solutions fiction and the imagination of writers helps us find solutions and imagine futures (both worrisome and benign) that can lead us through concrete steps towards sustainable futures. Above is a quote from a short story titled 'Blind Water' by Roy, a nature writer (Roy 2019). She has, in the context of the eastern part of India, normally a region with heavy rainfall, woven into fiction in this short story what can be and in some cases are current everyday situations around the scarcity of water. These are possible scenarios for the future if we continue with ‘business as usual’ attitudes towards precious resources, such as water.

Fiction helps us understand the gravity of problems that people face, for example, in relation to water scarcity, better than what cold data can convey as in the quote above. In imagining future scenarios, fiction, especially science fiction, can help us greatly. The most recent in that genre is a science fiction novel that is a product of collaboration between Chinese sci-fi writer Chen Quifan and former Google China Head and AI guru, Kai-fu Lee. The book is titled “*AI 2041: Ten visions for our Future*” (Chen and Lee 2021). Nathan Gardels, Editor-in-Chief of Noema Magazine published by the Berggruen Institute, wrote about this new path-breaking science fiction around artificial intelligence (AI) (Gardels 2021):

> Frugality — the prudent husbanding of resources to meet needs — has long been framed by ecologists as the only realistic alternative to the endless wants of consumer capitalism that are belching ever more warming emissions into a biosphere on the brink of breakdown. But what if a kind of frugal plenitude, a clean and equitable condition of post-scarcity, could be achieved through the awesome capacity of an AI-driven internet of things to drastically reduce the cost of producing goods, eliminate waste by precisely matching supply with demand and diminish the outsized carbon footprint of the industrial age through smart factories and cities wired up with sensors for energy efficiency?

In his interview with Gardels, Lee the AI guru argues that this vision of postscarcity is not as far-fetched as it sounds and cites science fiction author William Gibson’s observation (Gardels 2021):

> The future is already here — it is just not very evenly distributed. In 2020, the United States discarded $218 billion worth of food, while the cost to eliminate hunger in the U.S. has been estimated at just $25 billion per year. There are more than five times as many unoccupied houses as there are homeless people. So we already have theoretical plenitude in 2021 for food and shelter in the United States.

He concludes that once AI computation can ferret out the waste of inefficient allocation by creating a frictionless pairing of need and supply, we can arrive at a much fairer society. Political and social obstacles to achieving a fairer society always remain. Yet, it is worth considering when discussions on AI, especially around water and energy, focus more on what technology can deliver than on the other ends of fairness and equity being met.

These thoughts using science fiction are seen as necessary in the context of discussions on the use of technology, AI, and water management. Technology and its applications, especially the use of information and communications technology (ICT), satellite data, and Internet of Things (IOT) technologies, have great potential to make a significant contribution to the better and efficient management of water resources and their governance, especially when they fall between urban and rural governance institutions and systems. Drone technology can be used to analyse local water bodies where the current manual water quality monitoring entails tedious, time-consuming processes (Etikasari et al. 2019). To alleviate the problems caused by manual monitoring, remote water quality monitoring systems can be used. These systems leverage wireless sensors in detecting water quality and short-message service (SMS) technology in delivering alerts to those needing this information. Wireless sensor networks (WSNs) have since been considered a promising alternative to complement conventional monitoring processes. These networks are relatively affordable and allow measurements to be taken remotely, in real time and with minimal human intervention. This work helps the application of WSNs in environmental monitoring, with particular emphasis on water quality. A good example of automated water monitoring systems can be found in the integrated groundwater information services (GIMS) in South Korea (GIMS 2021).

Currently, many young engineers who want to contribute to the sustainable management of water and provide water-related services are technology-embedded businesses using technologies, such as smart metres, sensors, and the development of special apps for water supply management. As an example, UC-Irvine's Center for Hydrometeorology and Remote Sensing, Chulalongkorn University (Bangkok), UNESCO-Bangkok Office and the Asian G-WADI (Global Network on Water and Development Information for Arid Lands) secretariat have developed satellite-based rainfall estimates (PERSIANN) for planning and management regarding natural disasters in Asia (CHRS 2021). In relation to advance warning systems for natural disasters as well as helping farmers plan their agricultural activity using continuous weather warning systems, the Bangkok-based regional integrated multi-hazard early warning system (RIMES) also has been making significant and meaningful contributions (RIMES 2021). Floods continue to threaten many cities in East and Southeast Asia during the monsoons, and the contribution of improving hydrologic prediction to mitigation measures is significant and can be used elsewhere in the region. The ADB has also produced briefs on the use of AI for Smart Water Management Systems (ADB 2020).

To use AI and other advanced technologies to enhance the value of the NEXUS and its components, especially water, another useful metric is 'Sense of Place' (Mulvaney et al. 2020). This metric could be particularly useful in restoring wetlands and water bodies, such as local lakes in urban and semiurban settings. 'Sense of Place' can be used from the perspective of a cultural ecosystem service. The term cultural ecosystem services is used to represent a range of nonmaterial benefits that humans receive from their interactions with the environment, including aesthetic appreciation, spiritual services, cultural identity, recreation experiences, etc. These types of benefits provide some convincing reasons for environmental protection that may be compelling to different audiences than those who prefer other ecosystem service benefits. Because of the importance of cultural ecosystem service benefits to humans, their assessment is critical for understanding the impact of environmental change, including water quality degradation or improvement.

From a UNESCO perspective and keeping in mind the work and achievements of the UN Decade for Education for Sustainable Development, for which Decade UNESCO was the lead agency, it is important to keep in mind the importance of not only competence, technology, and skills but also attitudinal changes and shifts that are essential for sustainable futures (Bacha et al. 2007; Surendra 2011, 2014). The emphasis we have given to 'Healthy Citizens, Peaceful Societies and a Healthier Planet' (also the title of this chapter), is an urgent task that can be accomplished by focusing on the WEF nexus.

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