Green Energy and Technology

Oktoviano Gandhi
Dipti Srinivasan *Editors*

Sustainable Energy Solutions for Remote Areas in the Tropics

Springer

Green Energy and Technology

Climate change, environmental impact and the limited natural resources urge scientific research and novel technical solutions. The monograph series Green Energy and Technology serves as a publishing platform for scientific and technological approaches to "green"—i.e. environmentally friendly and sustainable—technologies. While a focus lies on energy and power supply, it also covers "green" solutions in industrial engineering and engineering design. Green Energy and Technology addresses researchers, advanced students, technical consultants as well as decision makers in industries and politics. Hence, the level of presentation spans from instructional to highly technical.

Indexed in Scopus.

More information about this series at http://www.springer.com/series/8059

Oktoviano Gandhi · Dipti Srinivasan
Editors

Sustainable Energy Solutions for Remote Areas in the Tropics

Springer

Editors
Oktoviano Gandhi
Solar Energy Research Institute of Singapore
National University of Singapore
Singapore, Singapore

Dipti Srinivasan
Department of Electrical and Computer Engineering
National University of Singapore
Singapore, Singapore

ISSN 1865-3529 ISSN 1865-3537 (electronic)
Green Energy and Technology
ISBN 978-3-030-41951-6 ISBN 978-3-030-41952-3 (eBook)
https://doi.org/10.1007/978-3-030-41952-3

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

My first encounter with the energy problems in the remote tropics was in early 2016, at the start of my Ph.D. journey under Prof. Dipti Srinivasan. At the time, I joined a community project organised by the Indonesian Students' Association in Singapore to an Indonesian island called Geranting. The island is located merely 30 km away from mainland Singapore, a global financial centre and one of the most prosperous countries in the world, but the difference in the level of development of the two islands could not be starker.

There are about 300 families in Geranting Island, and most of them are fishermen. The residents relied on an old diesel generator for five hours of electricity per day. When the diesel generator breaks down—a common occurrence—the residents resort to hazardous kerosene lamps for lighting. The island had actually received grants from the government in the forms of solar home systems for each house and communal solar PV systems for the local school and for water desalination. Nevertheless, without the transfer of knowledge to the community and proper maintenance, the systems quickly broke down and were abandoned.

After the community project in Geranting, a group of friends and I came back to the island to repair the PV system at the local school and decided to try and solve more of these problems. We discovered that this is the case not just in Geranting, but in many islands and communities across Indonesia, and across the developing economies. It is obvious that the technologies to solve the problems are already available, but without proper implementation, the situation will not improve.

Throughout my Ph.D. and rural electrification journey, I have encountered and learned from numerous people who have the same vision and passion to solve these energy problems as sustainably as possible. Their advice, which comes from their wealth of experience, has definitely helped me in the discovery and implementation of sustainable energy solutions in the remote tropics.

When the opportunity arises to put the lessons I have learnt, combined with Prof. Dipti's expertise in renewable energy and energy systems, into a book, we immediately contacted the experts whom I have encountered, as well as those whose works have been instrumental in the sustainable energy sector. Many

of them have agreed to become authors and shared their lessons learnt from their own journey in their respective chapters.

The lessons from these experts are now more important than ever. As we are faced with the "dual challenge" of meeting rising energy demand and emitting a decreasing amount of carbon, we need to collaborate and combine all our efforts, knowledge, and expertise to come up with, implement, and scale the solutions.

Working with such diverse groups of authors, from academia, industry, government, and non-profit sector—all of whom are experts in their chosen fields—has been very enriching both personally and professionally. I would like to thank the authors who have been committed in writing their respective chapters, particularly Christoph Luerssen, who has contributed immensely to the book since the ideation stage.

Singapore Oktoviano Gandhi

My interest has always been renewable energy in all its forms and its relation to sustainable development. Although sustainable energy was not a popular term even twenty years ago, the concept was widely discussed due to the fact that almost all developing economies that have grown in the past fifty years have done so either using non-renewable resources or by making formerly sustainable ecosystems, such as natural forests, unsustainable in the long run through industrial exploitation, and other activities. Furthermore, this development corresponds to nearly one for one increase in the use of energy.

Today, people use more energy than ever from a variety of sources for a multitude of tasks, which undoubtedly make our lives better. While Asia has an abundance of natural energy resources, the main challenge has been to balance the energy demand against sustainable practices. In 2008, I started offering a graduate-level course to provide the students with a thorough understanding of analysis and management strategies for promoting the advancement and use of economically and environmentally sustainable electrical energy systems. The course covered distributed generation and renewable energy sources and strategies for supply and demand-side management for efficient resource utilisation, as well as issues related to the environmental impact of electrical energy generation. My encounters with these disciplines provided much inspiration and conceptual linkages that enhance the potential for smart energy technologies to reduce or shift energy demand.

The last few years have seen a rapid increase in community-led sustainable energy projects around the developing world, capitalising on alternative energy initiatives taken by the governments and moving towards a sustainable low-carbon economy. These initiatives have included both energy generation and conservation projects, combined with micro-generation technologies and energy efficiency improvement programmes. In this book, rather than providing a typical overview of sustainability projects, various experts in the field provide an interesting account of projects to illustrate how smart initiatives are potentially transforming everyday practice. Our hope is that this book will speak to the engineers and economists who

are designing, building, and making the case for sustainable development in remote communities with little or no access to grid electricity. Towards this end, this book draws on experience from a wide range of fields to reconceptualise and extend the possibilities for sustainable development in remote regions. We hope to showcase innovations for sustainability transitions that have been successfully implemented as local projects and disseminate best practices to encourage innovation diffusion.

Singapore Dipti Srinivasan

Contents

Editors and Contributors

About the Editors

Oktoviano Gandhi obtained a master of physics degree from the University of Oxford, UK, in 2015, and a Ph.D. from the National University of Singapore (NUS) in 2019. He is currently a research fellow at the Solar Energy Research Institute of Singapore (SERIS), NUS. On the research front, he has worked on the engineering aspects of solar cells and modules, solar energy integration in power systems, all the way to analysing policies' impact on energy intensity. His scientific works have resulted in more than twenty international publications. Oktoviano has also held positions in many top universities across the world, namely Yonsei University in South Korea, University of Sao Paulo in Brazil, and Tsinghua University in China.

Through Alva Energi, a company that he co-founded, he is channelling his expertise in solar energy, rural electrification, electricity grid planning, and energy policy to promote renewable energy development in Indonesia. His works and achievements have been recognised internationally: he was selected to be part of Global Young Scientists Summit, Leader of Tomorrow at St. Gallen Symposium, One Young World Ambassador, and BP Advancing Energy Scholar. Most recently, Okto was featured in Vanity Fair 2020 Global Goals List, representing SDG7: Ensure access to affordable, reliable, sustainable and modern energy for all.

Dipti Srinivasan is a professor in the department of electrical and computer engineering (ECE) at the National University of Singapore (NUS), where she also heads the Centre for Green Energy Management and Smart Grid (GEMS). Her recent research projects are in the broad areas of optimisation and control, wind and solar power prediction, electricity price prediction, deep learning, and development of multi-agent systems for system operation and control. Her current research focuses on the development of novel computational intelligence-based models and methodologies to aid the integration of the new smart grid technologies into the existing infrastructure so that the power grid can effectively utilise pervasive renewable energy generation and demand-side management programs, while accommodating stochastic load demand. She has published more than 350 publications which have been highly cited.

She is a fellow of IEEE and was awarded the IEEE PES Outstanding Engineer award in 2010. She is an associate editor of IEEE Transactions on Smart Grid, IEEE Transactions on Sustainable Energy, IEEE Transactions on Evolutionary Computation, IEEE Transaction on Neural Networks and Learning Systems, and IEEE Computational Intelligence magazine. At the ECE department of NUS, she teaches courses in the areas of sustainable energy systems, smart grid, and computational intelligence methods. She is the recipient of the NUS Annual Teaching Excellence Award and Engineering Educator Award.

Contributors

Andrea Eras-Almeida is a Ph.D. researcher at Instituto de Energía Solar at Universidad Politécnica de Madrid (UPM). Her research focuses on off-grid renewable solutions on vulnerable contexts such as small islands, rural areas, and refugee camps. She is a member of the UPM Platform on Refugees. She has ten years of professional background in the energy sector. Among other positions, she has been Head of the Energy Planning Department at Electrical Company ELECGALAPAGOS (Ecuador) and also she worked in the UN Development Program as Energy Advisor. In Reiner Lemoine Institut, she has been Guest Researcher at the Off-Grid Research Unit. She holds an electrical engineering degree from Universidad de Cuenca (Ecuador), a master's degree in Renewable Energy and Environment by UPM, and a master's degree in Economic Development and Public Policies by Universidad Autónoma de Madrid. She is committed to energy transition based on holistic solutions for resilient energy supply. Currently, she is involved in energy research projects in Africa and Latin America.

Paul Bertheau is an expert in island energy supply and has been a member of the Off-Grid Systems team at the Reiner Lemoine Institute since 2012. He holds an international master's degree in Global Change Management and is currently doing his PhD at the Europa-University of Flensburg and the Reiner Lemoine Institute. His research focuses on sustainable electrification options for small islands in the Philippines. He has led several research projects, including market potential studies for renewable energy on islands and feasibility studies for specific renewable technologies and renewable energy projects. In this context, he has worked with partners from the public and private sectors and gained practical work experience in Africa, Asia, and the Pacific.

Dr. Philipp Blechinger is an international expert in renewable energies and rural electrification. He holds a Ph.D. in engineering from the TU Berlin. Currently, he is Head of unit Off-Grid Systems at Reiner Lemoine Institut. Here he managed and conducted a wide range of international projects on energy access and island energy supply. Examples include the rural electrification planning for Nigeria and the support to the Department of Energy of the Philippines to improve electrification efforts. Apart from that he continuously publishes and shares research results on conferences and in scientific journals (>50) acting as reviewer and co-editor as well. He is also a visiting scholar of the Renewable and Appropriate Energy Lab (RAEL) at UC Berkeley and a selected member of the Arab-German Young Academy of Sciences and Humanities (AGYA). During his fieldwork, he visited many Caribbean countries: Barbados, Grenada, Jamaica, St. Kitts & Nevis, St. Vincent & the Grenadines, and Trinidad & Tobago. In addition, he worked on the Cook Islands, the Philippines, in Tanzania, Nigeria, and Zambia.

David Cheong is the vice dean in the School of Design and Environment, National University of Singapore (NUS). In addition, he is the co-director (Centre for Integrated Building Energy and Sustainability in the Tropics) in the Department of Building, NUS. Dr. Cheong is also a fellow of the International Society of Indoor Air Quality and Climate. His research interest is in the area of indoor air quality, ventilation and energy efficiency in buildings as well as the migration of pollutants into buildings. He has more than 200 publications in international journals and conferences. He serves on several local technical committees and is a reviewer of numerous research projects for the Engineering and Physical Sciences Research Council (EPSRC) in the UK and Research Grants Council of Hong Kong.

Walter Commerell has been a professor for Energy Storage at THU, Ulm University of Applied Sciences since 2007. He is a member of the institutes "Energy and Drive Technology" and "Vehicle Systems Technology". His research areas are energy storage and energy management in stationary and mobile systems. He initiated and manages the "International Energy Competence Network" (IECN). Professor Dr. Commerell is a member of the Association Simulation (ASIM) and speaker of the department "Simulation of Technical Systems" and member of the German Society for Solar Energy and the International Solar Energy Society.

Since 2010, he is the director of the "Steinbeis Transfer Centre System Design", where he together with a group of engineers work on industrial projects. Since 2000, he has been in the Supervisory Board of Phocos AG, where markets solutions for off-grid systems are designed and sold. Before joining the university as a professor, he worked for T-Systems for several years as a project centre team leader model-based design, and he was CEO of VIAx Solutions Ltd.

He received his Dipl. Ing. (FH) in industrial electronics with a focus on renewable energies in 1988 and his doctorate after working in industry in 2001.

Alvin B. Culaba is an academician of the National Academy of Science and Technology, Philippines and a university fellow and professor of mechanical engineering at De La Salle University Manila, Philippines. A pioneer in the area of life-cycle assessment (LCA), he was the first to apply the LCA methodology to sustainability analysis of manufacturing processes and has developed streamlined LCA approaches to different energy applications. His various energy studies were the basis for the crafting of the Philippines twin energy bills, namely the Biofuels Act of 2006 and the Renewable Energy Act of 2008. He led a technical team that developed and commissioned a community-based micro-hydro power (MHP) system in an off-grid area in the northern Philippines. He is actively engaged in the country's energy sector since 1988 and has been the Philippines energy adviser and expert panel member

on the energy of the Congressional Commission on Science, Technology and Engineering. He was also a past president of the National Research Council of the Philippines, the Philippine-American Academy of Science and Engineering, and the Philippine Association for the Advancement of Science and Technology. A multi-awarded scientist, teacher, and science administrator, he holds a Ph.D. in mechanical engineering at the University of Portsmouth, UK, and is listed in the Who's Who in Philippine Engineering.

Tika Diagnestya is a social justice advocate and a management consulting analyst at Accenture. As a management consultant, She helps her clients to grow and sustain their business for a better global economy and to improve economic injustice. Her project ranges from sustainability to digital issues.

Her journey to reduce economic inequality started when she went to Tanzania for her foremost volunteer abroad in 2013. Since then, She has helped to rebuild low-income houses in a rural area within the USA before returning to Indonesia. In 2018, she and her co-founder won an award to launch Masak Bersih (MASIH). MASIH, in its first few years, aims to distribute 500 clean cook stoves to the rural areas of Indonesia.

She had internship experiences in a government agency and a multilateral organisation with a specific interest in macroeconomics and economic development. After graduating with a B.A. degree in Economics from New York University, She worked for a year as an investment analyst with an Indonesian government agency hoping to make a change for the country's economy.

Patrick Dolle is currently working as a project coordinator in the Department for International Cooperation at Physikalisch-Technische Bundesanstalt (PTB), the German Metrology Institute. Among other projects, he is working in Indonesia on a project to strengthen quality infrastructure for photovoltaics. The project aims to support the quality assurance services for photovoltaics systems in Indonesia. He has an academic background in environmental and forest sciences, as well as in international cooperation and sustainable development. He has worked for several research

institutes like the Bern University of Applied Sciences in Switzerland and the Forest Research Institute (FVA) in Baden-Württemberg, Germany.

Raluca Dumitrescu is the head of ME Consult, the consulting arm of MicroEnergy International. She is a rural electrification expert with extensive experience in countries in Africa, South Asia, and Latin America. She has participated in numerous feasibility studies on solar home systems and mini-grid and in the design of various intervention measures to intensify and improve the productive use of solar energy, particularly in unconnected rural areas, combined with an assessment of end-user financing for energy access (microfinance models, PAYG, and A-B-C). She is familiar with the local context of Tanzania and has worked extensively on previous projects in the country and region. In addition, she also has expertise in financial due diligence, strategy development, and business models, including risk analysis and market analysis. Currently, She is a doctoral candidate at the Technical University Berlin on the topic of "Community-Based Intelligent Rural Electrification—Swarm Electrification".

Sebastian Groh is a 2013 Stanford Ignite Fellow from Stanford Graduate School of Business and holds a Ph.D. from Aalborg University and the Postgraduate School MicroEnergy Systems at the TU Berlin where he wrote his doctoral thesis on the role of energy in development processes, energy poverty and technical innovations, with a special focus on Bangladesh. He published a book and multiple journal articles on the topic of decentralized electrification in the Global South.

He started his career and received his DNA at MicroEnergy International, a Berlin-based consultancy firm working on microfinance and decentralized energy. In 2014, He founded SOLshare, acting as its CEO since then. He is also an associate professor in the Business School of BRAC University in Dhaka, Bangladesh. On behalf of SOLshare, he received numerous awards, among them Tech Pioneer '18 by the World Economic Forum and best energy start-up in the world by Free Electrons. SOLshare also received the prestigious UN DESA Powering the Future We Want USD 1M Energy Grant, along with Grameen Shakti. He became

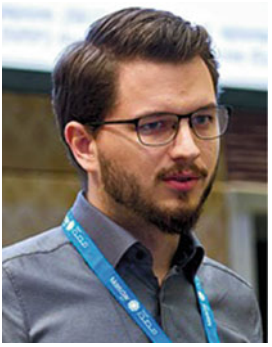
Ashoka Fellow in 2018, and UBS Global Visionary in 2019, as well as received the 2019 Unilever Young Entrepreneurs Award.

Martha M. Hoffmann is a researcher in the Research Unit Off-Grid Systems at the Reiner Lemoine Institut (Berlin, Germany). She conducts research on the simulation and optimization of sector-coupled local energy systems in the scope of the H2020 project E-LAND. She was enroled in the master's degree in Renewable Energy Systems at TU Berlin. In the context of her work, she wrote her final thesis examining the future operation options of micro grids interconnecting with weak national grids. For this, she developed off-gridders, a simulation and optimization tool for electric energy systems away from or connected to a central electricity grid, based on the Open Energy Modelling Framework (oemof). She holds a bachelor's degree in Energy and Process Engineering from TU Berlin. After conducting a student research project dealing with swarm grids, she spent three months in India for an internship at Oorja Development Solutions Limited, during which she worked on electrification with micro grids.

Swee-Sum Lam, Ph.D., Ph.D., CA, CFA, is an associate professor of finance at the NUS Business School and the director of the Asia Centre for Social Entrepreneurship and Philanthropy (ACSEP). She is an accountant by training, having earned her doctorate degree in finance from the University of Washington. Prior to joining NUS, Associate Professor Lam has had diverse work experience in corporate banking, corporate finance, and real estate. Since assuming the directorship of ACSEP in 2011, she has curated the addition of six new modules—on leadership, entrepreneurship, investing and consulting at the intersection of the business and social sectors—to both the BBA and MBA curricula at the NUS Business School. To build leadership in the people, public and private sectors, she seeded the Social Impact Prize Awards and Scholarships in Social Entrepreneurship and Philanthropy for both BBA and MBA students. She also oversaw the launch of the ACSEP Case Series on Social Entrepreneurship and

Philanthropy to advance impactful practices through formal education and executive training. In addition, she introduced the ACSEP Working Paper Series on Social Entrepreneurship and Philanthropy to foster thought leadership with the desired outcome being the reallocation of scarce resources to those who can deliver impact for social good.

Licheng Liu received his B.Eng. in engineering science from the National University of Singapore in 2010 and was subsequently awarded the NRF Clean Energy Scholarship, issued by the Singapore Economic Development Board, to pursue a Ph.D. degree in Advanced Photovoltaic at the Solar Energy Research Institute of Singapore in the National University of Singapore. Upon conferment of his Ph.D. degree in 2014, he started working closely with various governmental bodies, as the deputy head of the National Solarisation Centre, to promote solar energy as a reliable and sustainable alternative source of energy for Singapore. He kick-started the SolarNova project and was a vital contributor to the Floating PV Test Bed project. Thereafter, he moved on to the Independent Power Producer (IPP) business at Saferay, where he was in charge of the operations and maintenance, as well as the asset management for a fleet of utility-scale solar power plants that the company developed and built in Japan. Currently, he is focusing on the project development and project financing aspects of the IPP business, where he performs due diligence on legal, technical, financial, and tax-related topics, evaluates the profitability with financial models, and carries out a risk assessment and mitigation for potential projects.



Christoph Luerssen is currently a final-year Ph.D. candidate at the National University of Singapore (NUS) conducting his research on energy storage for solar-powered cooling applications at the Solar Energy Research Institute of Singapore (SERIS). His research interests also include product development and system design for rural electrification as well as the exploration of ways to enable clean energy transition in developing economies.

Prior to his Ph.D. studies, he pursued a bachelor's degree in Energy Systems Technology at Ulm University of Applied Sciences in Germany while

working part-time as a development engineer for Fosera, a solar home system manufacturer. He started his professional career with an apprenticeship as a hands-on Mechatronics Technician and continues to enjoy applied work.

Christoph co-founded Alva Energi, an Indonesian renewable energy company, where he serves as the CTO and aims to contribute to the clean energy transition in Indonesia, which is well aligned with his passion: developing and implementing various types of solar energy solutions.

Isidro A. Marfori III is a licensed mechanical engineer and an assistant professor of mechanical at De La Salle University Manila, Philippines. He finished his M.Sc. in mechanical engineering at De La Salle University and has been awarded outstanding thesis for his thesis titled "Design and optimisation of a propeller-type micro-hydro turbine using computational fluid dynamics". Ingko, as he is fondly called by his colleagues and friends, has been involved in the design and implementation of micro-hydro power (MHP) systems in the country since 2004. His expertise and knowledge in MHPs have contributed to the drafting of policies related to local MHP standards, technology deployment, and studies on MHP turbines and controllers. He received the Pillar of Excellence Award in Community Engagement in 2015 for his significant and impactful work on community-based MHPs. An expert in advanced computer-aided design and simulation, he is currently undertaking research on optimality and sustainability of community-based MHP system operations and cost competitiveness.

Daniel Philipp has more than 17 years of experience in energy engineering and economics, strategic business development, technology design, clean energy technologies (CET) implementation, testing of standards for CETs, supervision of CET installation and testing, as well as monitoring and impact evaluation. Since 1995, he has been involved with microcredits for developing aid policy. In 2002/2003, he conducted research in cooperation with the Technical University Berlin on the enterprise Grameen Shakti (GS) in Bangladesh, together with GS's loan officers on how green microloans can be disbursed for SHS. Ever since, he has tried to replicate through different technical assistance programs the Bangladeshi model of linking CETs with affordable financing in countries such as the Philippines, Peru, Tanzania, Burkina Faso, Senegal, Ghana, and Ethiopia. He possesses a deep understanding of the complexity of the supply chains of CETs in different socioeconomic and cultural contexts. He has been involved in technical and financial due diligence of PAYG companies in West and East Africa. He has conceptualised the swarm electrification (Peer-to-Peer Networks of CETs) approach and is currently coordinating the development and market distribution of swarm energy products and services.

Thomas Reindl is the deputy CEO of the Solar Energy Research Institute of Singapore (SERIS) and the principal research fellow at the National University of Singapore (NUS). He started with photovoltaics (PV) in 1992 at the SIEMENS Corporate R&D Labs. After holding several management positions at SIEMENS and running one of the leading German PV systems integration companies as a chief operating officer, he joined SERIS in 2010 and soon became the director of the Solar Energy System cluster. During his time at SERIS, he won public research grants in excess of SGD 20 million, founded two spin-off companies and authored strategic scientific papers such as the "PV Roadmap for Singapore". He holds a master in chemistry, a Ph.D. in Natural Sciences and an MBA from INSEAD, all awarded with highest honours. His research interests are high-performance PV and embedded systems, techno-economic road-mapping, and the reliable integration of renewable energies into power

systems. He is also the principal investigator of the "Floating PV test bed" project in Singapore.

Chandra Sekhar is a tenured professor and co-director (Centre for Integrated Building Energy and Sustainability in the Tropics) in the Department of Building, National University of Singapore. He was the programme director (M.Sc. in Building Performance and Sustainability) for 17 years until 2019. His research interests include thermal comfort, ventilation/IAQ, energy efficient HVAC systems, smart buildings, and building energy analysis with more than 250 publications in international journals and conferences. He is a co-inventor and holds three US and other patents. He is a fellow of ASHRAE and ISIAQ.

In addition, he has also been recognised through several other awards, including Uichi Inouyi Memorial Asian International Award from SHASE, Japan (2019); Environmental Health Award (2014), Exceptional Service Award (2013), and Distinguished Service Award (2010) from ASHRAE; SPRING Singapore Merit Award (2012), ASEAN Energy Award (2011), and The Enterprise Challenge (TEC) Award of the Singapore Prime Minister's Office (2004). He has been an ASHRAE Distinguished Lecturer since 2006 and is regularly invited as a speaker around the world. He currently serves as Director-at-Large on the ASHRAE Board of Directors. He is active in Standards and Technical committees in ASHRAE and is also actively involved in local standardization activities in Singapore.

Amalia Suryani has an overall twelve years of experience in the energy and environment sector. She started her career as a fuel price and subsidy analyst in the Indonesian Ministry of Energy and Mineral Resources. In 2010, she joined the Clinton Foundation as an energy efficiency analyst, supporting the Jakarta government in implementing energy efficiency measures for buildings and streetlighting. From 2011 to 2018, She worked for German Agency for International Development Cooperation (GIZ) as a renewable energy advisor in the Energising Development (EnDev) project. EnDev is a global partnership promoting sustainable access to modern, clean, and affordable energy services. She acted as the

project's team leader for three years, managing the support programme for photovoltaic mini-grids and micro-hydro power plants. She holds a master's degree in Environmental and Energy Management from the University of Twente in the Netherlands and is currently pursuing her second master's degree in Sustainable Development Studies at Universität Leipzig, Germany.

Xiang Ru Amy Tan is a research associate at the Asia Centre for Social Entrepreneurship and Philanthropy (ACSEP) in the NUS Business School. She holds a master of social science (Sociology) from NUS, and her research interests include food and preventive health care, ageing, and community-enabling in the urban environment. She is experienced in conducting ethnographic and mixed methods social research. She has been involved in various social research projects in the past, such as examining the rise of singlehood, delayed marriages; landscape study on the state of home and community care for seniors in Singapore; strategic philanthropy in funding public goods. She is deeply interested in using impact evaluation methods to build research capabilities in the social sector, and she has also written on social impact measurement in the growing impact investing sector.

Christian von Hirschhausen is a professor for Economic and Infrastructure Policy at Berlin University of Technology and research director for International Industrial and Infrastructure Policy at the German Institute for Economic Research (DIW Berlin). He holds M.A. (Economics) from the University of Colorado at Boulder (1988), Diplom-Ingenieur (Industrial Engineering) from TU Berlin University of Technology, Ph.D. (Doctor in Industrial Economics) from the Ecole des Mines de Paris (1995), and Habilitation (venia legendi) in Economics from TU Berlin University of Technology (2002). Previously, he has held position at Dresden University of Technology. His research focuses on environmental, energy and

resource economics, infrastructure and network economics, applied industrial economics, and political and institutional economics. He is the editor-in-chief of EEEP (*Energy and Environmental Economics and Policy*) and has published extensively on issues of the low-carbon energy transformation in Germany, Europe, and globally. His recent works are on electrification and network economics.

Jackie Yap Chee Wei was born in Ipoh, the state of Perak, Malaysia, in 1992. He received the B.S. degree in mechanical engineering from the University of National Energy (UNITEN), Putrajaya campus, Malaysia, in 2015. His research areas include renewable energy and entrepreneurship. From 2015 onwards, he has been the founder and chief executive officer of HiGi Energy Corporation, a company established to eradicate water hyacinth disaster across 52 countries by turning water hyacinth and other agricultural wastes into cooking fuels. He has extensive experience in business model innovation and community development in the sustainable cooking industry.

He is associated with the U.S. Department of States for the Global Innovation through Science and Technology (GIST) fellowship. He is also associated with Techtown, an entrepreneurial hub based in Detroit, Michigan, USA. He is a consultant in the For-Purpose Enterprise (FPE), a non-profit organisation to provide consultancy service to start-ups and corporations with sustainability-related initiatives within the organisation.

Dazhi Yang received his B.Eng., M.Sc., and Ph.D. degrees in electrical engineering from the National University of Singapore, Singapore, in 2009, 2012, and 2015, respectively. He is currently a research scientist with the Singapore Institute of Manufacturing Technology, Agency for Science, Technology and Research, Singapore. His research interests include solar forecasting, data science, and spatio-temporal statistics. He is a subject editor of *Solar Energy*, for the area of Solar Resources and Meteorology.

Abbreviations

AC	Alternating current
BNI	Beam normal irradiance
BTI	Beam-tilted irradiance
CAPEX	Capital expenditure
CFC	Chlorofluorocarbon
CFL	Compact fluorescent lamp
CHP	Combined heat and power
COP	Coefficients of performance
CSR	Corporate social responsibility
CSS	Control Systems Society
DC	Direct current
DHI	Diffuse Horizontal Irradiance
DRC	Democratic Republic of Congo
DRE	Decentralized renewable energy
DSCR	Debt service coverage ratio
DTI	Diffuse-tilted irradiance
EPC	Engineering, procurement and construction
ESMAP	Energy Sector Management Assistant Program
EYA	Energy Yield Assessment
FAO	Food and Agriculture Organization
FCU	Fan coil unit
FIT	Feed-in tariff
GADM	Global Administrative Areas
GDP	Gross domestic product
GHG	Greenhouse gas
GHI	Global horizontal irradiance
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Cooperation)
GS	Grameen Shakti (Village Energy)
GTI	Global-tilted irradiance

HCD	Human-centred design
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HOMER	Hybrid Optimisation of Multiple Energy Resources
HVDC	High-voltage direct current
ICT	Information Communication Technology
IDCOL	Infrastructure Development Company Limited
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineer
ILK	Institut für Luft- und Kältetechnik (Institute of Air Handling and Refrigeration)
IMF	International Monetary Fund
IoT	Internet of things
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IT	Information Technology
KYC	Know your customer
LCA	Life-cycle assessment
LCOE	Levelised cost of electricity
LED	Light-emitting diode
LGU	Local Government Unit
LPG	Liquefied petroleum gas
LVDC	Low-voltage direct current
MBE	Mean bias error
MFI	Microfinance Institution
MHP	Micro-hydro power
MKP	Misi Kami Peduli (Mission: We Care)
MOA	Memorandum of Agreement
MPPT	Maximum power point tracking
MSE	Mean square error
MTF	Multi-tier Framework
NAMRIA	National Mapping and Resource Information Authority
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organisation
NUS	National University of Singapore
O&M	Operations and maintenance
ODP	Ozone depletion potential
OECD	Organisation for Economic Cooperation and Development
OPEX	Operational expenditure
P2P	Peer-to-peer
PAYG	Pay-as-you-go
PCM	Phase change material
PLN	Perusahaan Listrik Negara (National Electricity Company of Indonesia)

PPA	Power purchase agreement
PU	Polyurethane
PV	Photovoltaic
QI	Quality Infrastructure
R&D	Research and Development
RE	Renewable energy
RLI	Reiner Lemoine Institute
RMSE	Root mean square error
SDG	Sustainable Development Goal
SHS	Solar home system
SPT	Simplified planning tool for hybrid systems
SPV	Special purpose vehicle
SROI	Social return on investment
TV	Television
UHI	Urban heat island
UN	United Nations
UNEP	United Nations Environment Programme
VRF	Variable refrigerant flow
VSD	Variable speed drive
WACC	Weighted average cost of capital
WHO	World Health Organization
YDD	Yayasan Dian Desa (Dian Desa Foundation)

Introduction

Oktoviano Gandhi and Dipti Srinivasan

Climate change is probably the most difficult and important challenge of this century. If left unsolved, it has the potential to end humanity as we know it. The world has experienced approximately 0.6 °C increase in temperature as of 2014 compared to the periods of 1950–1980 [1] and is predicted to suffer from a 3.5 °C increase in temperature by the end of the century should the business-as-usual activities continue [2]. So far, the temperature increase shows no sign of stopping: July 2019 was recorded as the hottest July globally since 1880, at 0.95 °C above the twentieth century average [3]. Even a mere 2 °C increase in temperature would cause sea level to rise by 56 cm by 2100—submerging many low-lying islands and countries—and increase the frequency of extreme weather conditions throughout the world, among other severe and irreversible effects [4, 5]. At 3.5 °C increase, the consequences are much worse.

The problem of climate change has been worsening due to the increasing use of energy in both the developed and developing countries. The world energy consumption has increased by approximately 40% from 2010 to 2017 and is predicted to increase by more than 25% by 2040 even in the International Energy Agency (IEA)'s "New Policies" scenario [6]. Under this scenario, the CO_2 emissions in 2040 would be 35.9 gigatonnes, up 10% from the 2017 value. Meanwhile, the United Nations Environment Programme (UNEP) warned that CO_2 emissions need to peak by 2020 and decrease drastically if we were to stay within a 2 °C temperature increase by 2100 [2].

The increase in the final energy consumption can be largely attributed to the expanding economy of countries with large population like India, China, and Indonesia, particularly in the form of increasing electricity demand for industrial motors,

O. Gandhi (✉) · D. Srinivasan
National University of Singapore, Singapore, Singapore
e-mail: okto@nus.edu.sg

D. Srinivasan
e-mail: dipti@nus.edu.sg

O. Gandhi and D. Srinivasan (eds.), *Sustainable Energy Solutions for Remote Areas in the Tropics*, Green Energy and Technology,
https://doi.org/10.1007/978-3-030-41952-3_1

as well as for space cooling and household appliances in urban areas [6]. The equipment does not only consume energy when used but also has to be manufactured using energy. Approximately, half of the increase in primary energy demand would be fulfilled by fossil fuel generation [6], which emits greenhouse gases, among other pollutants.

While the energy consumption of the urban dwellers continues to increase unabated, there remains large portion of the population which still does not have access to energy, especially in the form of electricity. These communities are usually located in remote areas (or islands) in the developing world, most of which lie along the Earth's tropical belt. These remote communities too experience a growth in their purchasing power, albeit at a slower rate than their urban counterparts. And, they too need to increase their electricity consumption (often from 0) to improve their livelihood, such as to have lighting in the evening, to have access to fresh food and working vaccines, among other basic needs.

Yet, if the remote communities obtain their energy sources in the same way as most of humanity before them did, i.e. by burning fossil fuels for electricity and cutting wood from the forest for cooking, the problem of climate change will be exacerbated. Ironically, these remote communities are also the most vulnerable to the consequences of climate change. Therefore, there needs to be sustainable energy solutions for the remote communities to improve their livelihood, while protecting the world's environment.

That is precisely the aim of this book, to not only provide an overview of the types of problems that exist in the remote tropics but also the details of what the solutions can be, accounts on how they have been applied in real life by experts in the field, as well as their impacts and how these solutions can be made more sustainable, not only for the environment but also for the communities. This book is targeted towards people who want to make a real difference in the world, by solving one of the world's most challenging problems at any scale—one community, an island, a country, or even a whole continent. These people can be existing energy practitioners in the rural areas, academics, policy makers, or even students who are embarking on a learning journey about energy and sustainable development. These people most definitely include you, who have picked up this book to learn about the defining challenge of our time and how to solve it.

1 The Remote Tropics

The tropics are the region around the equator, between $\pm 23°27'$ latitude as shown in Fig. 1, characterised by warm weather (averaging 25–28 °C) all year round. Unlike the temperate and the subpolar regions, the tropics only experience two seasons: wet and dry seasons—some areas even experience only one hot season. It is home to about a third of the world's population.

The tropics are also home to the world's largest tropical rainforests, one of the key ingredients in keeping our Earth's temperature to stay within a 2 °C increase.

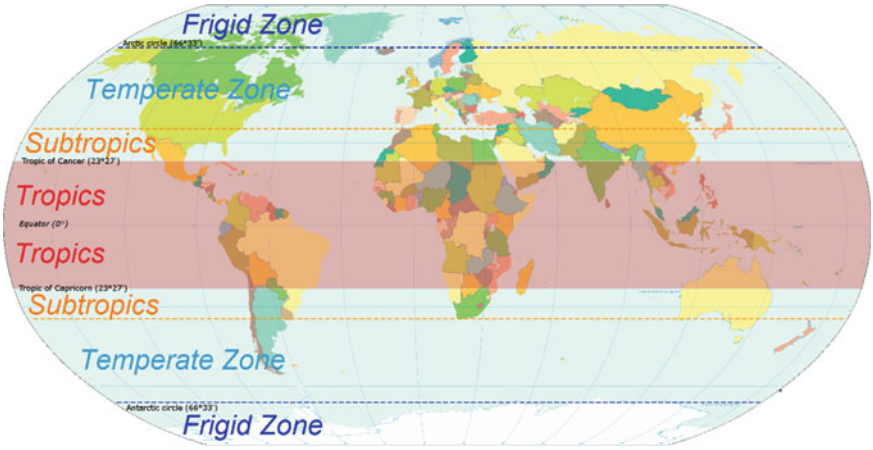


Fig. 1 World map with tropical region marked in crimson. Picture by Genetics4good/CC BY-SA 3.0

Unfortunately, the forest land keeps on decreasing due to corporate logging and mining activities, as well as deforestation by locals to obtain wood for cooking fuel and construction.

The countries that lie along the tropics are generally less affluent compared to its temperate counterparts, as can be seen in Fig. 2. Almost all tropical countries fall under the International Monetary Fund (IMF)'s category of "emerging and developing economies" [7]. As of 2019, they possess an average gross domestic product

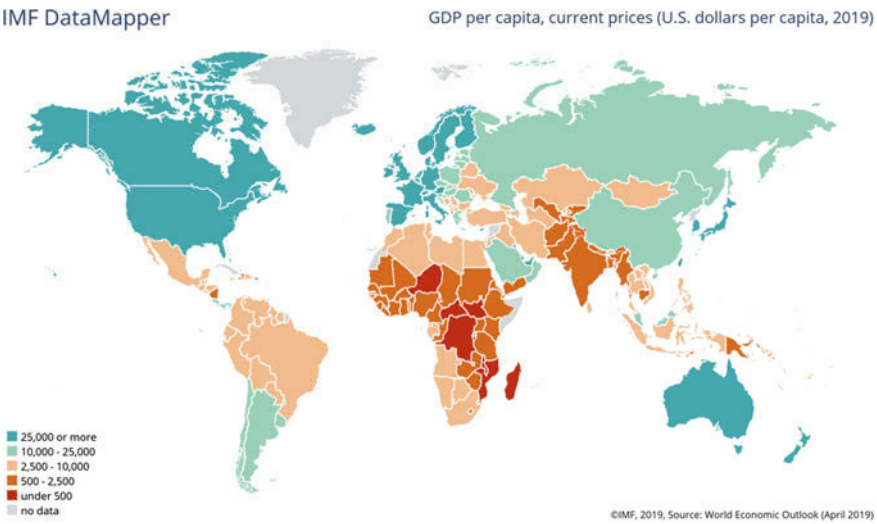


Fig. 2 Annual GDP per capita of countries around the world. *Source* IMF [7]