SCIENCE, TECHNOLOGY, AND INNOVATION FOR SUSTAINABLE DEVELOPMENT GOALS

Insights from Agriculture, Health, Environment, and Energy

EDITED BY

Ademola A. Adenle, Marian R. Chertow, Ellen H.M. Moors, and David J. Pannell

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Foreword by Mahmoud Mohieldin

In 2015, leaders from 193 nations made a commitment to achieve 17 Sustainable Development Goals (SDGs) by the year 2030, to end poverty, offer every person an opportunity for a better life, and protect our planet for future generations. This historic global agreement is one of the most ambitious ever conceived—and if it is to be successful, all of us will need to participate.

Each year, representatives from many of these signatory countries meet at the United Nations in New York as part of the High-Level Political Forum on Sustainable Development. Participants take stock of their nations' plans and progress toward the SDGs, with their 169 interlinked targets, measured by 232 indicators. I've attended all of these sessions as the World Bank Group's Senior Vice President for the 2030 Development Agenda, UN Relations and Partnerships. Watching these proceedings, I believe there is room for optimism that we can be successful. Yet it is also clear that we have set ourselves a daunting task that requires our best ideas, skillful implementation, and mobilization of resources on an unprecedented scale.

This book offers policymakers and practitioners a wealth of impactful ideas that could be instrumental in helping countries and the world reach the ambitious SDG targets, leveraging science, technology, and innovation (STI) to speed and improve the implementation of desired outcomes. It focuses on three key areas: environment and energy, health, and agriculture—areas which are critical to the SDGs and resource intensive. To reach the SDGs we will need STI solutions in areas such as these, displacing and disrupting existing systems, while protecting the people they are intended to help.

Indeed, we must carefully balance risks and rewards of these solutions so that progress is broad and fair to all people. Thus, our growth—increasingly driven by digital innovation—can and should be equitable and sustainable. Our planners and policymakers must also foster resilience against a variety of risks such as climate change and economic disruption. And we must invest in our people—especially in health, education, and workforce training. Successful interventions can help communities, including women, leapfrog to advanced technological solutions at an unprecedented pace and scale. For example:

- In healthcare, digital and web technologies have been shown to: expand health services in developing countries, increase health systems' efficiency, and lead to better patient outcomes through tele-medicine and improved access to information which is related to disease prevention, nutrition, and hygiene.
- In agriculture, breakthrough digital technologies have the potential to deliver significant positive impacts across food value chains. These range from innovations

that can make food systems more resource-efficient and climate-resilient such as precision agriculture, gene-editing, and biological-based crop protection; or technologies that improve traceability from farm to fork.
- Renewable energy is playing an increasingly vital role in helping countries develop modern, secure energy systems while disruptive technologies like smart grids, smart meters, and geospatial data systems have upturned energy planning and lowered carbon emissions.

These solutions are real and achievable, if we make the commitment to share and implement them at scale.

The authors who contributed their deep knowledge to this volume represent a diverse group of institutions and disciplines, from various regions of the world. As the authors note, progress on the SDGs will depend upon collaborative efforts between governments (at the national and local levels), civil society, the private sector, academia, multilateral organizations, and communities, each contributing their knowledge and resources to reach our shared objectives.

Of course, action on STI will also require adequate financing and policy tools to build institutional capacity to plan, implement, collect data, evaluate approaches, and to replicate and sustain successful interventions. The World Bank Group is working closely with the United Nations and many other partners to help mobilize resources and develop STI roadmaps to address specific challenges in STI solutions in country and subnational contexts and with diverse populations. This book is an important contribution toward making leaders aware of the financing challenges, and in sharing ideas for meeting revenue targets to implement STI solutions which can have a broad impact on people's lives.

The wise and regulated use of STI can boost productivity, raise global income levels, and improve quality of life for billions of people. Already, their aspirations are rising throughout the world, augmented by smart phones and social media. As STI redefines commerce and communities, we will have to adapt to a rapidly evolving workplace, requiring new skills and cultural shifts.

While there are risks and challenge on the road ahead, solutions enabled by science, technology, and innovation can and should be used to help us reach the SDGs—lifting up billions of people, protecting our planet, and achieving inclusive growth and shared prosperity.

Mahmoud Mohieldin
(Senior Vice President for the 2030
Development Agenda, United Nations
Relations and Partnerships
World Bank Group)

Foreword by Olusegun Obasanjo

The relative success of Millennium Development Goals (MDGs) over the period 2000–2015 encouraged the international community to venture into Sustainable Development Goals (SDGs). In a way, the SDGs are a continuation of the MDGs but deeper, wider, and more encompassing such that they capture major concerns of sustainable development around the world. From eight goals of the MDGs, SDGs consist of seventeen goals that not only involve developing countries but also bring developed countries and other relevant stakeholders on board. There are 169 targets and 232 indicators that are cross-cutting and multi-dimensional in nature, designed to monitor SDG progress, and provide accountability and performance assessment for broader implementation of SDGs.

The central issue of SDG's success, progress, achievements, and performance especially by developing countries hangs on the application of Science, Technology, and Innovation (STI) which are acknowledged as having a significant role in achieving the objectives of SDGs and therefore must be taken very seriously.

This book specifically focuses on using different types of science and technological innovation including digitization, artificial intelligence, modern biotechnology, agricultural technologies, information communication technologies, renewable energy and others to help achieve almost every target of SDGs. The authors' efforts are commendable given the fact that the book is unique in the context of STI for meeting SDGs, and touches on overarching issues that call for the indispensable role of STI in tackling sustainable development challenges around the world. Without hesitation, I agree with authors on the issues raised in the book because the key requirement for successful application of STI in the implementation of SDGs is partnership, collaboration, and cooperation at every level of government especially at the national, regional, and global levels. We have to swim together to survive together.

If anybody was in doubt that we are living on one world house, the recent COVID-19 global pandemic must have removed that doubt. SDGs are meant to make our world house more congenial for every occupant and to create harmony, wholesomeness, confidence, equity, comfort, availability of choices, freedom, peace, security, and human rights. And as a former United Nations Special Envoy, I strongly advocate all of these, where I am confident that STI can play a vital part in making them a reality. In this light, the authors believe and categorically state that a cardinal instrument or tool to achieve these goals and all that flow from them is STI. I unreservedly share their views.

I recommend this very readable and educative book to anyone who believes in SDGs as imperatives for environmental, social, and economic sustainability and stability of the world.

Olusegun Obasanjo, PhD
(Former President of Republic of Nigeria,
aka Father of Africa)

About the Editors

Ademola A. Adenle specializes in science and technology policy in addressing sustainable development challenges including climate change, food insecurity, energy, health innovation in developing countries, and social aspects of science and technology in sustainable agriculture and biodiversity conservation. He is the founder of a new initiative known as the Africa Sustainability Innovation Academy (ASI-Academy). He was a research fellow and principal investigator at the United Nations University Headquarters, Japan. Dr. Adenle was educated in Nigeria and the United Kingdom. He has a Bachelor in Natural Science from University of Lagos, a Master of Biotechnology from University of Sussex, and holds a PhD in applied toxicology with a focus on environment and health from Nottingham University, and a Master of Public Policy from the University of Oxford. He has over 20 years of combined experience in teaching and research at the international level. His publications straddle scientific assessment and stakeholder engagement for overcoming sustainable development challenges in developing countries. Most recently, he was lead editor of *Risk Analysis and Governance of GMOs in Developing Countries*, published in 2017 by Cambridge University Press.

Marian R. Chertow is a professor of industrial environmental management at the Yale University School of Forestry and Environmental Studies and Director of the Center for Industrial Ecology. She is also appointed at the National University of Singapore and the Yale School of Management. Her research and teaching focus on industrial ecology, business/environment issues, and reuse of waste and materials. Her primary research interest is thestudy of industrial symbiosis involving geographically based exchanges of materials, energy, water, and wastes within networks of businesses. Previously, Dr. Chertow spent 10 years in environmental business and state and local government. In 2019 she received the highest recognition of the International Society for Industrial Ecology, its Society Prize, for her "outstanding contributions to the field."

Ellen H.M. Moors is professor of innovation and sustainability at the Copernicus Institute of Sustainable Development of Utrecht University. She has more than 25 years of experience in science, technology, and innovation studies. Her research focuses on the dynamics and governance of technological innovations in science-based sectors in which emergent technology development occurs, such as in health and life sciences, and in the agri-food sector. Her research concentrates on studying changing institutional arrangements in health and food related innovations, using institutional, social entrepreneurship, and user-innovation theories. Dr. Moors publishes on the dynamics of sociotechnical innovations, sustainable innovation management, user-producer interactions, innovation-regulation issues, and responsible innovation, among other topics, in both life sciences and science, technology, innovation, and public policy journals.

David J. Pannell is professor of agricultural and resource economics, University of Western Australia; director of the Centre for Environmental Economics and Policy; an ARC Federation fellow (2007–2012); distinguished fellow and past president of the Australian Agricultural and Resource Economics Society; fellow of the Academy of Social Sciences in Australia; and a director of Natural Decisions Pty Ltd. He was a director on the Board of Land and Water Australia (2002–2005). Professor Pannell's research includes the economics of agricultural research and innovation, farmer adoption of new technologies and innovations, economics of land and water conservation, and environmental policy. His research has been recognized with awards from the United States, Australia, Canada, and the United Kingdom. He collaborates with a wide variety of environmental and natural resource management organizations.

Contributors

Ademola A. Adenle
Africa Sustainability Innovation Academy (ASI-Academy), Nigeria and School of Global Environmental Sustainability, Colorado State University, United States

Robyn G. Alders
KYEEMA Foundation, Brisbane, Australia and Maputo, Mozambique, Development Policy Centre, Australian National University, Australia and Centre for Global Health Security, Chatham House, London, United Kingdom

Brigitte Bagnol
International Rural Poultry Centre, KYEEMA Foundation, Brisbane, Australia and Maputo, Mozambique and Department of Anthropology, University of Witwatersrand, Johannesburg, South Africa

Catharina R. Bening
ETH Zurich, Group for Sustainability and Technology, Switzerland

Peter Berrill
Center for Industrial Ecology, School of the Environment, Yale University, United States

Nicola U. Blum
ETH Zurich, Group for Sustainability and Technology, Switzerland

Janet Bouttell
Health Economics and Health Technology Assessment, Institute of Health and Wellbeing, University of Glasgow, United Kingdom

Julia de Bruyn
Natural Resources Institute, University of Greenwich, United Kingdom

Hilary H. Chan
Sydney School of Veterinary Science, Faculty of Science, The University of Sydney, NSW 2006, Australia

Marian R. Chertow
Centre for Industrial Ecology, School of Forestry and Environmental Studies, Yale University, United States

Domenico Dentoni
Business Management & Organization Group, Wageningen University, The Netherlands

John Dixon
Australian Centre for International Agricultural Research, Australia

Nora Engel
Department of Health, Ethics & Society, Care and Public Health Research Institute, Maastricht University, The Netherlands

Marcolino Estevão Fernandes E. Brito
Faculty of Agriculture, Universidade Nacional de Timor Lorosa'e, Timor-Leste

Tomer Fishman
School of Sustainability, Interdisciplinary Center Herzliya, Israel

Cecilia G. Flocco
National Scientific and Technical Research Council (CONICET) and University of Buenos Aires, Argentina, and Leibniz Institute DSMZ-German Collection of Microorganisms and Cell Cultures, Germany

Delia Grace
International Livestock Research Institute, Nairobi, Kenya

Eleanor Grieve
Health Economics and Health Technology Assessment, Institute of Health and Wellbeing, University of Glasgow, United Kingdom

Ruihua Guo
School of Computer Science, University of Sydney, Australia

Freek de Haan
Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands

J. Brian Hardaker
Faculty of Science, Agriculture, Business and Law, University of New England, Australia

Kshama Harpankar
Lebanon Valley College, Annville-PA, United States

Neil Hawkins
Health Economics and Health Technology Assessment, Institute of Health and Wellbeing, University of Glasgow, United Kingdom

Niko Heeren
Center for Industrial Ecology, School of the Environment, Yale University, United States

Kathleen Hefferon
Department of Food Science and Technology, Cornell University, United States

Akira Homma
Bio-Manguinhos, Oswaldo Cruz Foundation (FIOCRUZ), Rio de Janeiro, Brazil

Koichi S. Kanaoka
Center for Industrial Ecology, School of the Environment, Yale University, United States

René Kemp
United Nations University-MERIT and Maastricht University, The Netherlands

Laurens Klerkx
Knowledge, Technology and Innovation Group, Wageningen University, The Netherlands

Anja Krumeich
Department of Health, Ethics & Society, Care and Public Health Research Institute, Maastricht University, The Netherlands

Felix Krussmann
International Development Studies, Wageningen University, The Netherlands

Cees Leeuwis
Knowledge, Technology and Innovation Group, Wageningen University, The Netherlands

Mu Li
School of Public Health, University of Sydney, Australia

Yiren Liu
Westmead Hospital, Western Sydney Local Health District, Australia

Mercy Lungaho
International Center for Tropical Agriculture (CIAT), Nairobi, Kenya

Mariana Machado
National Science and Technology Institute on Public Policies, Strategies, and Development (INCT-PPED), Federal University of Rio de Janeiro, Brazil

Tamar Makov
Department of Management, Guilford Glazer Faculty of Business and Management, Ben-Gurion University of the Negev, Israel

Reinaldo M. Martins
Bio-Manguinhos, Oswaldo Cruz Foundation (FIOCRUZ), Rio de Janeiro, Brazil

Agnes Meershoek
Department of Health, Ethics & Society, Care and Public Health Research Institute, Maastricht University, The Netherlands

T. Reed Miller
Center for Industrial Ecology, School of the Environment, and Department of Chemical and Environmental Engineering, School of Engineering and Applied Science, Yale University, United States

Marisa E. V. Mitchell
International Livestock Research Institute, Hanoi, Vietnam

Ellen H.M. Moors
Copernicus Institute of Sustainable Development, Utrecht University, The Netherlands

Caroline Mwongera
International Center for Tropical Agriculture (CIAT), Nairobi, Kenya

Chris M. Mwungu
International Center for Tropical Agriculture (CIAT), Nairobi, Kenya

Babette Never
German Development Institute, Bonn, Germany

Michael J. Nunn
Australian Centre for International Agricultural Research, Canberra, Australia

Christopher Oster
Energy and Environmental Policy, University of Delaware, United States

David J. Pannell
Centre for Environmental Economics and Policy, University of Western Australia, Australia

Simon K. Poon
School of Computer Science, University of Sydney, Australia

Cristina Possas
Bio-Manguinhos, Oswaldo Cruz Foundation (FIOCRUZ), Rio de Janeiro, Brazil

Maria Fay Rola-Rubzen
School of Agriculture and Environment, University of Western Australia, Australia

Tobias S. Schmidt
ETH Zurich, Energy Politics Group, Switzerland

Kalim U. Shah
Biden School of Public Policy and Administration, University of Delaware, United States

Hans De Steur
Department of Agricultural Economics, Ghent University, Belgium

Casey Stevens
Providence College, Rhode Island, United States

Govinda Timilsina
World Bank, Washington, DC, United States

Bernhard Truffer
Eawag, Swiss Federal Institute of Aquatic Science and Technology, Switzerland
Faculty of Geosciences, Utrecht University, The Netherlands

Serdar Türkeli
United Nations University-MERIT and Maastricht University, The Netherlands

Steve Twomlow
International Fund for Agriculture Development (IFAD), Rome, Italy

Mara J. van Welie
Eawag, Swiss Federal Institute of Aquatic Science and Technology, Switzerland
Faculty of Geosciences, Utrecht University, The Netherlands

Renato Villano
Faculty of Science, Agriculture, Business and Law, University of New England, Australia

David Font Vivanco
2.-0 LCA consultants, Aalborg, Denmark

Rui Wang
Urban Planning and Design, Xi'an Jiaotong-Liverpool University, China

Karin Wedig
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Germany

Justus Wesseler
Agricultural Economics and Rural Policy Group, Wageningen University, The Netherlands

Seerp Wigboldus
Wageningen Centre for Development Innovation, Wageningen University and Research, Wageningen, The Netherlands

Kate Wingett
School of Life and Environmental Sciences, University of Sydney, Australia

Paul Wolfram
Center for Industrial Ecology, School of the Environment, Yale University, United States

Johanna T. Wong
School of Life and Environmental Sciences, University of Sydney, Australia

Carlos Eduardo F. Young
Institute of Economics, Federal University of Rio de Janeiro, Brazil

INTRODUCTION

1

What Can Science, Technology, and Innovation Offer in the Achievement of Sustainable Development Goals?

Ademola A. Adenle, Marian R. Chertow, Ellen H.M. Moors, and David J. Pannell

1. Introduction

Since 2000, significant achievements in global development have taken place, as evidenced by the lifting of one billion people out of extreme poverty and in the reduction of chronic hunger in many regions of the developing world (Word Bank 2018). Concerted international efforts aimed at meeting the millennium development goals (MDGs) in the period 2000–2015 have drawn the attention of many governments in developing countries, and helped shift their public policy and decision-making priorities (UN 2015). Despite these important achievements, much more needs to be done to bring people out of poverty, to improve public health, and to respond to environmental problems.

To expand and build on MDGs' successes, the United Nations' (UN) 2030 agenda for sustainable development (UN 2015) has included the establishment of a set of sustainable development goals (SDGs). SDGs break new ground in that they incorporate additional dimensions of socioeconomic and environmental concerns into the development agenda, within the setting of novel indicators of success across various sectors. The new United Nations 2030 Agenda for Sustainable Development has primarily been designed to end poverty, protect the planet, and ensure prosperity for all and nurture peaceful, inclusive societies (UN 2015). Associated with the 17 SDGs (Table 1.1) are 169 targets and 304 proposed indicators that are cross-cutting and multidimensional in nature, designed primarily to monitor SDG progress and to provide accountability for the implementation of the SDGs.

New policies that recognize the benefits of science, technology, and innovation (STI) and their potential risks are needed to implement the SDG agenda successfully by 2030. Recognizing this need, the Technology Facilitation Mechanism (TFM) was agreed to among UN member states in 2015. To support the achievement of the SDGs, "the TFM will facilitate multi-stakeholder collaboration and partnerships through the sharing of information, experiences, best practices and policy advice among Member

Table 1.1 The sustainable development goals

Goal 1. End poverty in all its forms everywhere
Goal 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
Goal 3. Ensure healthy lives and promote well-being for all at all ages
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
Goal 5. Achieve gender equality and empower all women and girls
Goal 6. Ensure availability and sustainable management of water and sanitation for all
Goal 7. Ensure access to affordable, reliable, sustainable, and modern energy for all
Goal 8. Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
Goal 10. Reduce inequality within and among countries
Goal 11. Make cities and human settlements inclusive, safe, resilient, and sustainable
Goal 12. Ensure sustainable consumption and production patterns
Goal 13. Take urgent action to combat climate change and its impacts
Goal 14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
Goal 15. Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels
Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Source: United Nations (2015).

States, civil society, the private sector, the scientific community, United Nations entities and other stakeholders" (UN n.d.). The TFM includes three main elements: an interagency task team on STI for the SDGs, a multistakeholder forum on STI for the SDGs (occurring annually, starting in 2016), and an online platform that provides a gateway to information on STI initiatives, mechanisms, and programs (not yet operational, as of April 2020) (UN n.d.). The existence of the TFM, and the participation by numerous stakeholders, reflects a broad recognition of the essential role of STI in delivering SDGs, and of the potential for improving the capacity of many developing countries to undertake STI initiatives that will help them achieve SDGs.

STI applications can make multiple contributions to the achievement of SDGs. Developing countries in particular will need to harness STI, while managing resulting trade-offs, to deliver on the three pillars of sustainable development: environmental, social, and economic. The SDGs simultaneously touch upon all three aspects.

Integrating these aspects into the implementation of the SDGs is a key challenge for both policymakers and researchers who need to address them in interdisciplinary research and innovation projects (Biermann et al. 2017). There is a range of barriers to channeling STI toward accomplishing the SDGs. Therefore, to meet its SDG targets, the global community must mobilize STI across multiple sectors, new investments in innovation, and policy design that addresses the barriers.

A lack of clear vision and understanding among national governments about how STI can contribute to achieving the SDGs remains a significant challenge. Our aim in this book is to address the gap by raising understanding of STI among domestic and international organizations concerned with sustainable development in light of the SDGs.

This book contains 26 chapters and involves 74 authors from 55 institutions across 19 countries around the world. The chapters are not all inclusive across STI. Rather we target three themes in which STIs are crucial for sustainable development: environment and energy, health, and agriculture. Within each theme the chapters offer thoughtful background on particular issues concerning SDGs. We address each issue with analysis of a concept or theory, a set of tools or practices, or policy-relevant advice based on data collected to find paths forward to sustainability transitions. In this way our work is part textbook, part handbook, and part idea/concept book. Some chapters address SDGs in specific geographies and others are topical without a specific geographic focus. While intending to serve the broadest STI and policymaker audience, on balance the book tilts toward developing countries and regions more than developed ones for examples.

2. STI and Sustainable Development

Advances in science and technology can help to deliver basic human needs, enhance economic productivity, reduce environmental impacts, and improve the quality of products and services (Holdren 2008). The United Nations and other international organizations have long recognized the importance of STI to modern societies and the way the emergence of technological innovation has shaped the world and contributed to economic development (UN 2002).

As part of the efforts to achieve sustainable development, linkages between STI and the earlier set of MDGs were highlighted, particularly in the contexts of promoting industrialization, increasing productivity, achieving food security, promoting access to quality health systems, and creating decent jobs. Yet a limited emphasis was placed on the role of STI in meeting MDG targets both at the national and international levels, inhibiting the achievement of the MDGs, especially in developing regions (UN 2014).

The integration of STI into a broader agenda for achieving sustainable development remains complex, especially at the international level. According to the United Nations, despite efforts by the UN Conference on Trade and Development to conduct national STI policy reviews, such reviews are not compulsory so universal coverage was not achieved (UN 2016).

The World Bank (2010) argued that there has been a lack of partnerships between developed and developing countries around STI, meaning that systematic knowledge transfer between the Global South and Global North was lacking, thereby undermining the role of STI in fostering sustainable development and economic growth in the Global South. There are a number of reasons why international cooperation for STI activities has been problematic. In developing countries, lack of investment, poor institutional conditions, weak governance, and limited infrastructure, among other things, have been blamed for slow advances in scientific and technological development (Knack and Keefer 1995; Word Bank 2010). A case study by Ramón and Gaudin (2014), for example, argues that Central American countries fail to implement national STI policies owing to deficient funds and weak infrastructure, for research and development (R&D) and more generally. In addition, many developing countries lack the human capital, socioeconomic institutions, and technology systems to engage in international cooperation to advance STI's contributions to sustainable development (Adenle et al. 2015; Ramón and Gaudin 2014).

International regimes pertaining to intellectual property rights (IPR) are designed to protect the interests of (mostly developed-country) IP creators. While this has the advantage of incentivizing the creation of new IP that can be commercially exploited, it may not be the regime that would most effectively foster international cooperation to help drive sustainable economic growth in the developing world (Bozeman 2000; Roffe and Santa Cruz 2007). Nevertheless, some countries have tailored IPR to meet their specific needs by building national innovation systems that target human capital development, enterprise development, and STI policy development, all of which can contribute to economic transformation. Studies have shown that a number of countries have come out of poverty and built competitive economies through a growth trajectory aligned with strong STI capacities as underpinned by effective national innovation systems. For example, Chung (2002) argues that South Korea's industrialization is largely driven by STI policy that focuses on national R&D investment; entrepreneurship development; partnerships between academia, public research institutes, and industries; and a well-educated workforce. This experience reinforces the importance of STI in helping to achieve national level SDGs.

The role of frugal innovation in addressing sustainable development issues has also become more important in recent discussion (Khan 2016; UNCTAD 2017). Frugal innovation concerns the (re)development of products, services, and systems at the lowest possible cost, while retaining functionality. Here, the critical question raised in the UNCTAD report is how to harness STI policy to develop low-cost technologies that can service marginalized groups facing resource constraints as they try to advance sustainable development, and ultimately contribute to the SDGs. Unlike the STI activities driven by market-based incentives for R&D investments, frugal innovation is generally associated with untapped markets and very-low-income grassroots communities (Seyfang and Smith 2007). Yet STI policies to promote grassroots innovation for the achievement of SDGs are still largely absent at the global and national levels (Khan 2016; Levänen et al. 2016).

3. STI and the Framework of the Sustainable Development Goals

This book focuses on the 17 SDGs as guides and motivators to foster sustainable socioeconomic growth and improve quality of life around the world. Of 169 SDG targets, 48 targets are related to STI (GSDR 2016). Many of the remaining 121 targets also touch on STI, in that technological innovation has a role to play in reaching the targets. This underlines the critical role of STI in advancing economic performance and inclusive development, especially in light of the limited recognition of its contribution in the former MDG era (UN 2014). One could argue that weak coordination of STI at the global level contributed to the underperformance of STI in terms of its contributions toward the achievement of MDGs, especially in developing countries. Despite the 2004 Millennium Declaration promoting science and technology for MDGs (United Nations Economic and Social Council 2004), emphasizing the important role of human capital development and local capacity building to facilitate international technology transfer, the recognized role of new and emerging technologies as part of global STI activities was limited (see chapter 20).

We have structured this book around three science-based arenas in which it is clear that STI is important for achieving sustainable development: 1) environment and energy, 2) health, and 3) agriculture. While our themes tend to be studied by separate disciplines, we recognize that the SDG framework is cross-cutting, multidimensional, and interlinked (e.g., Biermann et al. 2017; Kanie et al. 2017). The framework covers some specific global thematic priorities, such as SDG2 (end hunger) or SDG5 (gender equality) and includes some with a broader scope, such as SDG11 (inclusive, safe cities) or SDG9 (sustainable industrialization).

As noted earlier, the lack of national STI policy frameworks has hampered the implementation of national sustainable development strategies. Such national policies can benefit from international frameworks providing guidance, especially the TFM (UN 2016). Through stakeholder participation in international forums and the sharing of knowledge and experiences related to STI initiatives, mechanisms, and programs, the TFM can make a substantial contribution to the delivery of SDGs. It is an important initiative, but only one element of many that will be needed if STI is to be fully effective in advancing SDGs.

Another initiative has been the clean development mechanism (CDM) created under the Kyoto Protocol by the UN Framework Convention on Climate Change (UNFCCC). To decrease greenhouse gas emissions, the CDM encouraged the transfer of low-carbon sustainable technologies. CDM technology transfer was relatively successful in China, Brazil, and India, and this was attributed to their strong technological capabilities (Dechezleprêtre et al. 2009), as well as to strong institutional support and high-quality infrastructure compared to other developing regions.

However, the CDM failed to achieve its aims in a number of developing regions, especially in Africa (Goldman 2010; van der Gaast et al. 2009). This can be partly attributed to the lack of STI capacity in developing countries. Moreover, CDM projects lacked an international STI framework that could sustain technology transfer and strengthen the capabilities of local firms to build strong and competitive global industries. As a result, the diffusion of low-carbon technology has been uneven. CDM projects have arguably been the largest market-based mechanism to facilitate low-carbon technology transfer to developing countries (Koch et al. 2014; Schneider et al. 2008). Nevertheless, the MDGs failed to emphasize the importance of the CDM projects.

As part of the 2030 Agenda, the SDGs and the recent Paris Agreement of UNFCCC aspire to transform the ways in which climate change and sustainable development issues are addressed. The Paris Agreement calls for a new STI policy framework to facilitate low-carbon technology transfer as part of the implementation of sustainable development programs. For both the Paris Agreement and the SDGs, the current absence of a broadly accepted international STI framework remains an impediment. Despite this limitation, donors including the international community and developing-country governments continue to promote the potential application of STI in addressing sustainable development challenges without a holistic approach to move the STI activities forward. A key question is how should stakeholder groups come together to prioritize investments, IPR reforms, and trade regulations that shape overall creation and deployment of STI to facilitate the implementation of the 2030 Agenda, including SDGs in developing countries.

Beyond the need for an international STI framework, the participation of a wider range of stakeholders including country governments, donors, nongovernmental organizations, academia, and the private sector is key to achieving global STI partnerships, especially where primary incentives to access innovation is driven by markets. The overall success of the SDGs will depend on various global socioinstitutional and governance factors, including the extent to which countries formalize their SDG commitments, strengthen global STI solutions and policy arrangements, and translate global SDGs into national contexts while integrating the environmental, economic, and social pillars of sustainable development.

4. Financing SDGs Requires Global Partnership

The pairing of SDGs with STI requires not only funding to carry out the needed research, development, and deployment to advance global goals, but also strong and coherent partnerships engaging diverse stakeholders to set priorities, evaluate plans, implement projects, and monitor the agreed upon programs at all levels. The recognition of the need for partnerships goes back to the 1992 Earth Summit in Rio and the creation of Agenda 21 which called for a global partnership that included important ideas such as science for sustainable development. By the time we get to the present day, recognition of the need for cooperation is so great that there is an entire SDG devoted to it, SDG17 (global partnership for sustainable development).

On the monetary side, the UN estimate is that meeting the global goals would require $5–7 trillion annually through until 2030. Roughly half of this amount is already being spent on infrastructure and other activities, so the estimate for additional "gap" funds is $2–3 trillion annually. To put this in perspective, annual global GDP is over $100 trillion on a purchasing power parity (PPP) basis, suggesting that providing $2–3 trillion could be in the realm of possibility (BSDC 2019). The three themes that we have chosen for this book, environment and energy, health, and agriculture, tend to be on the high end of expenditure given that all three engage the science to germinate ideas, the technology central to increasing productivity and well-being, and the flow of innovation needed to be able to adapt to a wide range of geographic and demographic contexts. Still, on a benefit-cost basis at the broadest level, it is reasonable to speculate that the health and welfare benefits of actually meeting the SDGs related to the three themes would greatly outweigh the costs.

Neither finance nor partnerships have been overlooked in the ambitious effort to create SDGs and move them forward. While the MDGs were more government-centered, the private sector has been called on many times to pave the way for creating the investment required to pursue the SDGs. The final report of the Business and Sustainable Development Commission, for example, is titled *Ideas for Action for a Long-term and Sustainable Financial System* (BSDC 2019). It is organized by focus areas including creating pools for long-term finance and getting infrastructure finance right. The Commission's flagship report, *Better Business, Better World,* describes how "sustainable business models" could attract $12 trillion in new market value and create as many as 380 million jobs by 2030 (BSDC 2017).

Regarding partnerships, Unilever, a company that has been active and effective in integrating SDGs, created a 2018 report on *How to … Build Partnerships to Change the World*, based on the idea that SDGs require important work across business, civil society, and government. A key barrier confronting many of the suggestions in this book is that the vast majority of private capital is spent in developed countries and over half of the monetary estimate for SDG implementation is required in developing countries. One inspiring crossover example is a partnership by the UK Department for International Development and Unilever that created an innovation fund (£40 million), TRANSFORM, with the aim to enable 100 million people in sub-Saharan Africa and Asia to gain access to products and services related to health, livelihood, and environment or well-being (Unilever and Department for International Development 2019).

It is easy to observe that there is never enough money for STI. And failure to pay adequate attention to R&D investment for any of the three themes covered in this book may undermine the implementation of relevant SDGs at the national level and international levels. In chapter 3, Timilsina and Shah emphasize the need to increase R&D investment in renewable energy technologies especially in Africa and South

Asia, where billions of people still lack access to electricity and cooking fuels. This is reflected in another study which also emphasizes that investment in energy infrastructure is very limited in Africa as current annual spending is estimated at $8 billion compared to an estimate of investment need of $55 billion yearly until 2030 (Africa Progress Panel 2015). Also, in chapter 7, the authors Machado and Young analyze expenditure on R&D for environmental science in Brazil, finding that there is a substantial shortfall in government expenditures despite many improvements in the nation's STI programs. Beyond the funding itself, the fragmented practice of grant giving and the prolonged timetables of public funding surely inhibit the achievement of many good intentions.

Imagine expanding this single study and applying it globally. This suggests what is likely the most difficult aspect of managing SDGs—the sheer level of coordination needed to make the changes that SDGs demand for a better world. We have seen that some of the work on finance and partnerships has been thoughtful and, like the SDGs themselves, even visionary. The execution, however, is demanding—requiring wisdom, patience, and forbearance that can seem distant from our competitive, sped-up world.

One distinct challenge for the SDG agenda is how to actively engage various institutions, sectors, and actors especially at the national and regional levels in order to achieve synergy for mobilizing and accessing STI finance at the international level. Yet this problem persists without a coherent approach to accessing finance for the implementation of sustainable development projects, especially in developing regions (Adenle, Ford et al. 2017). Further, despite the increased demand for the mobilization of financial resources for achieving SDGs, previous evidence suggests that lack of transparency, potential interests of various actors, unevenly distributed finance, and limited capacity at the national level remain as obstacles particularly with regard to the implementation of relevant STI projects. For example, evidence indicates that mitigation projects such as renewable energy were only funded in Africa where institutional capacity was relatively strong (Adenle, Manning et al. 2017). These challenges call for global partnerships to increase access to finance especially at the UN level, where strong leadership, higher levels of commitment, and improved allocation of responsibilities can be coordinated.

5. The Structure of the Book

This book examines the relationship between STI and the 2030 agenda for sustainable development, providing examples, experiences, and case studies from around the world. It uses an interdisciplinary approach to examine the contributions of STI to the implementation of the SDGs across various continents including Asia, Africa, South America, and Europe. The inclusion of contributions from multiple disciplines provides for a broad range of perspectives and ideas on how to address the challenges at which the SDGs are targeted.

The book focuses on three human-development themes—environment and energy, health, and agriculture—as these sectors are major ones in which a STI approach can support SDG goals. The chapters highlight how STI initiatives have been applied to address each of the themes. They explore a range of STI solutions and governance arrangements. The themes are described further in the following sections.

5.1 Theme I: Environment and Energy

The environment and energy theme has nine chapters on SDG-related topics ranging from evaluation of biodiversity institutions at the global level to financing environmental STI at the country level (in Brazil), to the outlook on autonomous vehicles at the local, city level. There are four chapters on renewable energy, including two that are empirical and two that are relatively theoretical. All of these mention solar energy and, from an STI perspective, it is easy to see that better planning and implementation of solar energy could quickly change the status of millions of people in Africa and Asia who would achieve energy access. Altogether, the chapters unite many critical pieces that present a wider platter of possibilities for more rapid implementation of renewable energy.

Chapter 2 on biodiversity by Stevens proposes that innovation around wildlife conservation linked to SDGs is within our reach as a means of reducing biodiversity loss if we can learn from past efforts. In earlier days, a fragmented system of biodiversity governance came into being. Over time, this system has developed localized centers of innovation that would, passing on STI improvements from smaller groups to larger ones, raise the chances for acceptance and transfer of innovation across scales.

What can be learned from the four energy chapters (3, 4, 5, and 6) related to STI for SDGs? Overall, SDG7 stresses "universal access to affordable, reliable and modern energy services for all" by 2030. In chapter 3, Timilsina and Shah regard such energy as a "golden thread" that is linked to numerous other SDGs and is therefore critical to achieving many SDGs simultaneously. Adenle examines solar energy and SDGs in Kenya and South Africa in chapter 4. He emphasizes not only the educational, diet, wealth, and time-management benefits that are possible with increased dissemination of solar energy, but also the importance of African government policy enabling these benefits through investment in R&D programs and provision of appropriate subsidies. As a clean technology, solar energy has advantages over conventional sources because lower air emissions are accompanied by health and environmental benefits.

Schmidt and colleagues, in chapter 5, examine small, isolated renewable energy micro-grids that can serve a number of households independent of the main grid. The authors track these decentralized systems in three countries—Cambodia, Indonesia, and Laos—following the methodology of technological innovation systems that uses multilevel analysis to compare across these countries. They stress the importance of social and cultural differences and the need to consider each country's energy needs individually. Finally, Kemp and colleagues in chapter 6 explore three successful instances of the phasing in of solar energy and energy efficiency in China and India. They use an integrated framework that merges political economy elements of interests, ideas, and institutions with capabilities and policy delivery. Through this the authors find that there are positive and useful opportunities for developing countries to economize by advancing STI activities influencing several SDG targets simultaneously, given the interdependencies among them.

The theme of chapter 7, authored by Machado and Young, is whether countries provide sufficient resources for the environmental science and technology innovation that is needed to meet SDG-related goals in the detailed example of Brazil. By making reasonable and transparent assumptions about the level of financing that would be needed to fully fund R&D, the study reveals a significant financial gap and an urgent need to create alternative sources of funding or to find new sources from taxes and user fees.

The SDGs are highly cross-cutting and require expertise from numerous perspectives. Addressing these needs, chapter 8 by Chertow and colleagues presents the relatively new systems science of industrial ecology and outlines how it can contribute to the delivery of SDGs. Using tools such as life-cycle assessment and material flow analysis and approaches such as industrial symbiosis, industrial ecology provides many useful takes on physical resource use and efficiency in the quest to achieve SDGs.

As presented by Wang and Oster in chapter 9, transportation for passengers and freight plays a crucial role in achieving many SDGs. The core message of their work is that the revolution anticipated by the introduction of autonomous vehicles seems unlikely to radically change ground transportation in the near future given the challenges and uncertainties associated with highly automated ("driverless") vehicles.

Understanding how systems respond to technological change, including from STI interventions targeted at SDGs, it is important for policy leaders to know in advance about the rebound effect. Vivanco and Makov in chapter 10 present the idea of rebound effects, explaining how they can reduce the level of environmental benefit that a policy delivers when inherent conflicts arise based on interacting effects. For example, when the fuel efficiency of automobiles increases, drivers may decide to travel greater distances because it is cheaper. Rebound effects are a particular risk with the SDGs because they are so interlinked.

5.2 Theme II: Health

Chapters in the health theme examine how health is intrinsically linked to 16 targets across the 17 SDGs. The SDG framework provides an expansive approach to creating better health systems. The health theme has seven chapters on SDG targets, emphasizing the role of new and emerging technologies in solving key health problems in both developed and developing countries. It also covers a healthcare innovation approach and entrepreneurship programs targeted at health. The issues range from STI approaches to responsible innovation in health such as the development of vaccines, biotherapeutics, and antimalarial treatments, digital health, urban sanitation services and infrastructure, and regulatory innovations to tackle accessibility, affordability, and safety of healthcare.

Four chapters deal with empirical examples of STI to meet SDG goals, including vaccine innovations, antimalarial drug development and diffusion, sanitation innovations in informal settlements, and the role of animal-source food in healthy diets. One chapter focuses on the supportive role of digital health in meeting SDGs, and three chapters are more methodologically oriented, focusing on health technology assessment (HTA) methods to improve the contributions of STI to SDGs, a new sustainable innovation framework for meeting SDGs, and the role of responsive and responsible science and technology studies for global health. Overall, the chapters in the health theme cover crucial aspects of scientific and technological developments aiming for SDG targets. They discuss the socioeconomic, regulatory, and institutional challenges for sustainable innovations, and novel inclusive methodologies, frameworks, and supporting digital innovations to overcome these systemic barriers.

Chapter 11 by Possas and colleagues provides insights into the technological and regulatory challenges affecting access to vaccines in developing countries and recommendations for vaccine STI performance strategies to achieve relevant SDGs. From a global sustainability perspective, only SDG3.b.1 refers explicitly to vaccines. The authors, however, identify fourteen vaccine-related goals in the SDGs, of which SDG9 (sustainable industrialization) and SDG17 (global partnership for sustainable development) are specifically related to innovation and technological development of vaccines. The authors provide recommendations for specific vaccine STI performance indicators and strategies to achieve these fourteen vaccine-related SDGs.

Readers will also learn about how development-focused HTA can help support decisions about the introduction of new technologies for the achievement of SDG3 (healthy lives). Chapter 12 by Bouttell and colleagues sketches five different scenarios regarding biopharmaceutical innovations in low- and middle-income countries. It shows how HTA can improve the efficiency of research prioritization and development processes while ensuring that the needs of vulnerable populations are met.

A novel sustainable innovation framework based on availability, affordability, accessibility, and acceptability dimensions of the SDGs has been developed in chapter 13. This framework by De Haan and Moors can be applied in low-income and middle-income countries to innovations for communicable diseases, such as malaria, tuberculosis, and HIV/AIDS. The ending of these epidemics that are mostly prevalent in low- and middle-income countries (SDG3.3) cannot be separated from universal access to healthcare (SDG3.8). The same holds for malaria burden versus poverty (SDG1), education (SDG4), and equality between countries (SDG10). Additionally, water and sanitation conditions (SDG6) and global warming (SDG13) may affect living conditions of mosquitos and therefore also affect malaria infections.

Given this interrelated, multifaceted nature of SDGs, systemic approaches should be at the root of tackling global health challenges. For example, progress toward the sustainable development goal on water and sanitation (SDG6) is very slow and the lack of sanitation is especially persistent in rapidly growing cities in the Global South. Chapter 16 by Van Welie and Truffer shows how such a sociotechnical systems approach helps us understand the interaction between health and sanitation technologies and services, the infrastructure and institutions which need to be in place, and the user practices of new health technology.

There is also a need for responsive and responsible innovations for global health in context, as discussed in Engel and colleagues in chapter 15. For example, in the development and implementation of point-of-care diagnostics and development of cook stoves in low- and middle-income countries, there should be continuous interrogation and reflection on the localized consequences (intended and unintended) of new innovations rather than use of traditional technology transfer mechanisms. Chapter 14 by Poon and colleagues focuses on the benefits of digital health for the achievement of SDGs. This chapter evaluates the potential relations between digital and universal health (SDG3), inclusive and equitable education (SDG4), and reduction of inequality (SDG10). More specifically, the authors show how digital health could be articulated and evaluated in four dimensions—translation, education, transformation, and technology—to bridge the gap between digital health and SDGs.

The health section ends with a holistic approach for stakeholder engagement in animal-sourced foods in sustainable, ethical, and optimal human diets, as proposed by de Bruyn and colleagues in chapter 17. An ambition of the 2030 Agenda is to include health in development, and to recognize that good health depends on and contributes to other development goals, underpinning social justice, economic growth, and environmental protection (Dye 2018). As proposed by Dye (2018), it is important to expand the scope and enhance the effectiveness of the systems and the services that prevent and treat illness to advance health and development. In this way the 2030 SDG Agenda is also an expanded agenda for systems research, assuming that better systems can indeed deliver substantially better health and well-being for all.

5.3 Theme III: Agriculture

Agricultural STI has made enormous contributions to development in the past, and has great potential to do so again in future. Although the global percentage of people living in rural areas has fallen below 50%, it is still well over 50% in much of Asia and Africa. Particularly in these countries, agricultural issues are connected to multiple SDGs and often involve trade-offs between them. The eight chapters in this theme present a range of agriculture-related opportunities and challenges for achieving the SDGs.

Four of the chapters focus on particular technologies or sets of technologies: technologies for providing nitrogen to crops; integrated crop management for rice; crop biotechnology; and climate-smart agricultural technologies. In each case, the SDG-related issues raised range across food production (SDG2), poverty reduction

(SDG1), environmental protection (SDG6 and SDG15), and various others. The other four chapters are more cross-cutting, covering the nexus between production, supply chains, policy, and sustainability; transformation governance that strives for economic development while protecting the livelihoods of the poor who depend on the same resources; the method of value network analysis (VNA) that assists with reorganizing businesses in ways that can contribute to multiple SDGs; and a framework for responsible scaling of agricultural innovations, so that the delivery of SDGs is maximized with limited negative consequences.

The section starts with chapter 18 by Harpankar on nitrogen management. Ensuring that crops have adequate nitrogen to yield well is important for food production (SDG2, end hunger) and the economic welfare of farmers (SDG1, end poverty). In traditional systems, nitrogen largely comes from natural sources and is applied at modest rates, but as farmers adopt modern technologies in order to increase their productivity, they apply more nitrogen and rely increasingly on artificial fertilizers. While this helps farmers with their economic goals, it can result in serious problems of water pollution (SDG6, water and sanitation for all), and it involves higher emissions of greenhouse gases (SDG13, combat climate change). Harpankar discusses a range of technologies that may help to strike a better balance between production and pollution.

We then look at crop management for poverty reduction (SDG1) and food security (SDG2) for smallholder rice producers in Timor Leste. In chapter 19, Rola-Rubzen and colleagues investigate integrated crop management, a comprehensive package of measures including high-yielding varieties, high-quality seed, best-practice transplanting, and sound harvesting practices. They find that farmers who adopt these technologies have significantly higher yields and higher incomes. However, in common with some other favorable agricultural technologies, adoption across the population of farmers is disappointing. This throws the spotlight onto whether improved forms of agricultural "extension" (including information provision and training) can be devised and delivered to overcome adoption barriers.

While Rola-Rubzen mainly covers what might be termed "low-tech" solutions, Adenle and colleagues in chapter 20 discusses the potential of biotechnology to contribute to delivery of SDGs. The potential role of genetically modified organisms (GMOs) in addressing low agricultural productivity (SDG1), tackling malnutrition (SDG2), and adapting to climate change (SDG13) is considered to be very large. However, the persistent opposition to the application of GMOs in Europe and parts of developing regions (Africa, Asia, South America, Central America, and Latin America) is inhibiting the delivery of these SDGs. The authors suggest that an international GMO regulatory framework would assist in achieving acceptance of biotechnology solutions where appropriate. They also argue for use of risk-assessment models that suit local circumstances in developing countries rather than following the lead of certain developed countries that have chosen a highly conservative precautionary approach.

With an emphasis on climate change (SDG13), but with consequences for various other SDGs, Mwongera and colleagues explore the potential for "climate-smart agriculture" (CSA) in Africa (chapter 21). CSA encompasses measures for both adaptation to and mitigation of climate change, including minimum tillage, improved crop varieties, and integrated pest management. Mwongera presents a novel process for rapid appraisal of CSA, and applies it to case studies in Tanzania, Kenya, and Uganda. As with integrated crop management in Timor Leste, adoption of CSA in these three African case studies is found to improve farmers' incomes (SDG1), with some elements of the package being more beneficial than others.

In chapter 22, Flocco unpacks the soybean "production complex" in Brazil, with the aim of identifying levers that can help to deliver SDGs. She argues for a systems approach, including actions along the supply chain, from the adoption of best management practices in agricultural fields to development of supportive governance frameworks at the policy level. The approach is essentially market-based, but with an emphasis on conserving soils, with consequences for poverty (SDG1), hunger (SDG2), health (SDG3), water quality (SDG6), and others.

Another high-level perspective on SDGs in a primary industry is provided by Wedig (chapter 23), who presents the concept of "transformation governance" in the context of small-scale fishers in Lake Victoria, which contains Africa's largest inland small-scale fisheries sector, involving over three million people. Challenges are created by a growing commercial aquaculture industry operating in the lake, with risks to social and environmental sustainability. Wedig's three-part approach to governance is designed to manage these risks.

A different way of analyzing agricultural industries is provided by VNA, as explained by Dentoni and colleagues in chapter 24. They describe how VNA can be used as a diagnostic tool for actors seeking to reduce poverty (SDG1) and hunger (SDG2), enhance economic growth (SDG8), and other SDGs. Their case study of the Agricultural Commodity Exchange in Malawi reveals a number of options for building cross-sector partnerships that can utilize STI to help deliver SDGs.

Finally, we address the crucial issue of delivering SDGs at scale. Wigboldus and colleagues (chapter 25) identify the need for a "theory of scaling" to help make sure that efforts to deliver SDGs are successful at large scales rather than just locally. They highlight that the process of scaling up to large impact is often more complex than accounted for by policymakers and program managers. In unpacking what is inside the black box of unarticulated assumptions about scaling, they identify a broad range of relevant issues, including that scaling often involves multiple linked steps, the importance of understanding the characteristics of the innovation being scaled and how these characteristics fit with the needs of potential users, that scaling always involves a range of partners and stakeholders, and the need to link the theory of scaling to decision-making processes. This chapter has relevance to all of the SDGs, each of which needs to be delivered at large scale.

6. Conclusion

Readers of this book will come away with no doubt that STI can be a powerful tool for delivery of SDGs. Indeed, delivery of some SDG targets is likely to be impossible without major contributions from STI. However, readers will also come to appreciate that harnessing and applying STI effectively in the pursuit of development goals is often not straightforward.

The chapters of this book help to identify the challenges and complexities that must be grappled with in order to succeed in the delivery of SDGs through STI. The challenges and complexities described and analyzed are many and varied, ranging from the need to account for trade-offs between different SDGs when particular technologies or innovations are being considered for application, to the risk of unexpected consequences from application of technologies or innovations, to the existence of community opposition to certain types of science or certain technologies, removing them from the available toolkit via the political process, to the need for supportive policy environments, capable institutions, and good governance if STI is to deliver on its potential. These and many other issues are expanded on throughout the book. The book as a whole provides a wealth of analysis, experience, insights, and cautions that will be valuable to all who are involved in efforts to utilize STI in the delivery of SDGs.

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THEME I

ENERGY AND ENVIRONMENT

2

Learning to Innovate

The Global Institutions for Biodiversity Innovation in the Sustainable Development Goals

Casey Stevens

1. Introduction

Global biodiversity governance occurs in a highly fragmented institutional arrangement. The six major global biodiversity agreements capture a significant portion of the governance discussion, but significant amounts of global decision-making occur outside of these organizations. Market certification schemes have added another layer of governance. Nongovernmental organizations play a significant role inside and outside the treaties and market certification realm. And finally, government-to-government aid and assistance remains a bedrock of action and particularly shifts in action on biodiversity.

It is possible that such disparate efforts could be seen as an insurmountable weakness when it comes to developing coherent governance of science, technology, and innovation (STI). Fragmented governance allows countries and corporations to forum shop and find agreements that fit their policy preferences while ignoring the other governance regimes, creating a race to the bottom. In addition, fragmented action could cause low-level progress without ever coalescing into a large-scale global effort to reverse severe biodiversity loss. Finally, this fragmented institutional space could lead to technological uptake by the wealthy countries and further marginalization by poorer countries.

This chapter argues, in contrast, that the global biodiversity governance system has significant opportunities for innovation, particularly in connection to the sustainable development goals (SDGs). The argument is that while fragmentation may provide serious impediments to the development of coherent STI, there are contexts in which it can allow diverse ideas and technologies to develop and then spread throughout the system.

The global biodiversity governance system has not always been a system that could serve as a context for such global innovation, but currently it is. The global biodiversity governance system has constructed focused areas for innovative ideas to be created and the organizations have gotten strong enough to transmit innovative ideas throughout the system. Of central importance are the role of the National Biodiversity Strategies and Action Plans (NBSAPs) in the SDGs process and the development of stakeholder inclusion in the expert panels like the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). The architecture for global biodiversity governance has the key structure to facilitate innovation in the post-2015 agenda.

The focus of this chapter is on in situ wildlife conservation. In this field, three different scientific innovations could become core parts of the global system through the SDGs. First, integration of biodiversity and ecosystem services into wider discussions of development, housing, agriculture, climate change, and so on. Such connections and trade-offs have been significantly underexplored (McShane et al. 2011), but the specific targets of the SDGs emphasize some of these connections. Second, ecosystem-based management has been developing as a usable tool for conservation for a number of years now. The SDGs is the first major nonbiodiversity governance arrangement to explicitly focus on these as targets and indicators for progress. Third, the technology of remote sensing for both habitats and species has been used to effectively track changes in a number of different contexts. There are significant scientific and technical challenges to scaling up the use of such technology, but the SDGs, their targets, and the emphasis on monitoring could make significant gains in this respect.

What is the likelihood of innovation in global biodiversity governance through the SDGs? This chapter answers that it is very high, by exploring the architecture of the global biodiversity system. It proceeds through three sections. The first section explores the STI potential within the SDGs when it comes to in situ biodiversity conservation. The second section develops a framework for innovation that emphasizes the needs for developing science and technology in small groups and then spreading it throughout a larger system. The third section argues that global biodiversity governance has such a system in place. Therefore, the conclusion is that there are significant opportunities for innovation in biodiversity within the SDGs framework. Far from being guaranteed, changes that emphasize wider participation and which improve capacity of global biodiversity organizations and networks can make a significant difference.

2. Biodiversity Innovation and the SDGs

Goal 15 of the SDGs is the most relevant to the topic of in situ biodiversity conservation. The goal has the stated aim to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss." This goal includes nine specific biodiversity-related targets and three dealing with funding and resources.

In many ways, SDG15 builds on the earlier Aichi biodiversity targets developed in the Convention on Biological Diversity (CBD). For example, while most of the SDGs have a goal date of 2030, the biodiversity targets largely adopt 2020 as the goal date which is the same as the Aichi targets. In addition, some of the SDG targets are very similar to the Aichi targets. SDG target 15.5 commits actors to "take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent extinction of threatened species." Aichi target 5 says that "by 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced." Similarly, the indicator for SDG15.9 is simply measured in terms of progress on the Aichi targets. An initial assessment may suggest that the SDGs add little additional benefits to these earlier targets.

There are three STI opportunities that the SDGs directly connect with that could be relevant for biodiversity conservation. First, SDG15 and its targets are more integrated into larger issues of sustainability than are the Aichi targets. SDG2.4 calls for sustainable food production which maintains ecosystems. SDG2.5 builds on this by explicitly committing states to "maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species." Similarly, SDG6.6 states "by 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes." Goal 14 on conservation and sustainable use of oceans, seas and marine resources also connects to SDG15. While not as linked as other goals (Le Blanc 2015), this is an opportunity for new policy approaches and science policy that focuses precisely on these interactions. Importantly, these connections across various issues may prevent some of the myopia in the CBD that could restrain scientific progress (Prathapan et al. 2018).

Second, the SDGs overall and the specific goals and targets relevant to biodiversity conservation are a significant endorsement of the ecosystem approach to dealing with biodiversity loss. The millennium development goals and the Millennium Declaration notoriously adopted a very narrow and ill-defined framework toward biodiversity loss and ecological services. SDG14 and SDG15, in contrast, emphasize an ecosystem approach to biodiversity loss. This comes at a key point as the scientific base for ecosystem-based management is "moving—albeit slowly—from the 'what's, why's, and when's' to the 'how's' of operationalization and implementation" (Link and Browman 2017, p. 379). The goals dealing with ecosystems are vaguer than SDG6.5, which calls specifically for "integrated water resources management at all levels." However, the SDGs could provide the context in which applicable principles and approaches for ecosystem-based management can become an international focus.

Third, while much of the focus is on the goals and targets of the SDGs, the indicator discussion is a significant part of this agenda. Similarly to ecosystem-based management, the SDGs comes during a pivotal period for monitoring biodiversity loss, particularly through remote sensing. A recent review noted that remote sensing remains a "blunt tool" that is workable at the individual site scale, but not at larger or national scales (Corbane et al. 2015, p. 12). Lack of standardization and difficulty in operationalizing the Food and Agriculture Organization's land cover classification system both will be problems in scaling up this technological approach to monitoring habitats and species (Pause et al. 2016). Most of the biodiversity related targets and indicators will need significant conceptual progress in order to provide adequate assessments. SDG15.1, SDG15.3, and SDG15.4, in particular, rely upon basic land cover understandings, but could provide an impetus for developing better technological approaches for conservation. Crucially, the universal approach of the SDGs monitoring efforts could mean that more developing countries can contribute and benefit from such efforts. To date, such discussions have not figured predominantly in the discussions.

3. Architecture for Innovation

In addition to the available stock of scientific understandings and technological opportunities available for biodiversity conservation, this chapter argues that crucial is the ability of a global governance system to support and diffuse innovation throughout the world. This argument combines knowledge creation theory in management studies with the learning approach in international organizations. The basic argument is that the most effective innovation is that which starts in small sets of actors and is able to be broadcast from that small group of actors to a wider, connected network.

Knowledge creation theory begins with a distinction between tacit knowledge and explicit knowledge (Nonaka 1994). Explicit knowledge is the knowledge that is expressed, discussed, deliberated, and made apparent within an organization. The listing of species in biodiversity governance is a fantastic example of explicit knowledge where criteria are established, the threats to individual species are discussed, and standards of protection are developed and disseminated. Tacit knowledge, in contrast, is the personal knowledge of habit, design, and thinking from analogies. In relation to biodiversity governance, traditional and indigenous knowledge provides an excellent example because it is "inherently scattered and local in character, and gains its vitality from being deeply implicated in people's lives" (however, it is an example that should highlight the heterogeneity and limitations of scientific knowledge rather than reify some hierarchy of knowledge) (Agrawal 2014, p. 5).

From this approach, knowledge conversion or the processes by which tacit knowledge is made into explicit forms is the crucial process for innovation (Nonaka and von Krogh 2009). Tacit knowledge though does not easily lend itself to conversion and normal politics may tend to prevent knowledge conversion (Hannan and Freeman 1984). Knowledge creation theory argues that the key processes of knowledge conversion are 1) diversity of tacit knowledge, and 2) a process to facilitate discussion about tacit knowledge. If large groups of actors share a similar tacit knowledge (from organizational culture, similar training/education, etc.), then there will be limited contestation and disagreement to spur innovation. Similarly, if there is no forum for discussing tacit knowledge and transforming it into usable knowledge, then tacit knowledge is going to remain largely unexplored. Innovation happens from diverse epistemologies and processes of engagement that productively convert that diversity into new forms of explicit knowledge.

This conceptual framework resonates with on-the-ground examples of biodiversity management in local contexts. Many studies have found that "a great societal opportunity related to implementing voluntary biodiversity conservation initiatives is integration of various types of knowledge (social, ecological, scientific, and local) in the conservation planning processes for greater legitimacy and effectiveness" (Paloniemi et al. 2018, 7; see also Crona and Bodin 2006; Pretty and Smith 2004; Zerbe 2005). Similarly, an analysis of community-based adaptation policies found that wide participation and links to the larger development context were key to success (Reid 2016). Case studies in local environments have demonstrated that working together on projects can facilitate trust and effective biodiversity outcomes more than goal-based governance or working on preformed ideas together (Borg et al. 2015).

However, at the international level, these conditions present a number of challenges. First, while inclusion of diverse stakeholders is possible in local biodiversity efforts, scaling up to the international level adds additional logistical, representational, and accountability problems. This has been a central tension in the construction of IPBES. While IPBES developed a reflexive effort at stakeholder access (Esguerra et al. 2017), there remained pressures about including and developing connections with local level institutions (Soberón and Peterson 2015). Second, and relatedly, learning from diverse stakeholders is a difficult prospect in local biodiversity contexts, but developing systems for feedback from experience to future efforts is difficult at the international level. Those international negotiations that operate based on consensus, however, have found that including too many perspective becomes a barrier to social learning (Chasek and Wagner 2016). In addition, bureaucratic cultures and the battle for authority between different institutions present multiple ways for innovation to be blocked (Matthijs and Blyth 2018).

Haas and Haas (1995) provide an argument for how learning can occur in global governance. The crucial process in their approach is small-group consensus developing and influencing other actors. In particular, learning or innovation occur when small groups of experts (often scientists) develop arguments that resonate with a small number of important governments. These governments then form a coalition built around this consensus which then captures an international organization and uses it to transmit the argument to a wider group of states. The conveyor belt is built by different forms of small-group consensus along the way: expert consensus introduces novel ideas into the governance system, a coalition of states begins pushing for that consensus to be the basis of action, and finally consensus among member states or of the secretariat of an international organization turns that organization into a transmitter of novel ideas to a wider audience. Evidence from global health governance has indicated that legal obligations from the international organization are not necessary, and direct contacts between international organization staff and government bureaucrats and particularly technical assistance can be effective in this process (van Kerkhoff and Szlezák 2016).

4. Innovation Opportunities in Global Biodiversity Governance

The global biodiversity system has grown tremendously from its starting point in the 1970s. Since the 1990s, the CBD has been a primary international organization on biodiversity issues serving as a focal point for efforts, a negotiating forum on crucial issues, and an arena for the creation of global biodiversity efforts. Before the SDGs pursued multifaceted and interconnected goal-based governance, the Aichi biodiversity targets were created to focus efforts on slowing biodiversity loss by 2020. The Aichi targets and other efforts have created a rich terrain for innovative ideas to quickly develop, achieve critical support, and be transmitted across the globe. This section will highlight the national biodiversity planning process, international expert reporting, and the transmission capabilities of the international organizations.

4.1 National Biodiversity Strategies and Action Plans

SDG15.9 calls for integrating "ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts." This connects the SDGs directly into the ongoing process of the CBD, most notably the Aichi targets. The CBD calls on all member states to develop National Biodiversity Strategies and Action Plans (NBSAPs) that approach biodiversity action in a manner integrated with the rest of government programs and efforts. These are crucial tools for global governance, linking international discussions to national and local level planning and policies. Ideally, these would be regular planning documents, agreed to in a wide participatory manner, that fully mainstream biodiversity into the overall policy approach being taken by a country and set new directions in terms of conservation, sustainable use, and equitable sharing of benefits (the three core goals of the CBD).

This ideal is rarely met and the NBSAPs have tended toward the technical, with minimal amounts of nonstate stakeholders involved, and are often light on specifics beyond declaring protected areas. The example of the Solomon Islands is instructive. The first time they attempted to develop an NBSAP they solicited individual plans from multiple different relevant ministries, but then when they met there was no common vision to bring everyone together. The Ministry of Environmental Conservation and Meteorology restarted the process in 2007, but with limited staffing and funding to pursue a broad, multisectoral plan (Carter 2007). The group completed an NBSAP in 2009 with the assistance of funding from multiple international organizations and nongovernmental organizations. A second NBSAP was completed in 2016 with direct reference to action to achieve the Aichi targets.

This example helps to understand the challenges which have to this point limited the innovative impact possible within the NBSAPs. A 2015 assessment found three relevant points throughout the submitted NBSAPs. First, few incorporated other biodiversity related conventions into their NBSAP. Second, conservation got more attention than either sustainable use or equitable sharing of benefits. And, finally, many NBSAPs appeared to be geared toward external funders and did not have effective domestic participation (Pisupati and Prip 2015). A 2016 analysis found that education campaigns were the primary mainstreaming effort involved in NBSAPs and that integration into decision-making beyond the environmental ministry was limited (UNDP 2016). The result of these problems led to Aichi biodiversity target 17, which specifically declared that "by 2015, each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan." By the end of June 2018, 146 states submitted NBSAPs that directly take into account the 2011–2020 Strategic Plan for Biodiversity.

While they have been limited to this point, the accumulated experience, focus, and commitment to NBSAPs makes them a potentially invaluable tool for innovation in global biodiversity governance. Earlier recommendations for improving NBSAPs have focused on the CBD providing clearer guidance, streamlining procedures, improving funding and support for NBSAPs, and widening stakeholder involvement (Adenle et al. 2015; Global Policy Unit-IUCN 2013; Pisupati 2007; Pisupati and Prip 2015; UNEP 2016). In addition, the process itself has gradually become more reflective of the NBSAP forum and their open peer review mechanism. SDG15.9 offers an opportunity for improving the NBSAP process and also possibly elevating these action plans to higher level discussions in domestic contexts.

NBSAPs and the supportive system they have built up offer unique opportunities for innovation in the SDGs. The SDGs, and particularly 15.1, 15.2, and 15.9, offer the opportunity to integrate specific, time-focused targets into each country's biodiversity plan and also to integrate it better across different ministries in government. Currently, both are limitations on NBSAPs (International Council for Science 2017). But, more importantly, the experience with prior NBSAPs and the existence of the NBSAP Forum both offer opportunities for significant efforts on biodiversity-relevant targets within the SDGs. In the SDGs process, the voluntary national reviews are being submitted by countries to demonstrate progress and the NBSAP process could be quickly combined, although it has not been in any of the national reviews to date. The peer review mechanism should become more institutionalized and develop clearer guidance on participatory inclusion. Institutionalizing the NBSAP peer review with other existing and nascent ones like the fossil fuel subsidy reform peer reviews, environmental management peer reviews, and so forth offers a unique opportunity for innovation. Domestic groups that have prepared NBSAPs should be well-positioned to participate actively in wider SDGs planning, and the community established to facilitate NBSAPs can be a guide to other areas of the SDGs.

Key recommendations for NBSAPs are to use the SDGs as an opportunity to 1) develop more participatory processes including more stakeholders; 2) develop, with the SDGs, time-bound targets that emphasize biodiversity outcomes; and

3) institutionalize and promote the NBSAP Forum and the peer review mechanism, particularly through greater synergy with the SDGs voluntary national reviews.

4.2 Expert Systems

Expert systems, those bodies tasked with developing robust information to guide decision-makers in international organizations, have traditionally been somewhat hindered in global biodiversity organizations. Some of the expert committees have been highly politicized, while others have been too weak. There are examples of times and forums which have worked effectively at developing robust understandings, including stakeholders, and delivering ideas to policymakers in timely and usable fashion. However, these have tended to be focused on very particular issues or individual species. For biodiversity innovation to occur or for SDG15.A to see progress, expert systems able to develop explicit knowledge would be necessary. The development of IPBES, established in 2012, has signaled a change from this prior political system. While the direct impacts from IPBES are still developing, the secondary impacts are equally important.

IPBES is the institutionalization of efforts that started in 2001 until 2005 with the millennium ecosystem assessment. Because of the scope of the problem, in both biological and socioeconomic terms, even during this period the construction of expertise was spread very widely. Each international organization had its own separate expertise procedures tailored to the specifics of the organization. In addition, a tremendous amount of expertise was constructed in locale-specific manner with only partial interconnections to other locales, for example in the man and biosphere agreement. Some of the expert bodies were quite effective, some were highly politicized, and some barely functioned at all (Gehring and Ruffing 2008; Haas and Stevens 2011; Koetz et al. 2008).

IPBES was designed with two particularly relevant features for the discussion here. First, it was designed to be multithematic and operate at multiple scales (Brooks et al. 2014). As opposed to the Intergovernmental Panel on Climate Change (IPCC), which is organized around focal reports every few years, the IPBES is allowed to bring together experts on various themes as decided by the IPBES plenary. To date, they have produced eight assessments on issues dealing with pollinators, land degradation, scenarios and models of biodiversity, regional reports for Europe, Asia, Africa, and the Americas, and a global report. At the 2018 plenary meeting, governments agreed to three new assessments on sustainable use of wild species, the multiple values of biodiversity, and invasive alien species. While some features of this are similar to the working group format of the IPCC, its scope is intentionally broader and more adaptive. Second, IPBES is "one of the first international expert organizations to have systematically developed a strategy for stakeholder engagement in its own right" (Esguerra et al. 2017, p. 60). While this is the case, in terms of initial institutional design and early efforts, stakeholder involvement has been focused and limited rather than broad and substantive. At the fifth plenary meeting in 2017, governments requested the secretariat to implement better participatory mechanisms particularly in dealing with traditional and indigenous knowledge and this appeared to show results by the sixth plenary in 2018 (Earth Negotiations Bulletin 2018).

Beyond the direct impact, IPBES has had a secondary impact that is potentially important for the topic of innovation. The focus on key integrative science topics to the IPBES has allowed much more of a focus on usable knowledge in the other science forums (Clark et al. 2016; Turnhout et al. 2016). What this means practically is that the science bodies of the various international organizations can focus more effort on the tractable issues of their governance efforts rather than on more fundamental issues under discussion. The clearest example of this is with the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) in the CBD. The SBSTTA has shifted its focus significantly from broad, largely bureaucratic recommendations to those focused significantly on technical issues and establishing scientifically-based frameworks for implementation. For example, at the sixth SBSTTA meeting in 2001, five of the nine recommendations dealt with basic organization of efforts and collaboration with other international organizations. By the 21st meeting in 2017, only one of the seven dealt with such topics and the rest were focused discussions.

The expert space is well-designed and offers a host of opportunities for consensual dialogue to occur. IPBES is one forum for such engagements, but it is not the exclusive organization and significant opportunities now exist in the science bodies of the other international organizations. This is a change from a decade ago where there was no clear institutionalized science forum dealing with biodiversity and where many of the bodies in the organizations were beset with significant challenges.

Key recommendations for expert systems are to 1) expand and institutionalize the participatory mechanism in IPBES; 2) encourage and foster stakeholder engagement in expert systems; 3) further strengthen the science bodies in the international biodiversity organizations; and 4) routinize feedbacks from IPBES into the international organizations and then back to IPBES.

4.3 Transmission-Capable Institutions

SDG17 deals with strengthening the means of implementation and focusing on a global partnership for sustainable development. The focus of the targets is at the national level, but improving the means of implementation at the global level may be equally important. As explored earlier, the biodiversity governance system may be able to develop diverse findings effectively, but the crucial aspect is whether they can diffuse those throughout the various organizations and at the local level. In this respect, the various international biodiversity organizations have developed such capacities and experiences. The examples are everywhere with the CBD-affiliated Global Partnership for Plant Conservation, Ramsar Advisory Missions, the Sustainable Ocean Initiative, the elephant efforts of the Convention on International Trade of

Endangered Species, and so forth. Working with national-level actors, both state and nonstate, through these efforts are essential to any transmission efforts because they ground the broad idea into the particular context of the state. In this respect, SDG15.9 and SDG17.9, which both focus on improving the capacity at the national level, offers a crucial opportunity for promoting innovation. In particular, operationalizing and standardizing ecosystem-based management and remote sensing could be essential aspects of allowing states to improve understanding of their ecosystems and take more meaningful steps to address them.

More crucially, though, is whether there is an effective system for learning that moves from one sector of the incredibly complex biodiversity system to others. If learning in one organization can move to other organizations, then that would be an architecture primed for innovation. This is crucial with the specific STI aspects highlighted in the first section of this chapter which have seen most of their development in the European Union context, but have seen only limited extension. This issue has been recognized for a number of years and led to the establishment of the Liaison Group of Biodiversity-Related Conventions in 2004. This brings together six biodiversity related organizations in regular meetings on key topics. Some ideas have moved between the organizations, for example the Addis Ababa Principles and Guidelines for Sustainable Use of Biodiversity developed largely within the CBD have had an impact on discussions in the other organizations (Secretariat of the Convention on Biological Diversity 2004). While such guidelines might be applicable across the various organizations, the evidence of specific innovative ideas moving across the different organizations is limited. The different discussions dealing with what types of access require a need for equitable sharing of benefits in the International Treaty of Plant Genetic Resources for Food and Agriculture and the CBD's Nagoya Protocol is illustrative. While largely supportive of each other, there are enough differences to make implementation complex.

The process to improve the ability of the regime complex to transmit across organizations is better interplay management by the various secretariats (Jinnah 2014). One option would be to establish one of the organizations as the primary coordinating agency, an approach the CBD wanted to take early in the 2000s, but there is no need for this coordination to happen only at the international level. Domestic coordination offers an opportunity for the implementing organizations to connect and transmit ideas at a focused level. Key in facilitating this would be the various national focal points of the agreement but also the officers of the United Nations Environment Programme and the United Nations Development Programme. Many forums have been organized recently which attempt to deal with these problems. Facilitating additional forums that bring in secretariat staff of the various agreements would be a positive step in both downward and horizontal ideal transmission.

Finally, there is an opportunity for temporal alignment and bringing various agendas together. The CBD has established a 2050 vision of biodiversity being "valued, conserved, restored and widely used." The plan at this point is for the 2011–2020 decade to be followed with a new strategic plan lasting until 2030. The ability to put all global biodiversity organizations on a similar timeframe would do much to facilitate the discussion and development of innovative ideas and their transmission across organizations. The correspondence between this strategic vision and the SDGs ending point in 2030 all provide an excellent opportunity for innovation of governance systems.

Specific recommendations are 1) continued use and strengthening of the Liaison Group; 2) strengthening the international biodiversity organizations to improve direct contacts and work with national level bureaucrats; and 3) temporal integration, bringing discussions in the various organizations together on a shared and overlapping time frame.

5. Conclusion

The temporal gap between the Aichi biodiversity targets and the SDGs offers an opportunity to reset the efforts after 2020 and really move forward on issues before 2030. How can the world make the most significant contribution possible for reversing biodiversity loss in the last decade of the SDGs? Three sets of scientific and technical ideas are primed to see significant progress forward: integration of biodiversity with other social spheres, ecosystem-based management, and remote monitoring of habitats and species. In order to do so, however, they will need to be spurred by the SDGs process to include more participants and be fostered by the global biodiversity organizations to spread to more settings. This chapter has argued that both of these are possible.

To achieve such innovation and scientific progress, however, would require planning right now for the post-2020 period. The urgency was reflected in both the High Level Political Forum meeting dealing with the SDGs in 2018 and in the regular meetings of the CBD. Maintaining a focus on widening participation, linking biodiversity with other spheres, and facilitating standards of remote sensing relevant to developing countries can help significantly. Innovation is not assured, but there are significant opportunities for turning the 2021–2030 period into one of significant scientific and technological progress on biodiversity issues.

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3
Energy Technologies for Sustainable Development Goal 7

Govinda Timilsina and Kalim U. Shah

> Energy is central to nearly every major challenge and opportunity the world faces today. Be it for jobs, security, climate change, food production or increasing incomes, access to energy for all is essential. Transitioning the global economy towards clean and sustainable sources of energy is one of our greatest challenges in the coming decades. Sustainable energy is an opportunity—it transforms lives, economies and the planet.
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> **—United Nations SDG-7, 2008**

1. Introduction

Globally more than one billion people do not have access to electricity and almost three billion people do not have access to modern fuels for cooking and home heating. More than two-thirds of the population without access to modern energy live in sub-Saharan Africa and South Asia. In sub-Saharan Africa alone, close to 90% of the rural population does not have access to electricity and 93% do not have access to modern energy for cooking (World Bank 2018). In 2015, the United Nations established the sustainable development goals (SDGs), a set of 17 global goals and 169 targets aiming to address a broad array of social and economic development challenges by 2030. These challenges include hunger, poverty, health, education, climate change, gender, clean drinking water and sanitation, modern energy, air pollution, and social justice (UN 2015). The theme of one goal, SDG7, centers on energy (ensure access to affordable, reliable, sustainable, and modern energy for all) and is composed of five targets, as listed in Table 3.1. Target SDG7.1 states the importance of access to affordable, reliable, and modern energy services for all by 2030. It is regarded as a "golden thread" because it is linked to other SDGs, namely SDG1 (end poverty), SDG2 (end hunger), SDG3 (healthy lives), SDG4 (equitable quality education), SDG6 (water and sanitation for all), SDG8 (economic growth, employment, and decent work), SDG9 (sustainable industrialization), SDG11 (inclusive, safe cities) and SDG13 (combat climate change) (de la Sota et al. 2017; Bhattacharya and Palit 2016). Therefore, meeting SDG7 is critical to achieving other SDGs as well.

Table 3.1 SDG7 goals and achievement indicators

Goals by 2030	Indicators
7.1: Universal access to affordable, reliable, and modern energy services	• Proportion of population with access to electricity • Proportion of population with primary reliance on clean fuels and technology
7.2: Substantial share of renewable energy in the global energy mix	• Renewable energy share in the total final energy consumption
7.3: The global rate of improvement in energy efficiency be doubled from 2015 level	• Energy intensity measured in terms of primary energy and GDP
7.a: Enhanced international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promotion of investment in energy infrastructure and clean energy technology	• Mobilization of $100 billion annually starting from 2020
7.b: Expanded infrastructure and upgraded technology for supplying modern and sustainable energy services for all in developing countries, particularly least developed countries, small island developing states, and land-locked developing countries	• Investments in energy efficiency as a percentage of GDP and the foreign direct investment in financial transfer for infrastructure and technology to sustainable development services

Source: Frankfurt School-United Nations Environment Programme (2015).

Since SDGs were launched in 2015, some progress has been made toward accomplishing SDG7. Global electricity access reached 85.7% in 2016 from 84.9% in 2014. An increase of 1% every year is needed on global energy access from 2016 to 2030 to achieve SDG7.1 (World Bank 2018). The share of renewables in the world's total final energy consumption (TFEC) increased 0.2% from 17.3% in 2014 to 17.5% in 2016. Still, more efforts are needed to achieve SDG7.

There are several challenges, however, in the quest to provide access to modern energy in access-deficit areas. Among the barriers to energy access, the main ones are lack of supply infrastructure, poor quality of supply, connection costs, and affordability. In many developing countries, especially in sub-Saharan Africa and South Asia, households and businesses do not have access to modern energy despite their affordability and willingness to pay because energy production capacity and supply infrastructure (e.g., transmission and distribution networks) do not exist. Per capita electric generating capacity in some poor countries, such as Chad, Nepal, and Cambodia, is a thousand times lower in comparison to developed countries (IEA 2018).

Even if supply is available, the quality is poor. Continuous disruption of electricity has become a characteristic of electricity supply systems in many developing countries. For example, unscheduled electricity disruptions occur more than 20 times in a typical month in several countries such as Yemen, Lebanon, Iraq, Pakistan, Guinea, Central African Republic, Democratic Republic of Congo, and Nigeria (IFC 2017). Scheduled power disruptions or load-shedding is common in many countries in South Asia and sub-Saharan Africa, where there is no electricity for hours and hours per day because of load-shedding. Therefore, reliable supply of modern energy is a key concern.

Affordability is another critical challenge for achieving SDG7 because households are not expected to spend more than 5% of their monthly income on energy in countries with tropical climates and 10% of spending in countries with temperate climates At present, however, 57% of the population living in energy access-deficit countries spend more than 5% of their gross nominal income on energy (World Bank 2017). A large number of poor people in South Asia and sub-Saharan Africa cannot afford electricity and modern cooking fuels such as liquefied petroleum gas (LPG) even if supply is available. In India, 22% of rural households and 6% of urban households in areas already electrified do not utilize electricity because they cannot afford connections or consumption (Ghosh-Benerjee et al. 2015).

In light of the challenges of reliability, affordability, and access to energy across the world, technology plays a pivotal role in achieving SDG-7. The transformation of the current energy system to a clean energy system requires new technologies to meet demand growth. This has catapulted the growth of renewable energy sectors such as solar, wind, and biomass (IEA 2017). Research, development, and innovation are making scalable renewable energy systems ready to be deployed to provide reliable and affordable power to people.

Renewable energy can be decentralized into off-grid systems thereby providing critical energy access to places with limited grid reach. Apart from the renewable energy sector, natural gas has grown into a comparatively cleaner way to generate electricity and heating, especially during peak periods. Along with renewable energy, energy efficiency technology has been touted to be one of the two foundational pillars of a sustainable energy system, but it has not taken off in developing countries owing to significant financing and technological challenges discussed later.

2. Conventional Technologies for SDG7

Various technologies and options are available to achieve SDG7. The main options are: (i) expanding the conventional energy supply systems; (ii) renewable and emerging technologies; (iii) modernization of traditional energy sources; and (iv) expansion of energy efficiency measures in residential and commercial buildings. Table 3.2 presents these key technologies required for meeting SDG7 and provides definitions

Table 3.2 Technologies and options for achieving SDG7

Technology/option	Definition	Examples
Expanding existing energy infrastructure	Rural electrification expanding electricity grids; adding infrastructure and supply chain for natural gas, LPG	Electricity grid expansion, natural gas distribution for home heating, cooking; LPG for cooking
Growth of renewable and clean energy technologies	Isolated single unit rooftop solar home systems; solar, hydro or wind power based mini or macro grid systems	Solar home systems, microgrids and mini grids for electricity, ethanol and biodiesel for cooking and transportation
Modernization of traditional energy resources	Conversion of traditional biomass to modern energy	Landfill gas or biogas for both lighting and heating, biomass fired electricity micro-mini grids
Expanding energy efficiency technologies	Reduction in amount of energy use for specific tasks	Energy efficient lighting, HVAC and appliances in residential and commercial buildings

Source: authors.

and examples. The critical challenge is that all of these options are relatively expensive and those without access to modern energy are mostly low-income populations who cannot afford these expensive energy services (Cecelski 2015). This implies that significant intervention is needed from governments and international development communities with respect to incentives and other policy supports for both producers and consumers of clean energy and energy efficiency technologies. (Dornan and Shah 2016; Ahlborg and Hammar 2014).

The number of people without access to electricity is striking (see Table 3.3). Based on 2016 data from the International Energy Agency, 1.06 billion people do have access to electricity in the world and over half of those defined as "energy poor" live in sub-Saharan Africa (Mohammed et al. 2013). North Africa, the Middle East and some Central and South American countries have experienced a remarkable increase in electrification levels by successfully supplying power to most of their residents. Haiti is the only country in the Americas with a 33% electrification rate, while other countries in the region have surpassed a 75% electrification level (Belt et al. 2018). Asia has experienced an increase in its electrification rate of nearly 22% for the 2000–2016 period, however. Yet 439 million people remain without electricity access.

Countries like Bangladesh, Nepal, Myanmar, and Laos have showed the highest increase in electrification for the 2000–2016 period, now supplying electricity to over 75% of their population from nearly 20% of their population in 2000. A similar scenario is seen in sub-Saharan Africa, which has experienced an increase of 20% for the same period (Mohammed et al. 2013; Brew-Hammond 2010). Less than 10% of the

Table 3.3 Electricity access

	Rate of access (%)						Population without access (million)
	National				Urban	Rural	
	2000	**2005**	**2010**	**2016**	**2016**	**2016**	**2016**
World	73	76	82	86	96	73	1060
Africa	34	39	43	52	77	32	588
• North Africa	90	96	99	100	100	99	<1
• Sub-Saharan Africa	23	27	32	43	71	23	588
Developing Asia	67	74	83	89	97	81	439
• China	99	99	99	100	100	100	—
• India	43	58	66	82	97	74	239
• Indonesia	53	56	67	91	99	82	23
• Other Southeast Asia	67	76	83	89	97	82	42
• Other Developing Asia	32	39	53	73	87	65	135
Central and South America	87	91	94	97	98	86	17
Middle East	91	80	91	93	98	79	17

Source: International Energy Agency (2017).

population in Chad, Central African Republic, South Sudan, and Sierra Leone have access to electricity, which is critically low and very alarming. The distribution of energy is also uneven in some regions—rural areas have a much lower electrification rate where the largest share of the population lives (Javadi et al. 2013; Khandker et al. 2012).

The main challenge to electricity grid expansion is that areas without electricity are often located far from the existing grids. Moreover, electricity load densities of those areas are too low. These factors cause the expansion of existing grids to be economically unattractive (Abdul-Salam and Phimister 2016; Akpan 2015; Nerini et al. 2016; and Javadi et al. 2013). Figure 3.1, reproduced from Nerini et al. (2016), indicates the importance of load density (in terms of number of households) and distance from the existing grids, on the cost of electricity supply through grid extension.

The figure also illustrates that the cost of electricity supplied through grid extension varies based on (i) distance from the existing grid, (ii) price of grid electricity, and (iii) load density. If the national grid electricity price is 0.15 USD/kWh, the electricity supply costs (or levelized cost of electricity supply or LCOE) increases up to 60% for each 10 km increase in distance to the grid.

An expansion of electricity grids would not be economically feasible without adequate demand or if the consumers cannot afford for it. These are typical characteristics of many areas not having electricity access around the world. The high costs of electricity extension and the low return coming from the extension in rural and remote areas helps to explain why electric utilities have little incentive have to pursue grid

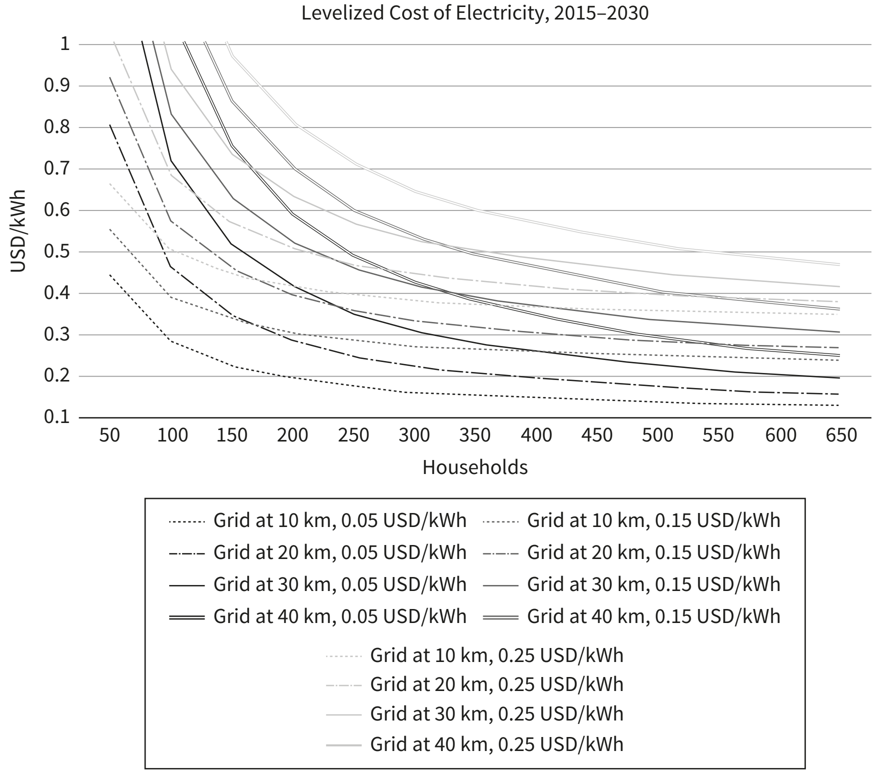

Figure 3.1 Cost of electricity through grid extension as a function of distance from existing grid and load density
Source: Nerini et al. (2016).

expansion or heavy investments on grid transmission and distribution assets (Dornan and Shah 2016; Williams et al. 2015). Therefore, governments should come forward with incentive packages to the utilities for grid expansion. Cross-subsidization schemes, where industrial consumers can pay more to generate the necessary funds, are the most common policy to promote grid extension (Picciariello 2015).

The situation is not different in the case of providing access to clean energy for cooking and heating. In many countries, modern fuels used for cooking (e.g., LPG, kerosene) are heavily subsidized. While conventional fuel subsidies are being phased out in many countries, it is unlikely that subsidies on clean cooking fuels, especially LPG, will be phased out any time soon Similarly, clean cooking technologies, such as improved biomass-fired cooking stoves, have been subsidized by almost every developing country around the world (Freeman and Zerriffi 2015). Landfill gas or biogas are also subsidized in virtually all countries where they are deployed (Siddiqui 2013).

Recent developments in smart grid technology have also provided technological options for expanding grid access. Such innovations have the potential to