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INDONESIA
POST-PANDEMIC OUTLOOK:

Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives

Editors:
Harun Ardiansyah
Putty Ekadewi

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First published in 2022 by BRIN Publishing
Available to download free: penerbit.brin.go.id

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Cataloging in Publication

Indonesia Post-Pandemic Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives/Harun Ardiansyah & Putty Ekadewi (Eds.)–Jakarta: BRIN Publishing, 2022.

xxiii p. + 306 p.; 14,8 x 21 cm.

ISBN 978-623-7425-82-3 (complete printed number series)
978-623-7425-83-0 (printed)
978-623-7425-86-1 (complete e-book number series)
978-623-7425-87-8 (e-book)

1. Energy
2. Indonesia's rich resources
3. Renewable energy

531.6

Copy editor : Sarwendah Puspita Dewi
Proofreader : Noviastuti Putri Indrasari & Dhevi E.I.R. Mahelingga
Layouter : Dhevi E.I.R. Mahelingga
Cover Designer : Dhevi E.I.R. Mahelingga

First Print : November 2022

Published by:
BRIN Publishing, member of Ikapi
Directorate of Repositories, Multimedia, and Scientific Publishing
Gedung B.J. Habibie, Lantai 8
Jln. M.H. Thamrin No. 8, Kebon Sirih,
Menteng, Jakarta Pusat,
Daerah Khusus Ibukota Jakarta 10340
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Contents

List of Figures

List of Tables

Publisher's Note

As a scientific publisher, BRIN Publishing holds a high responsibility to enlighten society's intelligence and awareness through the provision of qualified publications available to the public at large. The fulfillment of this statutory obligation is one of the publisher's roles in promoting the educational and intellectual life of the nation as mandated by the Preamble of the 1945 Constitution. Furthermore, this book has encountered quality control mechanisms through the editorial process, including peer review.

This book is one of the four book series titled *Indonesia Post-Pandemic Outlook* written by Indonesian scholars abroad to offer multidisciplinary strategies for Indonesia to recover stronger post-pandemic. In the discussions of this book series, the contributors propose their policy recommendations by referring to the Sustainable Development Goals, Indonesia's Long Term National Development Plan (RPJP), and the United Nations Research Roadmap for COVID-19 Recovery.

Indonesia Post-Pandemic Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives highlights some key aspects of energy in Indonesia that can contribute to achieving net-zero carbon emission by 2060. In the earlier part, this book explores Indonesia's current position and strategy for renewable energy. This book also offers a new nomenclature that will accurately describe net-zero carbon emission, carbon-free, and renewable. Furthermore, this book also covers the technical and non-technical aspects of energy: the potentials and challenges of carbon-free and renewable energy technology. Finally, this book suggests several points to re-strategize Indonesia's energy targets which help the country stay on track to its vision for a net-zero future by 2060.

On this account, we hope that this book can offer valuable inputs and great recommendations for policymakers and stakeholders. Besides, it is expected that this book can provide knowledge and insight for the readers on how we can meet the net-zero carbon emission target.

As a final note, we would like to deliver our heartfelt gratitude to everyone taking part in the process of this book.

BRIN Publishing

Opening Remarks The Minister of State Secretary of the Republic of Indonesia

Indonesian students and youths have a long history of shaping our nation. Their fresh and passionate minds have been influential—especially in supporting the development of Indonesia. In this context, the Overseas Indonesia Students' Association Alliance (PPI Dunia) has emerged as one of the vessels for uniting and organizing them to directly or indirectly contribute to a better Indonesia. The involvement of PPI Dunia in various activities has strengthened the bond between them and their homeland.

This book is the latest evidence of PPI Dunia's effort to accommodate Indonesian students currently studying abroad to express their insightful thoughts on strategizing Indonesia toward renewable and carbon-neutral energy through valuable collaboration with the National Research and Innovation Agency (BRIN). As someone who used to study abroad, I understand how hard it is to be involved in this kind of voluntary-based project as you also have to manage your time between studying or researching, taking care of your family, and sometimes doing your jobs. Therefore, I highly appreciate all writers, as well as all cabinet members of PPI Dunia and BRIN, for their hard work and dedication to publishing this book which I believe will provide invaluable insights into our beloved country.

The publishing of this book is timely as Indonesia is being assigned to hold the G20 Presidency. It is a historical role that provides an excellent opportunity for us to lead the global initiative, particularly accelerating the transition toward cleaner and more sustainable energy. This issue has been chosen as one of three priority issues of Indonesia's G20 Presidency, along with establishing the global health architecture and implementing the digital transformation. As the impact of climate change has begun to affect local and global development, Indonesia believes that an urgent transition toward sustainable energy is essential. President Joko Widodo has frequently mentioned that our local farmers and fishermen have already borne the brunt of climate change. Their output, for example, has begun to decrease as the weather is becoming increasingly difficult to forecast. Therefore, a global effort, mainly through the G20 forum, to ensure a transition to cleaner energy would be critical to avert a more serious climate crisis in the future.

However, it is evident that chairing this year's G20 forum will also pose enormous challenges, particularly in the current global complexities. The world is still struggling to bounce back from the COVID-19 pandemic. Unfortunately, the geopolitical crisis between Russia and Ukraine adds an extra layer of uncertainty due to its disruptive impact on the global supply chain for energy and agricultural commodities. The impact is significant as the prices of energy and food commodities, particularly crude oil and wheat, are skyrocketing, threatening the economic stability of many countries worldwide. For Indonesia, the current situation is unfavorable since we still heavily rely on fossil-based energy to run our economy. As a result, the Government is striving to formulate an appropriate strategy for managing the energy subsidy without burdening our state budget or jeopardizing our social and political stability.

This situation has elevated the urgency of accelerating our transition to carbon-neutral and renewable energy. Our country has enormous potential to become a leading renewable energy source, such as solar, wind, and hydro energy. We, for instance, have approximately 4,400 rivers across the country that could be utilized to generate hydropower. Moreover, Indonesia has abundant geothermal and the wind energy potential in several regions, particularly in South Sulawesi and West Java. In total, the Government calculates that our potential capacity for renewable energy could reach 418 gigawatts.

It is then great to know that this book addresses this potential and provides solutions to boost the competitiveness of our renewable energy industry in the global market. I believe this book is valuable in assisting Indonesia's transition to sustainable energy. This book provides an independent perspective on developing an action plan to achieve Indonesia's net-zero carbon emission goal. The ideas and contributions of overseas Indonesian students will be an important part of the building blocks of our future together on this planet. Hence, I would like to appreciate once again and congratulate PPI Dunia and BRIN—particularly the Energy Committee of the Directorate of Research and Policy Studies (Ditlitka), for publishing this book. I hope this great initiative can be maintained in the future to contribute to sustainable energy.

Pratikno

The Minister of State Secretary of
the Republic of Indonesia

Opening Remarks Coordinator of OISAA

The history noted that on October 25, 1908, Indische Vereeniging was established as an Hindia students' association in Leiden, Netherlands. In 1922, the name was changed to Indonesische Vereeniging or Indonesian Students Association, with Mohammad Hatta as one of its leaders (1926–1930). In Australia in 2007, the Indonesian Students Association, which has spread worldwide, agreed to declare itself as an alliance. Since then, this organization is called Overseas Indonesian Students' Association Alliance (OISAA) or Perhimpunan Pelajar Indonesia Dunia (PPI Dunia), becoming the most extensive Indonesian students' organization comprising 60 member countries spread across three regions: Asian-Oceania, America-Europe, and Middle East-Africa. In its journey, OISAA has contributed to various activities such as education, research/study, training/workshop, and community service as the commitment to achieving Golden Indonesia 2045.

In the OISAA Cabinet of "*Cendekia APIK*", we focus on the strategy and approach called "Penta Helix" strategy and approach as a methodology for integrating multi-stakeholder and governance in response to all the current challenges and issues in Indonesia. With this model, OISAA has collaborated and synergized with the government, universities, industries, media, and community. It takes a strategic synergy between the whole elements of Penta Helix so that the goals of Golden Indonesia 2045 can be accomplished. These components are linked to the five directorates and three bureaus; one is the Directorate of Research and Policy Studies (Ditlitka), which focuses on facilitating Indonesian scholars to contribute their scientific knowledge to Indonesia's development.

The Indonesia Post-Pandemic Outlook series is one of the most crucial works by Ditlitka of OISAA. The books highlight the persistent changes and impacts due to the outbreak of COVID-19. Not only that matter, but the essence of these books will also articulate the mitigation plans for the future pandemic or crises in Indonesia. Written and researched carefully by the authors, the books tell various topics within four categories: "Rethinking Health and Economics Post-COVID-19", "Social Perspectives", "Environment and Technology Role for Indonesia Development", and "Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspective".

Above all, what are the hope and possible solution to this global super-pandemic for all humanity, especially Indonesia? Those are the areas we are trying to address in these books, to see the outlook beyond COVID-19 in Indonesia based on the UN Research Roadmap for the post-pandemic recovery. These books will be presented and promoted to the government and related stakeholders such as scholars, policymakers, and, most importantly, society. This condition will ensure that the quintessence of these books will positively impact the nation towards the Indonesia's greater. I think this book series can be helpful as a beautiful masterpiece that provides valuable insights and mitigation plans for crises in Indonesia, in the same manner as we have learned from this super pandemic that caused the global disruptions.

In this opportunity, I greatly appreciate all the parties involved in finishing this book series, namely the authors, editors, reviewers, board of directors, commission chairs and members, and the National Research and Innovation Agency publishing house (BRIN Publishing). After all, the collaboration from all the parties who worked tirelessly has enabled the achievement of this critical goal.

Although many possibilities and challenges will happen in the future, I believe these books will encourage legacy to the scientific knowledge in Indonesia. Moreover, this legacy is proof of Indonesian students' awareness of their country, even though they live and study worldwide.

Faruq Ibnul Haqi, S.T., M.RgnlUrbPlan., Ph.D. (Cand.)
President of Overseas Indonesian Students' Association Alliance (OISAA)

Opening Remarks Directorate of Research and Policy Studies OISAA

The Directorate of Research and Policy Studies (Ditlitka) of the Overseas Indonesian Students' Association Alliance (OISAA), commonly known as PPI Dunia, focuses on facilitating Indonesian scholars to contribute their scientific knowledge to the development of Indonesia by promoting knowledge translation and evidence-based policymaking.

COVID-19 has ravaged the world's economy in the past two years, upended existing social support structures, and strongly impacted global geopolitics. Written by over 85 scholars from 22 countries, which are part of the Directorate's nine commissions, this book series titled *Indonesia Post-Pandemic Outlook* aims to present the perspectives of Indonesian scholars on the current pandemic and propose multidisciplinary strategies for Indonesia to recover stronger post-pandemic.

In brief, four books constitute the series as follows:

1. Rethinking Health and the Post-COVID-19 Economy by the Health, Economics, and Tourism & Creative Economy Commis-

sions, covering a wide range of topics, including digital health, virtual tourism, international corporate taxation, and green bonds.

2. Social Perspectives by the Education, Culture, and International Relations Commissions, covering a wide range of topics, including international relations, social and culture, and education.
3. Role of Environment and Technology for Indonesia's Development by the Environment and Technology Commissions covering a wide range of topics, including disaster and greening management, food defense, and security, waste and pollution management, as well as human resource and public service.
4. Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives by the Energy Commission, covering a wide range of topics, including renewable energy and carbon-neutral related strategies in achieving Net-Zero Emissions in 2060.

Through this book series, the Directorate strongly believes there are many lessons from the current crisis that provide valuable references as the guides for us to anticipate future pandemics and other crises. The books emphasize the need for comprehensive joint efforts between government agencies and the various components of our nation and the need for forward-looking policies to benefit future generations.

Written with policymakers and the public in mind, the books will be presented to the Indonesian government and relevant stakeholders such as academia, NGOs, and the media and made open access to the public. The authors have also aligned their policy recommendations with the Sustainable Development Goals, Indonesia's Long Term National Development Plan (RPJP), and the United Nations Research Roadmap for COVID-19 Recovery.

The completion of this series is a testament to what is possible when individuals work across siloes and push boundaries to support nation-building. While change and challenges are inevitable for any nation, we hope this series will leave a lasting positive impact on society and promote a legacy of knowledge translation from OISAA *Cendekia APIK*.

On behalf of the Directorate, we extend our deepest appreciation and gratitude to all the parties involved—authors, reviewers, commission chairs and members, OISAA *Cendekia APIK*'s President and Board, national-level Indonesian Student Association chapters, and the National Research and Innovation Agency publishing house (BRIN Publishing) that made all of this possible.

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Radityo Pangestu
Anthony Paulo Sunjaya
Afifah Muharikah
David Firnando Silalahi

Chapter 1

Introduction

Harun Ardiansyah & Putty Ekadewi

"Idealism is the last luxury that only young people have"
-Tan Malaka

The young generation has always been Indonesia's powerhouse since its formation. Young Indonesians have contributed to many sectors of Indonesia, and with the bonus demography of youth, soon it is expected that Indonesia will thrive as part of the big 5 in the world's economy. This economic aspiration may not be achievable if Indonesia lacks a strong energy sector to support economic growth. Without sustainable energy, Indonesia will always be the market, not the producer, on the global stage. Economic growth is interlinked to energy. On the other hand, the threat of climate change has risen significantly in recent years, and it has become more evident than ever before. The

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Ardiansyah, H., & Ekadewi, P. (2022). Introduction. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (1–5). BRIN Publishing. DOI: 10.55981/brin.562.c1
ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

increased frequency of natural disasters in Indonesia can be attributed to climate change. Therefore, Indonesia, as a part of the G20, needs to become a leader in global efforts to tackle climate change.

Indonesian students abroad come together in this book, trying to contribute from afar to how Indonesia can achieve energy sustainability while also strengthening Indonesia's economic growth. By looking from an "outside perspective" of Indonesia, we would highlight some key aspects of Indonesian status to energy sustainability and climate change and how it can progress further.

The Indonesian Government has some plans to manage Indonesia's rich resources of carbon-free and renewable energy. It can be seen through the National General Energy Plan (*Rencana Umum Energi Nasional*-RUEN). RUEN manages to accommodate all the potential and develop some energy diversification in Indonesia. Strengthened by the National Energy Policy Law (*UU No. 14 Tahun 2007 tentang Kebijakan Energi Nasional*), Indonesia plans to achieve 23% renewable energy in the energy mix by 2025. On the other hand, Indonesia has been hit hard by the COVID-19 pandemic. The pandemic delays a few major renewable energy projects that should have been done in 2020–2021. Indonesia needs to increase the rate of renewable energy deployment. However, the current status of renewable energy in Indonesia is still around 15%. Indonesia's primary energy sources are still heavily dominated by coal, oil, and gas. On the other hand, pressure from around the world is mounting due to climate change. Indonesia has pledged to become a net-zero carbon emitter by 2060. It was written in Indonesia's Nationally Determined Contribution (NDC) at the Conference of Parties (COP) 26 in Scotland. Aside from the critique of whether this pledge is achievable to be done by Indonesia, one certain thing is that Indonesia needs to circle back on its plan toward energy sustainability and climate change. Some efforts need to be accelerated to keep Indonesia on pace to become a net-zero carbon emitter in 2060. It motivates Indonesian students abroad through the Energy Commission of Overseas Indonesian Students'

Association Alliance (OIAA) to contribute their ideas through this book.

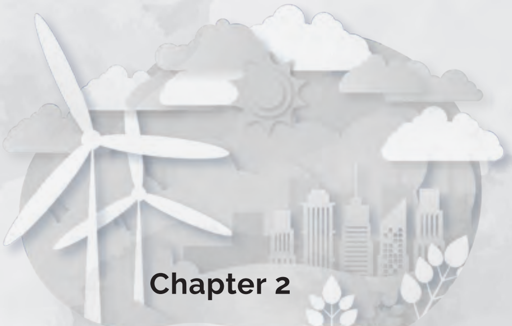
This book is entitled *Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Free Energy Perspectives* because we want to highlight some key aspects of energy in Indonesia that can contribute to achieve net-zero carbon emission by 2060. We divide this book into three general ideas/parts. In the first part, we highlight the policies that have been implemented and how it helps Indonesia's effort toward energy sustainability and efforts to tackle climate change. Specifically, we explore Indonesia's current position and strategy for renewable energy. This is an important basis to work on as we already know what has been decided and done in the past. This part consists of two chapters. Chapter 2 discusses Indonesia's current national strategy and commitment toward the transition to carbon-free and renewable energy. The discussion includes bills and laws that have been ratified and implemented throughout the years. We discuss the impact of those bills on Indonesia's current energy situation, and the commitments that have been proclaimed on the world stage. From the ratification of the National Energy Policy in 2014 to the COP26 in 2021, Indonesia has had a specific target and roadmaps on tackling climate change and smoothly transitioning from a fossil fuel energy-dependent country to the hub of renewable energy. However, just like everything in the world, implementing of the policies may meet some challenges. Chapter 3 discusses those possible hindrances and challenges to achieve the net-zero carbon emission target. In this chapter, we explore many possible angles that could be the hindrances to achieve the energy transition. Dependencies on fossil fuels and the reluctance of industries to transition to renewable energy are a few examples of the challenges in achieving net-zero carbon emission. These topics are explored more in the chapter.

The second part of the book discusses a new nomenclature that will accurately describe net-zero carbon emission, carbon-neutral and renewable energy. The term "carbon-free" energy is used instead of new energy because the term new energy still includes some energy sources that heavily emit carbon. The examples are gasified coal, methane, and dimethyl ether. Carbon-free energy should be the term broadly used to describe energy transition. After introducing carbon-free and renewable energy, we discuss the current status, potentials, and challenges of carbon-free and renewable energy technology. The chapters discusses mainly the technical aspect of each technology. The technology includes solar power, hydropower, wind power, biomass, geothermal, nuclear energy, and hydrogen energy. Carbon capture technologies are also rising to push the net-zero carbon emission target even further. Technologies such as Bioenergy Carbon Capture and Storage (BECCS) are being made around the world. However, this book focuses on the primary energy producer technologies from renewables and carbon-neutral technologies. There are a lot of things that can be expanded and implemented better in each type of energy. For example, the use of hydrogen should be boosted because hydrogen is one of the most versatile types of energy carrier. Energy storage is still a problem on a renewable energy-based grid, and hydrogen as an energy carrier can create stability and reliability in the system. Another topic explored in each technology is the future of the technology and how it can be improved to tackle climate change. For example, the idea of floating solar panels has been discussed in several conferences and academic presentations in solar energy. It is said that it can help expand without causing any harm. Another example is the use of pumped-storage hydroelectricity plants in hydropower technology and small and modular reactors in nuclear technology.

With the background of technical aspects explained in Part 2, the third part of the book discusses the future of energy transition and how the existing net-zero carbon emission roadmaps and plans can be improved to truly meet the target. The discussion is not only limited to the policy aspect, but also the socio-economic aspect of the target including improvement of human welfare, gender equality, and job creation. Lastly, the book concludes with ideas and recommendations from Indonesian students abroad on how we can meet the net-zero carbon emission target. This recommendation is vital for us, Indonesian students, because we are the ones that will implement these roadmaps, plans, and recommendations in the future.

In the last few years, the OISAA has published several books and recommendations, especially energy. This book is a complement to those previous books. We hope it creates impacts for the future, as small as it can be.

Section 1
Indonesia's Current Position and Strategy for Renewable Energy



Chapter 2

Indonesia’s National Strategy and Commitment towards Transition to Renewable Energy

Elisa Wahyuni & Harun Ardiansyah

A. Overview of Indonesia’s Position on the Global Stage

Indonesia is set to take on global leadership. Furthermore, Indonesia has been actively engaged on the international stage and getting some recognition globally. In previous years, Indonesia has been more than once to become a non-permanent member of the United Nations Security Council (UNSC) (Ministry of Foreign Affairs, 2019). In 2022, Indonesia hosts the G20, the forum of the world’s 20 biggest countries to meet and discuss multiple things. It shows that Indonesia has started showing itself to the world. However, this is not the case for the problem of climate change. Indonesia has set ambitious plans to achieve net-zero carbon emission, which is not reflected by the policies enacted within the country. Indonesia is still one of the larg-

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Wahyuni, E., & Ardiansyah, H. (2022). Indonesia’s national strategy and commitment towards transition to renewable energy. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (9–22). BRIN Publishing. DOI: 10.55981/brin.562.c2 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

est coal importers in the world. Indonesia is also one of the largest polluters in the world (International Energy Agency (IEA), 2020).

This chapter explores Indonesia's current position and strategy based on the bills and laws that have been ratified. The draft of the New and Renewable Energy Bill (RUU EBT), National Energy Policy of 2014 (KEN/ PP no. 79 Tahun 2014), National Medium-Term Development Plan (RPJMN), and General Plan for Electric Power Supply (RUPTL) will be part of the references used in the following chapters. This chapter also explores Indonesia's commitment toward Net-Zero Carbon Emission 2060 which President Joko Widodo has announced.

B. Development of National Energy Policy in Indonesia

The role of government in the energy sector starts from the policy. Given this importance, developing of policies for the energy sector in Indonesia has undergone several renewals. Chronologically, the energy sector got special attention in the 1980s with the General Policy on Energy (KUBE) publication in 1981. KUBE went through two renewals in 1987 and 1991. KUBE focuses on the intensification, diversification, and conservation in the energy sector by considering energy industry, investment climate, and energy price mapping aspects (KESDM, 2006). Furthermore, KUBE got its third update by making the environment and energy prices the main aspects in 1998.

In the next decade, the Government issued Presidential Decree no. 5 of 2006 concerning National Energy Policy (KEN). The purpose of KEN is the setting of goals and objectives policies as initial guidelines for the General National Energy Plan (RUEN). However, KEN cannot stand alone without legal protection from Law, which then in 2007 Law no. 30 the year 2007 about Energy which is still used as the primary legal protection related to energy today. That regulation also determines the establishment of the National Energy Council (DEN) as a committee assigned to formulating KEN. In 2014, KEN as Presidential Decree No. 5/2006 was revoked along with the update of PP No. 79 of 2014 concerning the National Energy Policy which is used as the foundation for the RUEN (issued as Presidential Regulation No. 22 of 2017 focused on the General National Energy Plan). Until now, the 2017 version of RUEN is the main guideline for deciding the direction of energy development in Indonesia until 2050.

In its implementation, Law no. 30/2007 about Energy, could not stand alone, which was then supported by the authorization of the Law No. 30 of 2009 concerning Electricity used as the foundation of the Plan General Electricity National (RUKN) and Law no. 32 years 2009 on Environmental Protection and Management. Apart from these two regulations, there are still many other policy instruments related to the energy sector in Indonesia. Apart from historical aspects, the complexity of policy and bureaucracy is one of the reasons why investment in the energy sector is difficult. Renewable energy is developing in Indonesia; therefore, innovation is needed in policies to facilitate the development of New and Renewable Energy.

As of March 2022, the House of Representatives of Indonesia (DPR RI) is still finalizing the New and Renewable Energy Draft Bill. This bill is supposed to be the comprehensive legal base of Indonesia's commitment to new and renewable energy. Current regulations are still scattered in many bills and presidential regulations. With the mandate from this bill, it is expected that the investment in new and renewable energy in Indonesia will become more accessible and more accommodating. Thus, the energy transition that the Indonesian Government has planned can become an actual realization.

As a comprehensive bill, this bill includes the A–Z of new and renewable energy, the road map and transition to new and renewable energy, and all legal matters that can push the investment of new and renewable energy in a progressive way. This bill defines new energy as all types of energy that come from new non-renewable technology or non-renewable energy sources. This includes nuclear energy and other types of energy which will be defined by Government Regulation. In terms of nuclear energy, this bill would provide a legal case to start the investment on nuclear energy. Nuclear energy is no longer considered "the last option" of energy to be deployed. In some discussions, new energy includes hydrogen, and carbon-based new energy/storage systems such as gasified coal, methane, and others.

This draft bill provides a legal case to justify the investment in renewable energy, which is defined as, among others, solar energy, wind energy, hydropower, geothermal, biomass, and waste energy. This bill is intended to create a sustainable climate to invest in renewable energy in Indonesia. It includes regulations on the business permit of renewable energy suppliers, supply and demand regulations, health and safety environment, renewable energy cost, incentives, and many more.

One distinct topic that will also be included in this bill is the renewable energy portfolio standard. It is defined as a standard to be fulfilled by non-renewable energy suppliers and operators to produce electricity using non-renewable energy sources. This portfolio standard will be based on the carbon emission targets defined in the National Energy Policy and National General Energy Plan (DPR RI, 2021; *Rancangan Undang-Undang Energi Baru Dan Terbarukan*, 2021).

Carbon capture technologies such as Bioenergy with Carbon Capture and Storage (BECCS) and Integrated Gasification with Combined Cycle and Carbon Capture and Storage (IGCC + CCS) are also potential to be part of the effort to transition from fossil fuel technologies to new and renewable technology. Undoubtedly, these technologies will be important to change Indonesia's energy mix drastically. However, this chapter focuses on the primary energy source, as defined in the New and Renewable Energy draft bill.

C. Indonesia's Nationally Determined Contribution along the Years

The Copenhagen accord is one of the outcomes of the 15th Conference of Parties (COP) that highlights the importance of global efforts to tackle climate change. The accord was drafted by the United States and the BASIC countries (Brazil, South Africa, India, and China). Although this accord is not legally binding, it underlines the importance of a strong political will to cut greenhouse gasses with "principal of commons but differentiated responsibilities and respective capabilities. This accord also endorses the continuation of the Kyoto Protocol and the establishment of the "Copenhagen Climate Fund" to support the efforts to reduce greenhouse gas emissions (UNFCCC, 2009). As a result, the countries that ratified this accord included their emission pledges, including Indonesia.

Indonesia, through the National Council on Climate Change, has pledged to reduce the CO_2 emission by 26% to 41% by 2020. To fulfill such a plan, a National Action Plan would be enacted through a Presidential Decree, said to be released by March 2010 (Dewan Nasional Perubahan Iklim, 2010). There are seven major areas to focus on to reduce CO_2 emissions. They are peatland, forestry, agriculture, energy, industry, transportation, and waste.

In December 2015, the Paris Agreement, a global agreement adopted by Paris climate conference (COP21), was launched as the first-ever universal, legally binding global climate change agreement. Today, 193 parties (192 countries and the European Union) have joined the agreement. The agreement includes pledges from all countries to decrease their emissions level and collaborate to adapt to the effects of climate change, as well as a call for countries to strengthen their pledges over time. The agreement paves a pathway for developed countries to assist the developing countries with their climate mitigation and adaptation efforts while also establishing a framework for transparent monitoring and reporting of the Governments' climate targets. The Paris Agreement set a long-term framework to guide the global effort for decades. The agreement is the start of a world with zero emissions. The implementation of the agreement is also very critical to achieve the Sustainable Development Goals.

Today, the Governments agreed to keep the global average temperature below 2 degrees Celsius compared to pre-industrial levels and 1.5 degrees Celsius as the maximum increase could be achieved. To contribute to the agreement's objectives, all parties must submit a comprehensive national climate plan known as national determined contributions (NDC). Besides, all countries must come together every five years to assess their progress to achieve the agreed long-term goals and upgrade their NDC. Those countries also have to report transparently to the public how the implementation process works and track their progress on their commitments under the agreement through a strong transparency and accountability system.

In this event, the Government of Indonesia pledged its commitment to reduce the emissions to 29% by 2030 unconditionally (business as usual) or up to 41% conditionally or with international support. The unconditional target is increased by 3% compared to 2010 in the Copenhagen Accord. In the first term of the Joko Widodo presidency, the priority actions within the national *Nawa Cita* (Nine Priority Agendas) framework was determined and implemented. These include protecting the Indonesian citizens, encouraging rural and regional development, improving the quality of life, and increasing productivity and global competitiveness. These fundamental missions align with the country's commitment to a low-carbon, climate-resilient development path, with climate change adaptation and mitigation as a central and cross-cutting goal in the National Medium-Term Development Plan (RPJMN).

According to the agreement, countries should come together five years later to update their objectives. The 26th session of the conferences of the Parties or COP 26 was initially scheduled to take place from November 9–19, 2020 in Glasgow, United Kingdom. However, due to COVID-19, the event was postponed to October 31–November 13, 2021. This event was attended by 120 heads of state and governments. On November 13, 2021, all countries in COP26 Glasgow agreed to the Glasgow Climate Pact to keep the 1.5 degrees Celsius and finalize the outstanding elements of the Paris Agreement. The Glasgow Climate Pact also concluded that many countries wish to fully integrate science into the decision-making process. It recognizes the significance of the Intergovernmental Panel on Climate Change (IPCC) according to most recent report. The Pact frames the action in science here and in later sections, demonstrating that COP26 is responding to what scientists believe needs to happen to keep 1.5 degrees Celsius in reach.

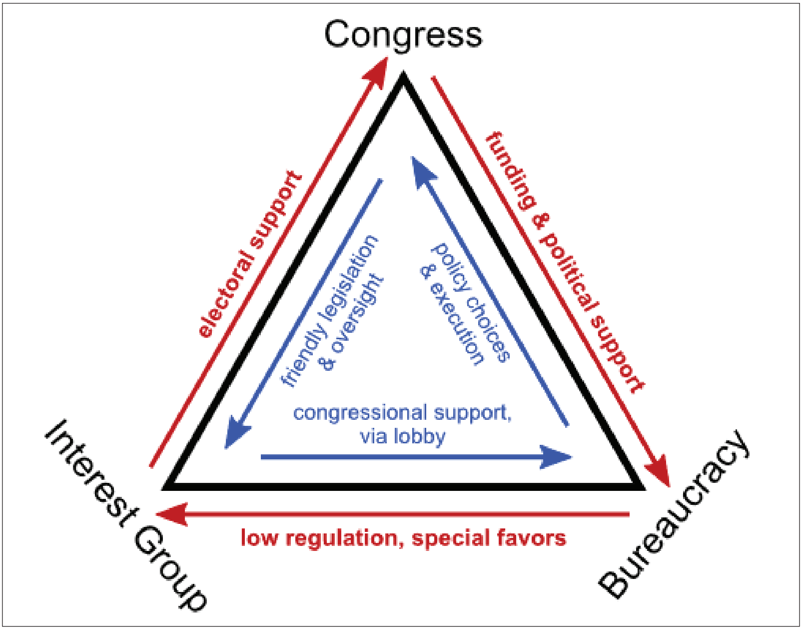
At this event, Indonesia recognized for the appearance of its President, Joko Widodo, was attracting global attention. One of the main issues of COP26 was deforestation and Indonesia was one of the countries known for this issue. The Indonesian President pledged during the event that the forestry sector, which contributed 60% of Indonesia's emissions, will reach the carbon net sink by 2030 (Suoneto & Paramitha, 2021). Besides the forestry sector, the energy sector is the other main contributor to Indonesia's emissions. In this sector, Joko Widodo added that Indonesia utilizes new renewable energy, including biofuels, and develops clean energy-based industries, one of which is the construction of the world's largest green industrial area in North Kalimantan province (Sekretriat Kabinet RI, 2021).

In the updated version of Indonesia's NDC for COP26, Indonesia has pledged to reduce carbon emissions and prepared a long-term strategy (LTS) that defines the pathways to achieve low carbon emissions by 2050. In the energy sector, Indonesia has pledged to increase the use of new and renewable energy by at least 23% of the total energy mix in 2025 and at least 31% of the total energy mix in 2050; reduce the use of oil for energy mix less than 25% in 2025 and less than 20% in 2050; reduce the use of coal for energy mix by minimum 30% in 2025 and minimum 25% in 2050; and reduce the use of gas for energy mix by minimum 22% in 2025 and minimum 24% in 2050. It is a rather ambitious target since Indonesia is one of the main coal exporters in the world.

D. Stakeholders in Indonesia's Energy Ecosystem

Energy is a unique topic. The ecosystem consists of many stakeholders that play a significant role in understanding how Indonesia's energy system works in terms of industry and policy making. In United States politics, there is a concept called the *Iron Triangle*. Iron Triangle is a concept of policy making and governance relationship between three major stakeholders in the United States: the House of Representatives (Congress), the State/Federal Government (Bureaucracy), and the interest groups that may consist of the lobbyist, non-governmental organizations, and many others. The relationships between those three institutions highly affect the policy-making process in the United States. Those relationships are shown in Figure 2.1. Meanwhile, Indonesia is not like the United States, though the relationship between the energy stakeholders in Indonesia is quite similar to the United States. These three groups have influenced each other to implement energy policy in Indonesia.

Indonesia's electricity grid is centralized. It means that PT PLN Persero has the control to provide a reliable grid throughout the country. PT PLN Persero is one of the stakeholders in the bureaucracy part (PT Perusahaan Listrik Negara, 2021). The Ministry of Energy and Mineral Resources (MEMR) is also one of the stakeholders of energy in Indonesia. The role of MEMR is to regulate the energy industry from the front-end to the back-end.



Source: Hayden (2002)
Figure 2.1 The Illustration of Iron Triangle

The House of Representatives plays the role to oversight the implementation of energy policies in Indonesia. The House of Representatives, in collaboration with the executive branch, has a role to legislate new rules and policies to be implemented in Indonesia to foster Indonesia's energy market.

Another stakeholder that is rarely talked about is the interest groups. Interest groups are individuals or organizations with the same concern on energy policy in Indonesia and try to push a specific agenda on energy to be implemented in Indonesia. In many countries, interest groups push policies to benefit society. These groups are, for example, non-government organizations and inter-government organizations. However, these groups are still very limited in numbers and influence in Indonesia. It is, in fact, important to have interest groups control and balance the policies in Indonesia.

E. Energy Distribution from Generators to End Users

PT PLN Persero considers the realization of the power load and the completion of power plant projects and various indicators affecting the condition of electricity supply such as economic growth, then prepares a business plan for providing electricity from 2021–2030. The main activities in the electricity supply business plan include general policies and assumptions, demand forecasting, generation planning, transmission planning, distribution planning, GI planning, isolated generation planning, and consolidation. The realization of this activity is divided into several operational areas: Sumatra, Java, Madura and Bali, Kalimantan, Sulawesi, Maluku, Papua, and Nusa Tenggara (PT Perusahaan Listrik Negara, 2021). Since energy distribution is centralized in PT PLN Persero, it plays a huge role in energy transition.

PT PLN Persero has planned the electricity supply in Indonesia through the Electricity Supply Business Plan (RUPTL). In this plan, PT PLN Persero has mapped out some plans for adding new renewable energy producers and the reliability of the transmission grid.

F. Indonesia's Current Energy Targets

National Energy Policy was introduced by Government Regulation No. 79 the year 2014. National Energy Policy is an energy management policy based on a principle of fairness, sustainability, and environmental insight for the independence of national energy and energy resilience. National energy policy covers both demand and supply side policy and underlines the need for immediate implementation of energy conversion in all sectors to reduce the dependence on oil fuel, diversify energy, alleviate poverty, increase economic growth, and promote environmentally friendly development. A clear target is set for each type of energy in 2025: the share of oil will be reduced to no more than 25%, natural gas to 22%, coal no more than 30%, new (nuclear energy) and renewable energy (geothermal, biomass, hydro, solar cell, and wind, coal bed methane, etc.) up to 23%. In 2050, the share of oil will be reduced to no more than 20%, natural gas to 22%, coal no more than 24%, and NRE will increase by up to 31% (Indonesia, 2014). This regulation has been the legal basis of Indonesia's renewable energy target. Since then, the investment in renewable energy has been boosted. However, in 2019, the National Energy Council reported that the share of renewable energy in Indonesia's energy mix is still less than 15% (National Energy Council of Indonesia, 2020). It proves that more aggressive regulations and enforcement are necessary to achieve the carbon emission target.

Furthermore, Indonesia sets new goals for the COP26. Indonesia's National Determined Contribution updated 2021 highlights greenhouse gas reduction of 26% by 2020 and 41% by 2030; limiting global temperature rise to 2°C by 2015–2019 and presses it to 1.5°C after 2019. In this chapter, we only limited the climate factors to greenhouse gas (Ministry of Environment and Forestry Directorate General of Climate Change, 2021). On the other hand, the Ministry of Energy and Mineral Resources released its roadmap toward net-zero carbon emission. The plan includes a solar power-dominated renewable energy mix that will account for 23% of Indonesia's energy mix by 2025; 42% of renewable energy in Indonesia's energy mix by 2030; 71% of renewable energy by 2040; Commercial Operation Date (COD) of Indonesia's first nuclear power plant by 2045; 87% of renewable energy by 2050; and finally, 100% of renewable energy by 2060.

The Ministry of Energy and Mineral Resources (MEMR) made an Energy projection scenario in Indonesia Energy Outlook 2019 with three scenarios: Business as Usual (BaU), Sustainable Development (PB), and Low-Carbon (RK) with any assumption as shown in Table 2.1. MEMR uses two programs that synergize them to get optimal results: LEAP for the energy total model and Balmorel for the electricity model. Based on the projection, the primary energy mix for the BaU scenario in 2025 is 21% NRE, 24% gas, 34% coal and 21% oil, while the primary energy mix in 2050 is 29% NRE, 23% gas, 32% coal and 16% oil. The energy mix target mandated in National Energy Policy has not been reached. The primary energy mix in the PB scenario in 2025 is 23% NRE, 21% oil, 24% gas, and 32% coal. In 2050, it will become 32% NRE, 15% oil, 24% gas, and 29% coal. Compared to the target in National Energy Policy, the NRE target in 2025 can be reached and the NRE target in 2050 is higher than the National Energy Policy's target. The primary energy mix in the RK scenario in 2025 is 36% NRE, 19% oil, 21% gas and 24% coal. In 2050, it will become 58% NRE, 8% oil, 12% gas, and 22% coal. Compared to the target in National Energy Policy, the NRE share in 2025 and 2050 is very optimistic and higher than the target in National Energy Policy. In conclusion, the NRE share target of 23% by 2025 and 31% by 2050 can be achieved by at least by implementing assumptions in the PB scenario (National Energy Council of Indonesia, 2020).

Table 2.1 Scenarios of Assumptions towards Net-Zero Emission

Assumption	BaU	PB	RK
Economic Growth	5.6% (Based on 2045 Indonesian Vision-Bappenas)		
Population Growth	0.7 % (Based on Statistics Indonesia-Bappenas 2045)		
Biodiesel Target	2025: 20%	2025: 30%	2025: 30%
	2050: 30%	2050: 30%	2050: 100%
Bioethanol Target	2025: 5%	2025: 20%	2025: 20%
		2050: 50%	2050: 85%
City gas development	Year 2025: 4.7 million household connection	The development of 1 million household connection/ Year starting from 2020	The development of > 1 million household connection/Year starting from 2020
Substitution of LPG to Induction Stove	2025: 0.5%	2025: 1%	2025: 2%
		2050: 2%	2050: 5%
LPG substitution with DME	2050: 20%	2025: 20%	2025: 20%
Electric Car Target (% toward total vehicle population)	2025: 0.01%	2025: 0.01%	2025: 0.5%
	2050: 0.07%	2050: 0.24%	2050: 1.18%
Electric Motorcycle Target (% toward total vehicle population)	2025: 1.38%	2025: 1.44%	2025: 1.18%
	2030: 1.5%	2030: 1.7%	2030: 3%
Power Plant	RUPTL	RUEN	Emission reduction > RUEN
		Switching 10% capacity of Steam PP to Biomass PP	Switching 30% capacity of Steam PP to Biomass PP
		25% of luxury houses use Rooftop Solar	30% of luxury houses use Rooftop solar

Source: National Energy Council of Indonesia (2020)

From the calculation of CO_2 emission based on IPCC, the total projection of emission in 2030 will increase to 912-million-ton CO_2-eq (BaU), 813-million-ton CO_2-eq (PB), and 667-million-ton CO_2-eq (RK). Thus, the CO_2 emission projection in three scenarios is lower than the emission target in NDC for the energy sector (National Energy Council of Indonesia, 2020). This questions Indonesia's commitment to the transition to renewable energy. Moreover, no official document (other than NDC and its LTS) currently describes and enforces Indonesia's plan and strategy toward net-zero carbon emission. Some presentation documents from several ministries might be found to address this problem. Still, an official statement from the government (probably through Presidential Regulations) is also important to enforce Indonesia's commitment. A necessary intervention from the Government is crucial to achieve Indonesia's target of net-zero carbon emission. More investment in the development and deployment of carbon-free and renewable energy should be pushed harder by the Government.

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Chapter 3

Challenges in Facing Indonesia's Energy Commitment

Elisa Wahyuni

A. Overview of Indonesia's Energy Security and COVID-19

As the largest country in population and geographically among other ASEAN countries with abundant natural resources, Indonesia has enormous potential for sustainable energy resources, especially form an energy perspective. Located on the equator line, this country has had a constant solar power supply over the year. Indonesia is an archipelago surrounded by water standing above the ring of fire, granting this country abundant geothermal energy sources and other climate-friendly energy sources such as biogas and biomass. Additionally, we shall not forget new kinds of energy that are making trends: hydrogen and nuclear energy. However, these energy potentials need to be aligned with proper human resources to meet the supply and demand and to enforce Indonesia's sovereignty over energy.

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Wahyuni, E. (2022). Challenges in facing Indonesia's energy commitment. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (23–40). BRIN Publishing. DOI: 10.55981/brin.562.c3 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

In the past ten years, the costs of solar and wind energy have fallen by 90% and 70%, respectively, and this trend will no doubt continue. Yet today, fossil fuels—coal, oil, and gas—provide 80% of energy worldwide (Lomba, 2019). With the addition of COVID-19 which has spread since early 2020, the shifting process from fossil-based energy sources to renewable resources outweighed the existing effort as the world is focusing on living with it and reducing the fear inch by inch.

Since World Health Organization (WHO) raised the COVID-19 status from endemic to pandemic at the beginning of 2020 after its first outbreak in Wuhan, China in 2019, everyone has been forced to vastly adapt and make quick decisions to put everything under control. Years afterward, this ambiguous event affected broad sectors including the energy sector. The urge to shift the energy reliance into climate-friendly options is getting even higher, as today, Indonesia is one of the top countries with the highest ecological footprint in the world along with China, India, the United States, Russia, Brazil, Japan, Germany, Mexico, and the United Kingdom (Pata et al., 2021). This chapter highlights five crucial challenges related to the energy sector that Indonesia is currently facing to actualize its national and international commitments. Those five challenges are Reviving the National Economy Post-Covid, Battle of Energy Security and Energy Transition, The Hardship to Challenge the National Coal Industry, The Reliance of the Industrial Sector on Fossil Fuel, and Regulating and Financing the Transition.

B. Reviving the National Economy Post-Covid

It has been more than two years since the World Health Organization (WHO) officially declared the COVID-19 pandemic on March 11, 2022. A week prior, Indonesia's President, Joko Widodo announced the first discoveries of 2 positive cases in Indonesia's territory on 2 March 2020. Today, we are facing more than the original strain of SARS-COV-2, but also the mutated variants named Delta, Omicron, and possible future variants with less overwhelming effect than its original.

At the end of 2019, the Indonesian Statistics Bureau (BPS) recorded economic growth of 5.02% during the year despite the global situation especially in the trading sector. The economy during this year was dominated by the domestic demand for government consumptions and investments. This increase in growth has successfully decreased the unemployment rate and gap while also maintaining social welfare (Kementerian Keuangan Republik Indonesia, 2019).

Unfortunately, at the beginning of 2020, the world is facing one of the most unpredicted situations with the outbreak of COVID-19. Indonesia started the year with a good start in the trading sector after the US and China finally sealed a deal to end the trade war between them (Kementerian Keuangan Republik Indonesia, 2020). However, the dawn of the pandemic has forced people to adapt to the concept of "new normal" by living in a series of lockdown situations, working from home, wearing masks daily, and maintaining physical and social distance. This situation automatically slows down economic activities. Not only nationally, but also globally. Indonesia's composite stock price or IHSG was freefalling instantly for more than IDR 2000 or lost almost 50% from its initial value compared to December 2019 (Kiky, 2020). Globally, the pandemic forced many businesses to bankruptcy and sent people home unemployed. Even more, it was recorded for the first time in history that US crude oil prices fell into negative territory in late April 2020, which means that the sellers are effectively paying the buyers to purchase the crude oil.

As a pandemic, COVID-19 hits not a specific country or region but the whole world. For the economic sector in Indonesia, in 2020, the BPS officially announced the country was facing its first economic recession since the financial crisis in Asia in 1998 with economic growth standing below zero, precisely at -3.49% compared to 2019. This event forced companies to cut off their employees due to the lack of economic activity, which consequently impacted the unemployment number to 9.77 million people by August 2020. With all this disturbance, the Government needs to go the extra mile to keep national stability and strengthen economic resilience. In this context, the Government has decided to widen the deficit to 6.34% of Gross Domestic Product (GDP) to handle both COVID-19 situations and recover the economy.

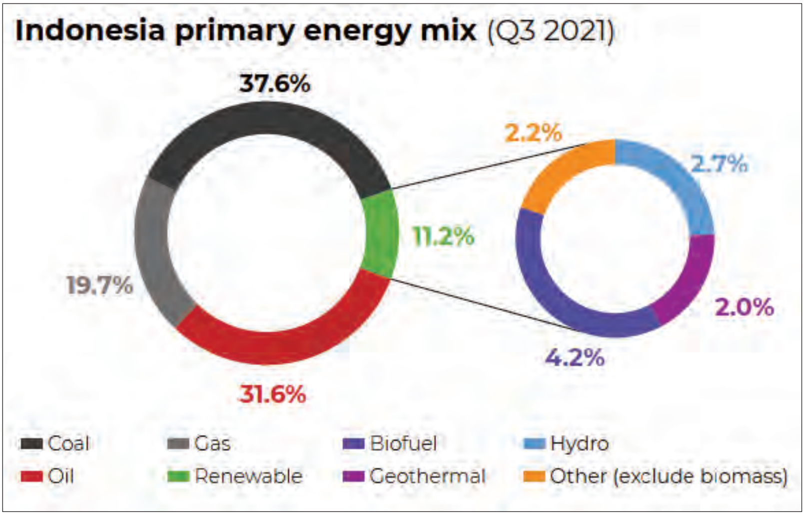
In late 2020, the invention of COVID-19 vaccines to fight against the current pandemic brought an optimistic hope to restore the situation to the "real normal" gradually. The President, Joko Widodo opened the national vaccination program at the beginning of 2021, with high hopes that this stressful event could end soon. Economically speaking, since having huge contraction by having a negative economic growth level of 5.32% (year-on-year), Indonesia showed a positive trend as the growth stood better at -3.49% (year-on-year) in Q3 and closed the year of 2020 with -2.19% (year-on-year) (Kementerian Keuangan Republik Indonesia, 2020). BPS stated that the economy grew 3.51% (year-on-year) in Q3 2021 compared to the previous year, while for 2022 the World Bank predicts Indonesia Economy situation will grow to 5.2% in 2022 (the base year 2020) under the assumption of the absence of another massive shock from COVID-19 (Badan Pusat Statistik, 2020; World Bank, 2021)

C. Battle of Energy Security and Energy Transition

One extensive challenge facing Indonesia during the pandemic from an energy perspective is balancing energy security while staying on track with shifting the energy supply to sustainable energy resources. Since the pandemic hit the country, the domino effects have hit many sectors, leaving out-of-control situations in multiple sectors. In the energy sector, these events have disturbed the energy transition agenda as the Government needed to focus on the health and socio-economic sector first as a priority.

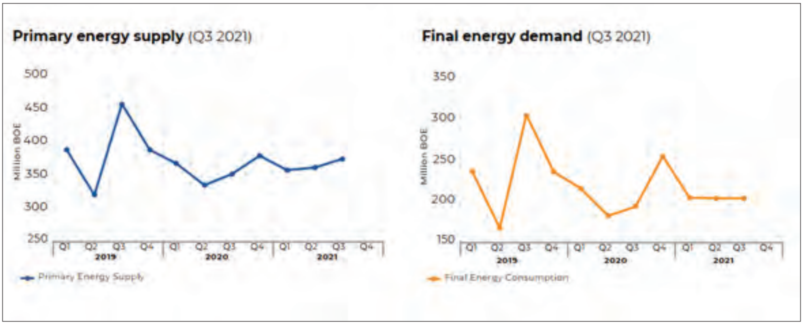
An unusual event is seen during the pandemic, namely an unprecedented decrease in carbon emissions since the industrial era due to the drastic change in the way of life globally. Unfortunately, this reduction is neither substantial nor long-lasting as carbon emissions are set to surge post-COVID-19 as many countries, including Indonesia, try to bounce back their economy. As a result, energy demand is expected to increase dramatically to support simultaneous global development. Therefore, Indonesia is urged to assess its current position on energy transition to meet its commitment to have new and renewable energy at least 23% in 2025 and at least 31% in 2050 on its primary energy supply mix based on the updated NDC 2021.

In a pre-COVID-19 situation in 2019, more than 90% of Indonesia's primary energy demands were supplied from fossil fuels. Renewable energy only accounts for approximately 8% of the total energy supply mix (National Energy Council of Indonesia, 2020). Moreover, Indonesia has had a relatively unambitious growth in developing new and renewable energy capacity in the last decades, specifically at around 334 MW per year, far below our neighbor, Vietnam, which can achieve 1745 MW per year (Sumarno & Sanchez, 2021). Some major renewable energy deployment projects were delayed. This postponement leads to the slower growth of the renewable energy sector. As seen in Figure 3.1, renewable energy accounts for only 11.2% of Indonesia's energy mix by Q3 of 2021 (IESR, 2022).



Source: IESR (2022)
Figure 3.1 Indonesia Primary Energy Mix (Q3 2021)

During the recovery process from COVID-19, economic growth showed a positive trend and the situation is under better control than in these past years. The energy sector also offers a recovery in increasing activity after experiencing a massive shock in 2020 due to COVID-19. As seen in Figure 3.2 below, the energy activity plunged drastically. Consequently, the Government should ensure the security of the energy supply to meet these growing demands that are predicted to keep increasing in the future alongside the peak in economic development targets. However, until the third quarter (Q3) of 2021, fossil fuel still dominates the primary energy mix (IESR, 2022).



Source: (IESR, 2022)

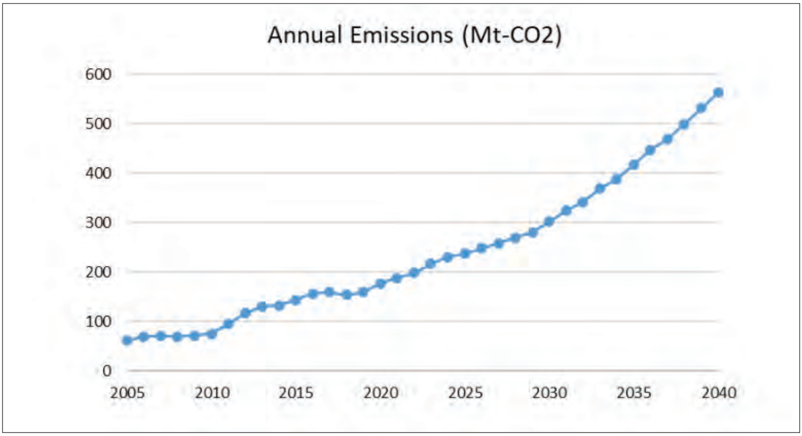
Figure 3.2 Primary Energy Supply (Q3 2021) and Final Energy Demand (Q3 2021)

Additionally, according to the National Economic Recovery (PEN), fossil fuel is still supported by representing 8% of Indonesia's total budget in the form of cash in most packages. PEN 2020 also supports cleaner energy sources, but only biodiesel receives a direct injection of cash. It appears that investing in fossil fuels is still more attractive than renewable energy sources. Therefore, the battle of energy security and energy transition would be very tricky to implement as the Government was forced to face another dilemma. A stronger policy and a more attractive package for investors to accelerate the transition to cleaner energy sources are urgently needed to keep Indonesia's climate change mitigation commitment on track.

D. The Hardship to Challenge the Coal Impact of the Country

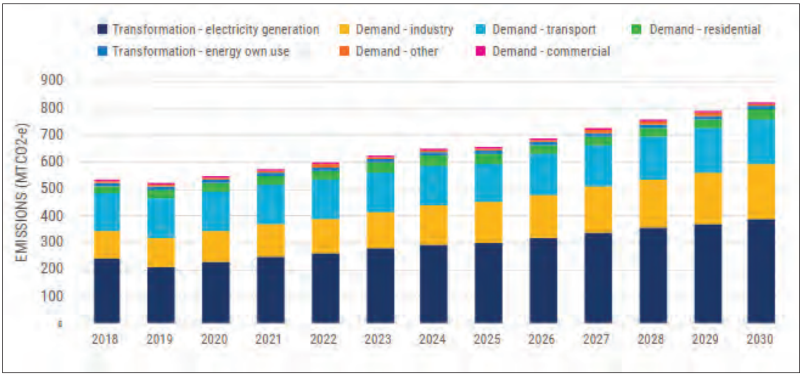
It is a fact that fossil fuel is the main energy source until today, with coal making up the biggest portion of it. Indonesia has around 3% global coal reserves (bp, 2021). Additionally, this country is the biggest coal exporter in the world, with 80% of coal being exported and the rest being used domestically. Almost 20% of the total share of national final energy consumption is electricity, with 47% of the portion still dominated by coal in June 2021 (Indrawan, 2021). Domestic use of coal in Indonesia mostly goes into electricity production under Perusahaan Listrik Negara (PLN), a state-owned company monopolizing Indonesia's power market. As a state-owned company, PLN has a constitutionally mandated monopoly on transmission and distribution. They also have a legal obligation to provide "reasonably priced" power to the citizen, the price of which is set by the Ministry of Energy (Guild, 2019). This political perspective shows the impact of PLN is on the country.

Indonesia has four types of Coal-fired Power Plant (CFPP): subcritical, supercritical, ultra-supercritical, and fluidized bed. Subcritical is the most common use of CFPP in the country. Based on a study conducted by ASEAN Centre for Energy (ACE) on CO_2 emissions from CFPPs (see Figure 3.3), emissions from CFPPs in Indonesia are projected to rise between 2017 and 2040, reaching an accumulative amount of 8623 million tonnes from 2005 to 2040 due to increased demand for electricity (ASEAN Center for Energy, 2021). Additionally, coal-fired power plants are major sources of air pollution in the country and are considered a direct cause of numerous non-communicable diseases (Sanchez & Luan, 2018). Thus, this sector is crucial to consider when discussing Indonesia's energy.



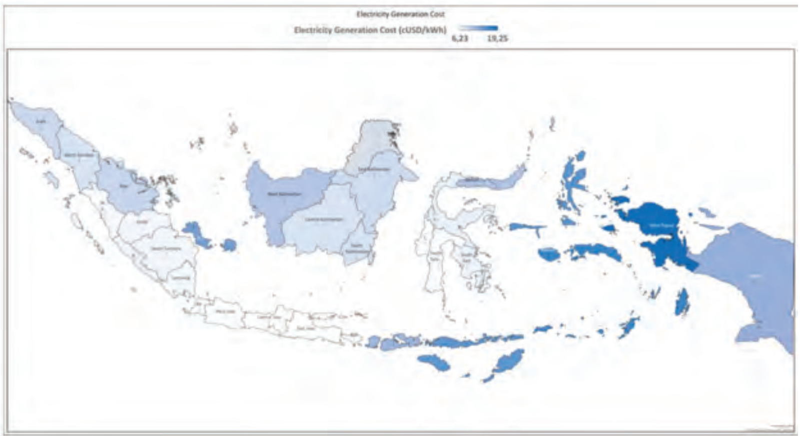
Source: ASEAN Center for Energy (2021)
Figure 3.3 Annual Emissions Profile of the CFFP in Indonesia

According to the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), the report of Indonesia's energy sector emission outlook in the current policy scenario 2020–2030 shows that as the energy needs keep increasing, the emission also follows, following the BAU scenario (see Figure 3.4). The graph shows how the transformation from electricity generation is the top main source of emission, and it still dominates until 2030.



Source: UNESCAP (2020)
Figure 3.4 The Outlook of Indonesia's Energy Sector Emission in the Current Policy Scenario 2020–2030

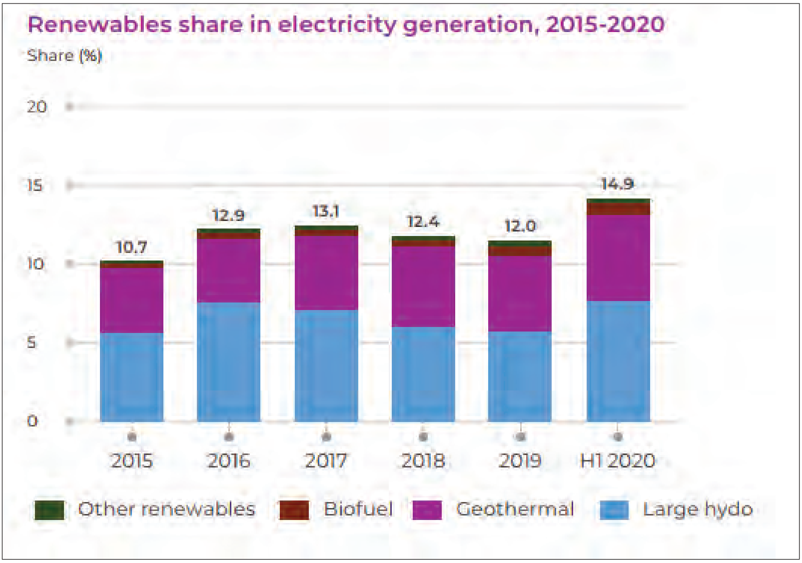
In addition, due to the geographical characteristics of the country with thousands of islands spread across the archipelago, Indonesia struggles with an uneven electricity generation cost. As shown in Figure 3.5, electricity generation costs in the eastern part of Indonesia could be three times more expensive compared to the cheapest cost in Java Island as the center of economic activity in the country. It is a huge gap that needs to be filled, especially in the eastern part of the country, where the development is still low and yet at the same time, it is rich in mining products. The uneven price of electricity generation costs is a big reason why renewable energy is a crucial solution for Indonesia, especially in terms of electricity generation aside from emission reduction.



Source: Kementerian ESDM RI (2021)

Figure 3.5 Geography of Electricity Generation Cost under MEMR 2021

Figure 3.6 shows very few renewables in Indonesia's electricity generation share. Until the half of 2020, the share of renewables in electricity generation is less than 15% (IESR, 2021). From this point of view, PLN, the main actor in the energy industry, should be active in decarbonizing its annual emissions to support the Government in achieving its commitments to reducing carbon emissions.



Source: IESR (2021)

Figure 3.6 Renewables Share in Electricity Generation, 2015–2020

The study conducted by the UNESCAP with the LCOE (Levelized Cost of Electricity) method shows that the electricity generation using renewable power plants such as solar photovoltaic, geothermal, hydro, and on-shore wind, is cheaper than coal-fired power generation which is used abundantly in Indonesia (Fig. 3.7). The LCOE method sums up the lifetime costs of an energy system divided by their respective lifetime energy generation. The use of lifecycle costs of the systems balances out the disparity among technologies with high capital costs but low operating costs or vice versa (UN, 2020).

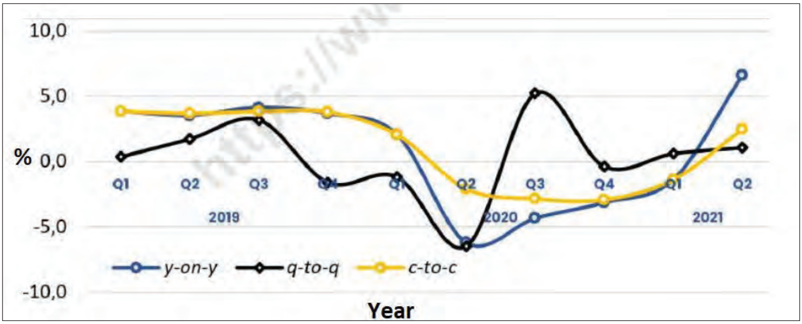
Source: UNESCAP (2020)

Figure 3.7 LCOE of Different Power Plant Technologies in Indonesia

Additionally, with current conditions, international development agencies and NGOs are actively promoting and spreading awareness to fight against climate change, particularly in the energy sector as the most influential source of a global emitter. However, these actors are seen to be sided and bring no influence on Indonesia's energy policy. A growing civil society movement and NGO network that criticizes coal mining and the construction of new coal power plants have emerged over recent years and contributed to changing public attitudes and evaluating and revoking of mining permits (Fünfgeld, 2019).

E. The Reliance of Industrial Sector on Fossil Fuel

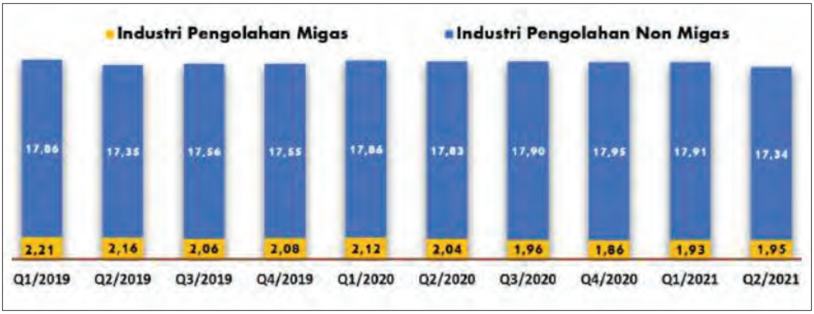
The energy sector is responsible for more than 70% of global greenhouse gas emissions. Meanwhile, energy use in industries contributes more than 24% or almost a quarter of total GHG emissions that need to be decarbonized to keep the global average temperature increasing below 2°C from pre-industrial levels, as stated in the 2015 Paris Agreement. As an emerging country whose economic growth depends on the industrial sector, Indonesia has a huge percentage of energy use in its total energy consumption. Specifically, this country relies heavily on gas and coal as the main energy sources in industry, which is predicted to remain at that level until 2050 in BaU condition (National Energy Council of Indonesia, 2020).



Source: Badan Pusat Statistik (2021)

Figure 3.8 Industry Sector Growth, 2019–2021 (%)

The industrial sector, specifically the highly intensive energy sector, has been a crucial driver of growth in the Indonesian economy. Besides making a big contribution to Indonesia's GDP, these sectors also absorb huge workforce, especially those from lower economies. Figure 3.9 shows a disruption in 2020 (y-o-y), but it keeps increasing until Q2 2021.



Source: Badan Pusat Statistik (2021)

Figure 3.9 Industry Sector in GDP, 2019–2021 (%)

However, regardless of the pandemic, the Indonesian industrial sector experienced an insignificant change throughout the year. It shows how the industrial sector is a strong aspect and an essential factor for Indonesia's economic growth. In a recent event, the Government stated they would like to increase their export industry to support the national economic growth and improve the economic structure, especially after the COVID-19 event which caused disruptions in many sectors, including the industrial sector. The increase in export and industrial activity will directly impact on the increasing GHG emissions, mainly for highly intensive energy use subsectors, simultaneously with the rise in fossil fuel use and production capacity.

The industrial sector in Indonesia, in particular the non-oil and gas manufacturing industry, is the country's major user of energy consumption. Specifically, six industrial sub-sectors highly consume energy, such as cement, metal, food and beverage, fertilizer, ceramics, and pulp and paper industries (National Energy Council of Indonesia, 2020). The total energy demand of these six industries contributes 87% of the total energy consumption in the industrial sector. Specifically, on the energy source, gas is mainly used to meet the metal demand, fertilizer (as feedstock), and ceramics industries. These three industries consume around 83% of gas from the total gas demand in the industry. While coal is 90% consumed by the cement industry. Moreover, Decarbonisation Data Portal from Climate Action

Tracker found that the intensity of carbon emission from cement production in Indonesia is higher than the world average, 657kgCO_2/tonne product compared to 614 kgCO_2/tonne product. These facts put a lot of pressure on decarbonizing and penetrating their energy use into low carbon energy options due to the high reliance on fossil fuel energy sources (Climate Action Tracker, 2020).

These dilemmas will indeed become another tough challenge for the industrial sector in Indonesia as the Government has pledged to reduce their emission to 29% by 2030 with their effort, or 41% conditionally with international support. The country must stay on its commitment to fight climate change, but at the same time, must increase the production activity in the industrial sector. Therefore, the Government needs to arrange its deep decarbonization roadmap from introducing technological innovation to lowering energy use by increasing efficiency. Moreover, using more sustainable alternative fuels such as hydrogen and electrification, or any other climate-friendly choices in the sector.

F. Regulating and Financing the Transition

Transitioning is not a one-night process, including energy transition, as people have been living and relying on fossil fuels for decades. Proper movement on regulating and financing the transition is crucial to assist the implementation. However, despite the commitment that Indonesia's leader has stated in the international and national events, it is seen that fossil fuels still got favoritism in the implementation process.

Indonesia currently subsidizes fossil fuels as part of its yearly budget and has offered support to fossil fuel-intensive sectors. In particular, cash support to PT PLN (state-owned electricity enterprise that mainly uses coal for power generation), PT Pertamina (state-owned energy enterprise that operates in the oil and gas sector, both upstream and downstream), PT Garuda Indonesia (state-owned aviation enterprise), and PT Kereta Api Indonesia (state-owned rail enterprise). The budget totals IDR 95 trillion (USD 6.6 billion), also included in COVID-19 recovery packages (Sumarno & Sanchez, 2021). The "forever existence" subsidy on fossil fuels in the country encourages energy consumption to lean on cheap energy sources. Hence, this policy instrument keeps making the conventional energy source more attractive than cleaner choices.

Besides, from a financing perspective, Indonesia's current financial market is relatively small and dominated by the banking sector, in which the low carbon infrastructure projects in the country would significantly depend on bank lending (Setyowati, 2020). A recent study stated that the national bank's policy is yet to explicitly present a commitment to moving away from fossil-fuel investment to renewable energy. The study found that only one national bank obtains a score in climate change due to transparent disclosure of investment portfolios toward efficiency and conservation of energy. While foreign banks dominate others as they have already had policies to mitigate climate change risks by setting specific targets for reducing carbon emissions (Perkumpulan PRAKARSA, 2019). The local banks also often opt to invest in coal power generation rather than in renewable energy because coal is deemed more economically feasible and they perceive that investing in renewable energy in a high risk (Setyowati, 2020).

Additionally, the financial services regulator, OJK (Otoritas Jasa Keuangan), issued a roadmap for sustainable finance in 2014. Since then, the Ministry of Energy and Mineral Resources has been experimenting with various incentives for jump-starting growth in renewable energy since at least 2011. These efforts have included the feed-in-tariffs (FiT) and government financial guarantees for qualified projects. However, despite years of tinkering, these efforts have yielded almost no growth. For instance, between 2013 and 2017, FiT produced almost no increase in solar, wind, or biomass energy due to poor policy design and regulatory architecture that constantly change, which drove down investor confidence (Guild, 2019).

Moreover, at the end of 2017, the Ministry of Energy and Mineral Resources introduced Ministerial Regulation 50/2017. It benchmarks the price that the state-owned company, PLN (Perusahaan Listrik Negara), can pay to off-take power from IPP (Independent Power Purchase) to its local and national costs of production (knowns as Biaya Pokok Penyediaan or BPP in Indonesia). In other words, PLN will not pay more to IPPs to purchase power than it costs for the utility to generate electricity from its plants. In Java and Sumatra, where large grids are powered mainly by cheap coal-fired plants, more expensive renewable energies like solar or wind will struggle competitively. With this regulation, PLN becomes more constrained in what it can pay as solar is less likely to be financially competitive on Java, where the demand is at the highest (Guild, 2019).

Regulating and financing the transition is one of the essential processes in implementing the energy transition. As an emerging economy country, Indonesia should be able to serve affordable and accessible energy across the country. In addition, for local sovereignty, the policymakers need to take their words seriously on their commitment to shifting their energy source to cleaner choices to reduce emissions and save the planet.

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Section 2
Carbon-Neutral and Renewable Energy in Indonesia

Chapter 4

Moving from New and Renewable Energy to Renewable and Carbon-Neutral Energy

Putty Ekadewi

A. Overview of Renewable and Carbon-neutral Energy

Energy is an essential part of human life. The discovery of woodfires in the early ages of civilization has helped the human population survive cold winter days, increased life expectancy, and resulted in better sanitary practices in nutrition, i.e., no longer eating raw meat. In the centuries that followed (19th century), we discovered that we were sitting on years' worth of energy naturally deposited deep within the Earth's crust in the form of fossils. Fossil fuels differ in their forms and uses. For instance, coals were used to generate steam, while oils were refined to produce liquid transportation fuels. Our decades of reliance on fossil sources have led to the technological advancements used in

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Ekadewi, P. (2022). Moving from new and renewable energy to renewable and carbon-neutral energy. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (43–62). BRIN Publishing. DOI: 10.55981/brin.562.c4 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

their exploitations. Oil and gas explorations have even shifted from land to offshore activities, where new deposits have been discovered lately.

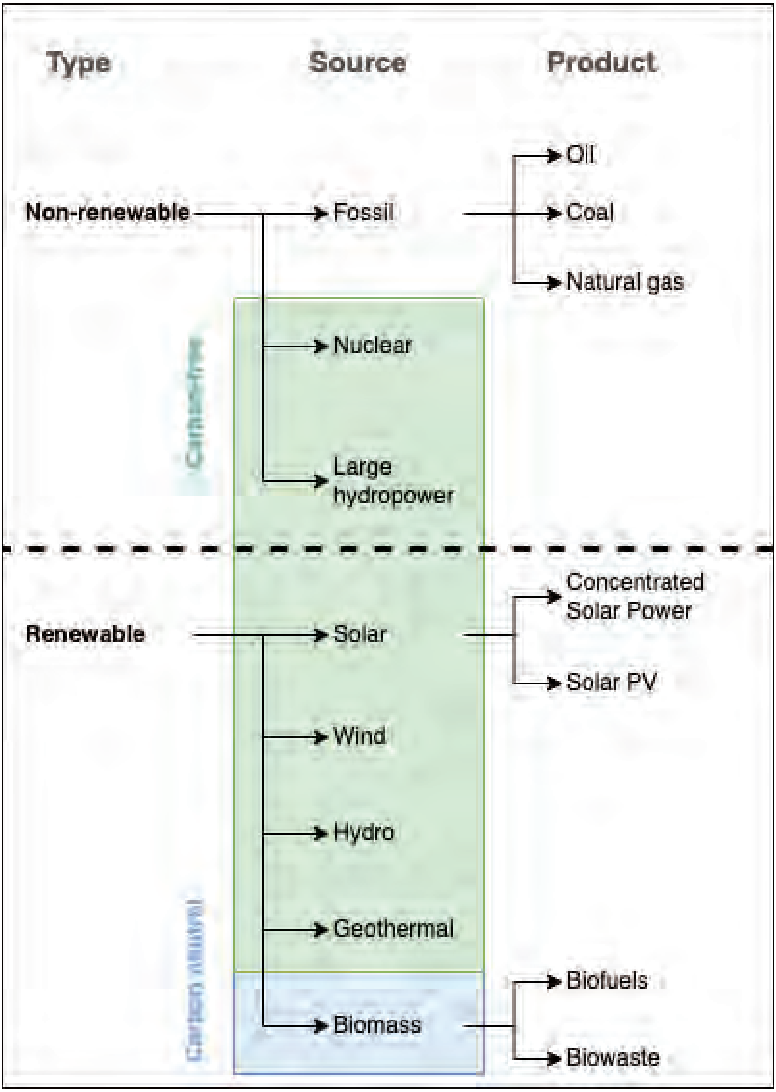
Despite their conveniences, fossil fuels have long been at the heart of the sustainability debate. Proponents of the climate crisis have put a share of the blame for global temperature rise on the activities that involve fossil use. This allegation is not without reason because burning up fossil fuels releases carbon into the atmosphere (CO_2) along with harmful gasses, such as nitrogen oxides (N_2O, NO, and NO_2) and sulfur oxides (SO_2 and SO_3). In the case of sulfur, the operation of coal power plants generates around half of the total industrial SO_x emissions in a case study in China (Wang et al., 2018). These gasses work a range of harmful actions on the atmosphere, partly responsible for the global warming. The Earth's global surface temperature has reached terrifyingly worrying levels, an increase of 1.19 °C compared to pre-industrial levels (Lindsey & Dahlman, 2021). The number is already close to an agreed limit of 1.5 °C set to avoid inciting devastating effects globally. This phenomenon has not escaped the public's attention and the world's governing officials. Most recently, world leaders around the globe met at the COP26 Climate Change Conference forum in Glasgow (UK) to convene on global actions required to halt the progression of looming climate disasters. The COP26 forum can also be recognized as the five-year check-in of the Paris climate agreement and our collective progress thus far. This chapter aims to check on our progress in halting the climate crisis by looking at the energy transition and outlining a way forward towards our carbon emission mitigation goals using a mix of low carbon energy sources.

To fulfill its goals, this chapter discusses the status of renewable energy use globally, elaborate on the carbon impact of energy shift from fossil to renewable sources, and introduce a new criterion in renewable energy: carbon-neutral energy.

B. Checking-in on Renewable Energy Sources in 2021

The term 'renewable energy' can be loosely assigned to non-fossil-derived energy sources. The International Energy Agency (IEA) defines renewable energy as "all forms of energy that are produced sustainably from renewable sources " (IEA, 2002 in S.G. Banerjee et al., 2013). In this case, the agency further elaborated that renewable energy sources are derived from natural processes with a higher rate of replenishment than consumption (S.G. Banerjee et al., 2013). The definition allows for a new type of energy to come in and is classified as renewables. As far as this chapter concern, we will be looking at the status of several types of renewables already widely applied: solar, wind, hydropower, biomass, geothermal, biofuels, and hydrogen obtained from renewable resources (S.G. Banerjee et al., 2013). Renewables can be further grouped based on their carbon status: carbon neutral or carbon-free. The two groups will be discussed in more detail in the coming section of this chapter.

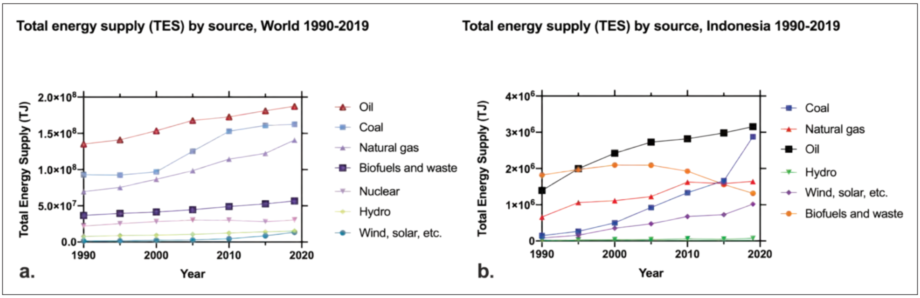
The classification used in this chapter is presented in Figure 4.1. We divide the type of energy into two categories of energy sources: renewable and non-renewable. Non-renewable energy sources consist of fossil, nuclear, and large hydropower. Fossil sources can be further divided into several products: oil, coal, and natural gas. Oil is commonly used as transportation fuel, while coal is widely known as the feedstock of coal power plants' electricity generation. Natural gas may serve several purposes, mainly heating and electricity generation. The three derivations of fossil sources are targets for alternative energy sources to replace. The second type of non-renewable energy source is nuclear. Albeit posing major advantages over other renewables, especially in terms of carbon emission, nuclear power plants require feedstocks available in finite amounts on Earth. Hence, it is still categorized as the non-renewable category. Lastly, large hydropower is considered non-renewable due to the high environmental risk they pose that weighs over the technology's potential for clean energy generation.



Note: Renewable and non-renewable energy sources are separated by a dash (--) line.

Figure 4.1 Energy Resources Typing and Classification

The second category is renewable energy. In this type, we can find various energy sources like solar, wind, hydropower, geothermal, and biomass. The use of solar energy can be divided into two: electricity from solar photovoltaic (PV) panels or heat from concentrated solar power (CSP). For biomass, we can separate the product into two: energy coming from the conversion of biowastes or from a crop specialized to produce biofuels. We will discuss these energy sources in detail in this chapter. Finally, Fig. 4.1 divides these energy sources based on their carbon-emitting characteristics. Those considered carbon-free are nuclear, hydropower, solar, wind, hydro, and geothermal, if we think only the energy sources converted to the end product. However, considering the project's whole lifecycle, no power plant is really carbon-free since construction involves carbon emissions. Biomass is considered carbon-neutral because it requires assimilating carbon as a principal nutrient for growth, taking up carbon from the environment.



Note: a. World scale, b. Indonesia
Source: Adapted from IEA (2021a)

Figure 4.2 Total World Energy Supply from Various Energy Sources

1. Solar

Solar energy is one of the most famous forms of renewable energies. The technology relies on converting sunlight to electricity as a usable form of energy. Sunlight is captured using specific light-harnessing panels, called Photovoltaic (PV) panels. The challenge with solar power lies in the varying amount of sunlight received by a geographical surface throughout the day due to weather factors and seasonal variations in a year, which poses a stability challenge in generating steady electricity output. Moreover, solar panel installations on dedicated sites require large amounts of land, which pose land use problems due to the clearing of lands to provide space for the panels. To overcome this drawback, solar panels can be installed on already functionalized areas, for example on the roofs of houses in residential areas. The main advantage of solar power lies in the ability of the panels to be installed in remote areas with relative ease compared to installations like wind turbines or dams. Due to this feature, solar energy is one of the most widely applied types of renewable energy worldwide.

In 2019, solar power generated 680,952 GWh of electricity worldwide (IEA, 2021a). In Indonesia, solar is underutilized relative to its potential at 0.04% in an installed capacity of 78.5 MW (Rencana Umum Energi Nasional, 2017). The latest IEA data showed a significant increase in solar PV electricity generation in the country at 118 GWh in 2019 (IEA, 2021a). Nevertheless, China has installed a lot more solar PV in Asia.

2. Wind

Wind power can be converted into electricity using turbines. However, wind turbines are large in scale and difficult to install due to the limited availability of materials required to construct them, leaving environmental footprints in the process. Nevertheless, this drawback is little compared to its benefits. The carbon footprints of wind installations can be paid off by themselves in less than six months of operation (Sayed et al., 2021). Wind power and solar are considered the most technologically advanced renewables (Sayed et al., 2021). It is also incredibly eco-friendly in terms of gaseous emissions. In European countries, wind turbines can be found abundant on land, in contrast to Indonesia with little to no full-scale prototype installed. This contrast is often attributed to the characteristics of the region in Indonesia, in which wind power is considered low in potential compared to solar.

Countries with the most wind power electricity output are usually characterized by strong regional wind profiles. For this reason, Indonesia is not geographically strategic to rely on wind power. Therefore, we need to look to other renewables instead. However, research on wind power in Indonesia is still necessary to move past geographical limitations. Exploration of areas with a large potential for wind power needs to be intensified. Geographical mapping shows that despite the few availabilities, compared to the total land area, the country has areas with windspeed above 6 m/s. For instance, though rare, wind power is slowly implemented in locations such as in the South Sulawesi region, where the country's largest wind power plant project is located, i.e. PLTB Sidrap at 75 MW capacity with plans for expansion in the future.

3. Hydro

Hydroelectric energy is one of the biggest contributors to the renewable energy market. Power generated from hydro is bigger than all other renewables combined. However, its electricity generating potential also comes with a major drawback. The nature of hydropower installations involving dams has concerned many. If we look at hydropower from the perspective of the environment, this type of electricity generator is not sustainable in the long run. Dams have shifted water flows and disrupted the seasonal migration of water organisms. To overcome the drawback, solutions such as micro hydro power generators are proposed. It is expected that by limiting the scale of the generator, ensuing detrimental environmental effects can be limited.

Indonesia has planned on developing hydropower in the future. A cooperation was made between the ministry of energy and mineral resources (Kementerian ESDM), the state-owned electricity company (PT PLN Persero), and Japan international cooperation agency (JICA) to assess hydropower development in Indonesia (JICA, 2009).

4. Geothermal

As the name suggests, geothermal energy is sourced from heat stored within the Earth. Because of its nature, geothermal energy can be used directly for heating or converting it into electricity. To use geothermal, first, users need to overcome challenges like the isolated nature of sites with geothermal potentials. Luckily for Indonesia, areas with abundant geothermal potential are widespread. Challenges may lie in the energy distribution, if we consider the country's archipelagic nature. Another potential hurdle is the need for large capitals upfront, in contrast to alternatives like solar and wind. Nonetheless, geothermal energy is more stable compared to solar and wind.

Indonesia is considered a geothermal powerhouse. As a result of the country's location, which sits above the Ring of Fire, 276 geothermal sites with abundant geothermal energy potentials have been identified in the country. It is estimated that around 40% of the world's geothermal reserve, the largest in the world, is located in Indonesia (ADB & Bank, 2015). The country has several working geothermal power plants, in descending order of production output are: Gunung Salak (375 MW), Wayang Windu (227 MW), Darajat (255 MW), Kamojang (200 MW), Dieng (60 MW), Lahendong (60 MW), and Sibayak (12 MW) (Samyanugraha & Lestari, 2011). The management of geothermal working areas (GWAs) in Indonesia was previously managed only by PT Pertamina. PT Pertamina is the Indonesia's state-owned oil and gas company, and operates most of Indonesia's oil and gas resources. However, GWAs can now be managed by private entities through tender mechanisms.

5. Biomass

Living matter contains energy in the form of chemical substances. In principle, biomass is similar in utilization to fossil fuels. However, the time needed to regenerate usable biomass is much shorter than fossils. Hence, they are categorized as renewables. The main energy storage of biomass can be found in the forms of fats and oils. Vegetable oils, i.e., palm oil, are already utilized as biofuel in the form of biodiesel through physicochemical conversion processes. Carbohydrates can be fermented to produce ethanol, another form of liquid biofuel used in transportation. Biomass' versatility means that it can be used as solid, liquid, and gaseous fuels according to demand.

Biomass holds an important position in the energy mix since adopting electric vehicles will need some time to complete. It is predicted that in 2050 fuels will continue to contribute significantly to the global energy mix. Biomass can also generate electricity through combustion processes, namely direct combustion, co-firing, or converted into biogas. The versatility of biomass to play a role in the energy sector made this energy source very attractive, both in the academic setting and industrial.

Indonesia's share of renewables is also dominated by bioenergy. Indonesia came second (after Spain at +1.7%) in terms of renewable energy growth (+1.4%) back in 2018 due to the use of bioenergy for power generation (IEA, IRENA, UNSD, WB, 2021). Biofuels are an inseparable part of our current energy transition strategy. At least in the short term, the Government has planned a complete phasing in of biodiesel to a final mix of 100% termed B100 from B20 or 20% biodiesel mix. Indonesia is a major palm oil exporter. In the production of palm oil, energy-rich wastes are generated. These wastes can be converted to obtain energy, for example, biogas, biodiesel, or bioethanol. The conversion of palm oil waste to biofuels is a hot topic among Indonesian researchers.

C. The Carbon Impact of Energy Shift

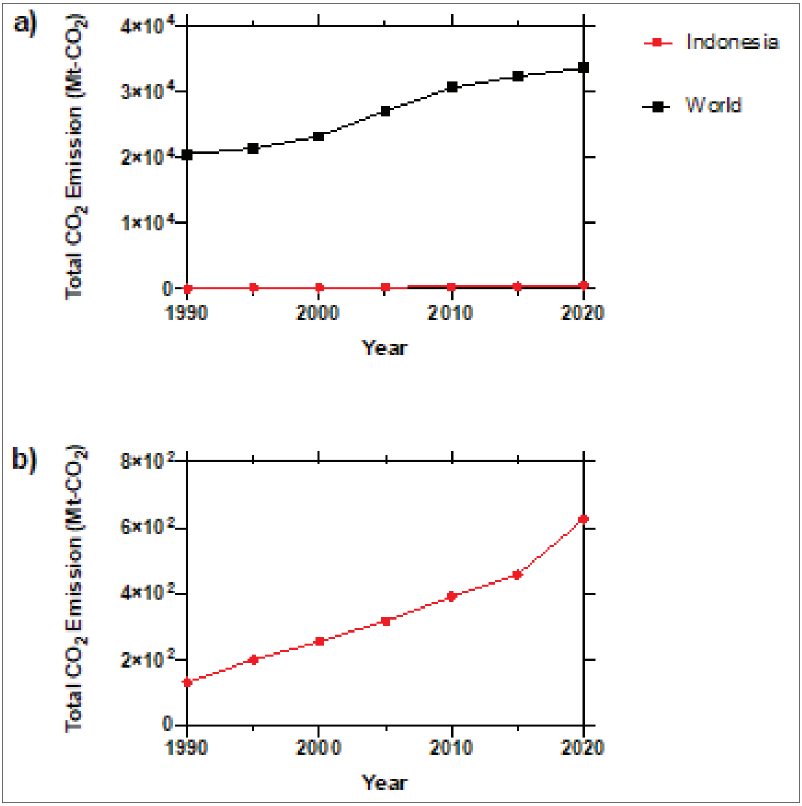
The ultimate goal of shifting from fossil-based energy resources to renewables is to reduce the anthropogenic impact on the rise of global surface temperature, which will ultimately lead to a climate crisis. Carbon is commonly regarded as the 'currency' to measure this impact. The use of carbon to measure environmental impact stems from the idea that the combustion of fuels generates carbon, often in the form of CO_2. The release of CO_2 into the atmosphere leads to an enhanced greenhouse effect, wherein energy received by the

Earth from the sun is trapped within the atmosphere. Normally, this radiative energy is only absorbed in 70%, with the rest released back to outer space (WMO, n.d.), and heat is trapped within the atmosphere to support organic life. However, human activities have disturbed the natural CO_2 balance in the atmosphere to the degree that the Earth is warming up abnormally over time.

The energy sector is a major contributor to CO_2 emissions. A shift to renewables is expected to bring carbon emissions down, coupled with other CO_2-targeted measures, which are anticipated to hold global surface temperature rise at 1.5°C. Collectively, the world generated 34,156 Mt of CO_2 back in 2020, this number is slightly lower than the year preceding it at 35,966 Mt yet higher by almost 2,000 Mt CO_2 than ten years ago at 32,345 Mt CO_2 (IEA, 2021b).

The reduction in emissions in the year 2020 is attributed to the global emergence of the COVID-19 pandemic. The pandemic caused a global phenomenon of sudden and drastic decrease in human activities, which is the main cause behind large CO_2 emissions in normal conditions. To emphasize, global pandemic finally lowered our total CO_2 emissions. Thus, it is hard to imagine the effort required to reduce CO_2 emissions to a level compatible with the sustainable development goal of only 28,487 Mt CO_2 by 2030 (IEA, 2021b). It is a large target if we look at the relationship between CO_2 emissions, economic growth, and human activities that tend to go together without special interventions. The impact of the COVID-19 pandemic on energy shift is expected to be significant and directly observable in the next few years. Ever since the pandemic hit, world governments have pledged a staggering USD 16 trillion in fiscal support to counter the impact of the crisis. From this number, around USD 380 million is aimed at the sustainable energy sector (IEA, 2021b).

Global and Indonesia-specific trends of CO_2 emissions can be consulted in Figure 4.3. The differences are stark within the last two decades (the year 2000 onwards). Indonesia's emissions are showing a drastic increase, while world emissions are levelling off between 2010–2020 compared to 2000–2010. Under the current policy scenario (CPOS) model, the Government of the Republic of Indonesia, will not be able to meet its Paris Agreement target with the CO_2 emissions trend expected to continue to increase until after 2030. The Paris Agreement compatible scenario (LCCP) is expected to meet Indonesia's 2050 CO_2 emissions level (GOI, 2021).



Source: Adapted from IEA (2021a)

Figure 4.3 Total CO_2 Emissions at (a) Global Scale and for (b) Indonesia

Through a long series of analyses and discussions, eventually, world governments have mostly agreed to a Net-Zero Emission (NZE) target by 2050. This scenario is the most ambitious to date in terms of emissions reduction.

1. Inequality in the Global Push for Emissions Reduction

At the dawn of the era of industrialization, the West was leading in technological developments and innovation. As a direct result of the intensification of human activities driven by industrialization, CO_2 emissions skyrocketed. The lag between Western countries and the rest of the world was large for the following decades. Only recently have large and densely populated economies like China and India caught up in renewable energy growth and reforestation efforts. In recent years, almost half of the global increase in renewable energy production is a Chinese contribution. As the major economy in Southeast Asia, Indonesia contributes to renewable energy production in the region, which is not the case as the country still lags behind other fellow Southeast Asian countries in renewable power generation. On the other hand, Western countries have mainly developed and are less dependent on fossil resources. These countries are also the ones that are vocal in pushing for global emissions reduction. However, international cooperation is necessary for the rest of the world to achieve what Western countries have succeeded in decoupling CO_2 emissions from economic growth trends.

A carbon budget is a way to gauge carbon emissions limit to avoid a catastrophic rise in global surface temperature. Much like its counterpart in finance, it means the acceptable amount of CO2 emitted globally. Using cumulative CO2 emissions puts both large and small economies responsible for reducing emission. According to Friedlingstein et. al. (2022), the decrease of global CO2 emissions in 2020 was at 5.4%, back to the 2012 level, yet it rebounded quite fast in 2021 by 4.8%, almost on par with 2019 levels at 36.7 ±1.8 Gt-CO2/year). The recent IPCC (intergovernmental panel on climate change) report suggests that the remaining global carbon budget to stay under 1.5°C of surface temperature rise is only 400 billion tons of CO2 (starting from 2020). This can be paraphrased into a remaining nine years to evade climate catastrophe and environmental collapse (IPCC, 2021).

Countries belonging to the organization for economic OECD group peaked in their fossil CO2 emissions by around 2005 (Friedlingstein et al., 2022). Still to the same report, in the decades that followed (2010–2019), 23 countries with significant economic growth (dominated by large economies in the Northern hemisphere) combined only produced around 25% of the world's fossil emissions. Hence, most fossil emissions are produced from non-OECD countries during the aforementioned timeframe. Knowledge transfer and cooperation between countries with different technological advancements on low-carbon technologies and renewables are necessary. This point is reinforced as one of the target actions of SDG 7 on energy, namely to promote access to research, technology, and investments in clean energy by putting forward international cooperation (United Nations, 2018).

2. Emerging Carbon-Neutral Technologies

We have presented an overview of traditionally recognized renewable and carbon-neutral energy options in the previous sections. Solar, wind, geothermal, and biomass are well-known energy sources aimed to feed into our current energy system as fuel, heat source, or to generate electricity. We have not recently discussed the future of non-fossil-based sources that are gaining momentum recently. In this section, we are looking into hydrogen and nuclear, specifically. Hydrogen is widely dubbed the future of renewables, while nuclear is a controversial subject with a large potential, yet strong voice of opposition.

Hydrogen in the energy sector refers to the highly energetic, combustible dihydrogen (H_2) gas. H_2 can be derived from fossils or renewables, in which the carbon footprint of the hydrogen production process will define the final H_2 product as either 'clean' or 'unclean'. In 2018, almost all (99%) of hydrogen obtained from dedicated production facilities (a total of 70 Mt) was derived from natural gas or coal, while 45 Mt was obtained as a by-product of other industrial processes (Energy Transitions Commission, 2021). The versatility of hydrogen as energy storage in the power system has gained momentum these past decades. The hydrogen-based economy is planned on the horizon by multiple countries, including Japan which started this campaign in 2017 and France with a big pledge to build the hydrogen economy. The year 2020 saw world governments seriously planning on integrating green hydrogen into their national energy strategies, at least 33 countries have committed themselves to this goal (Lee & Zhao, 2021). All previously identified renewables were identified in the literature to contain significantly lower power density than fossils and nuclear; even coal scored higher than solar (van Zalk & Behrens, 2018).

The Hydrogen Council has identified the roles hydrogen could be a vital aspect in our road to net-zero emissions. These roles are divided into seven (Hydrogen Council, 2017):

1. Enable large-scale and efficient renewable energy integration,
2. Allow energy distribution across regions and sectors,
3. Function as a buffer to ensure energy supply,
4. Act as a solution for hard-to-transport energy needs (long-range transport, intensive energy-consuming industries, residential heating),
5. Decarbonizing feedstocks in coupling with CCU or CCS.

Hydrogen presents a way to bypass challenges faced by renewables. It allows storage of renewables, reducing intermittency problems. Additionally, hydrogen is not only energetic, but also used in chemical industries.

Nuclear energy is often regarded as the hot seat of non-fossil energy sources. Everyone wants nuclear power plants, but all fear the occasion of failure that would lead to nuclear disasters. Nuclear energy relies on specific materials that are only present in finite amounts on Earth, making it non-renewable by design. The material in question is uranium isotope 235 (^{235}U), which usually only accounts for 0.711% of the uranium in nature. Currently the world's combined identified recoverable uranium reserves stood at 9.24 million tons of uranium across all cost categories (OECD & IAEA, 2020). According to the same report, our current identified resources can sustain our needs for over 135 years if we base consumption on 2019 data (OECD & IAEA, 2020).

Discussions on nuclear energy are always polarized. Proponents of nuclear energy base their arguments on technology's energy generation potential and low emissions aspect. Meanwhile, the opponents are more focused on the environmental impact of radioactive waste and risk avoidance of a nuclear accident. In terms of potential, nuclear energy came in at the top of the list of other renewables. It is mainly due to the feedstock's potential stability and energy density.

Australia is the world leader in uranium reserves, accounting for up to 28% of the global identified resource (OECD & IAEA, 2020). Indonesia has also reported uranium reserves under the cost categories of <80 USD/kg-U, <130 USD/kg-U, and <260 USD/kg-U missing only the lowest cost category in its arsenal (OECD & IAEA, 2020).

D. Renewable Energy from the Carbon and Environmental Perspectives: Weighing the Ecological Cost of Renewables

When we talk about carbon-free energy, the term renewable almost always comes to mind. However, the reality is that carbon-free energy does not always mean ‘renewable’. For example, in most nuclear power plants (NPW) energy is released from the nuclear fission of the Uranium atom. As a result, supply becomes the barrier that separates nuclear from other carbon-neutral renewables, effectively placing nuclear in the non-renewable category.

Aside from the problem of supply, ecological impact matters. It is particularly highlighted when discussing the case of large hydropower. To harness kinetic energy from water into a large-scale electrical energy, the building of dams is required. The problem with the construction of dams is not limited to the construction phase only, but the effect is long-term. Water flows are disturbed, affecting aquatic life and the migratory habits of several aquatic organisms (Gasparatos et al., 2017). Due to this ecological effect, large hydropower cannot be classified as renewable, albeit carbon-neutral. Since the energy generated from this setup is not sustainably produced.

The question with carbon-neutral energy sources can be summarized as "can [a particular energy source] be used to generate energy sustainably?". This question is important to consider when assessing alternative energies since the main motivation for energy shift is to avoid environmental disasters, including biodiversity collapse. We need to carefully thread the balance between our energy needs and environmental protection.

One important backbone of a green economy is energy transition. Economically, energy transition would open opportunities, ultimately driving economic growth in the long term through climate change mitigation, new job opportunities, and better health from a higher quality of living. Therefore, energy transition from fossil to renewable resources is non-negotiable. However, transitioning from one source to another needs to consider its impacts in a multisectoral view that involves the human aspect, and other living systems, in other words, biodiversity.

The shift from fossil-based energy infrastructure to renewables will involve heavy construction and installation in multiple sites worldwide. The process will undoubtedly leave significant environmental and carbon footprints in the early stages. Carbon emission as a way to measure environmental impact does not consider parameters like biodiversity loss. It is the case when land use is shifted, reducing forest coverage, i.e., plantation and power plants. The drawback of construction and specific land use can be justified in the long term if we evaluate the project based on its emission reduction potential. Although the end goal is still carbon emissions reduction, it is worth considering another aspect of the environment when aiming for sustainable energy transition practices, namely biodiversity conservation. Previous studies have tried to identify the ecological costs of energy transition for several types of renewables from solar, wind, hydropower, and bioenergy (Sayed et al., 2021).

Solar energy is generally regarded as environmentally friendly since the basic principle of harnessing and utilizing solar power generates no carbon dioxide. Solar panels can also be installed in urban settings, for example, on the roof of houses. The impact is aggravated when solar panels are installed on large surface areas as is the case for the CSP that was initially green areas like forests. In the end, the ecological impact of solar panels is minimal and does not outweigh their benefits in fulfilling of the world's ever-rising energy demands.

We can also examine the case of biomass energy from palm oil utilization. The problem starts with land use. Deforestation is carried out to clear out lands to provide space for palm oil trees, usually in areas that were previously forests. In Indonesia, palm oil industries thrive on the islands of Sumatra and Kalimantan, replacing rainforest-covered areas with palm oil plantations. In the land-clearing process, the ecological impact is significant that palm oil industries are closely associated with unsustainable business practices. Biodiversity loss easily occurs due to replacing various vegetation types with a single type of vegetation. The loss of biodiversity has threatened the extinction of endemic species in the region. Indonesia, one of the world's leaders in palm oil export, is facing this issue head-on since the region is also regarded as one of the world's leading biodiversity hotspots.

E. Conclusions

The information discussed in this chapter aims to bring our focus back to terminologies often used when discussing energy sources. Renewable energy is often regarded as a way out of our dependency on fossil fuels. However, the term renewable energy can vary according to how we assess energy sources. Classical discussion on renewables almost always includes solar, wind, geothermal, and biomass energy. While these renewables are rightly in their spot as contenders to replace fossil energy, their adoption still has a long way to go to fulfill the requirement of global energy mix targets.

In this chapter, we have discussed how nuclear energy, despite being classically considered non-renewable, may provide a lasting solution to enhance the energy transition rate. In this case, the fact that its source material, ^{235}U, is present in a finite amount on Earth can be outweighed by nuclear energy's carbon-free characteristics and potential. On the other hand, in the case of large hydropower, although generally considered carbon-neutral, the environmental damage of large hydropower installations is not negligible in the long run. Despite their renewable nature in terms of resources, large hydropower has been put into the non-renewable category due to its harm to biodiversity.

The energy transition is a complex goal that involves multi-sectoral components, including the environment. Environmental parameters play an important role in pushing for the transition. To assess impact, carbon (CO_2) is most used compared to other parameters. CO_2 is a well-known greenhouse gas that is involved in the progression of climate change, so the aim is to lower CO_2 released into the atmosphere in human activities.

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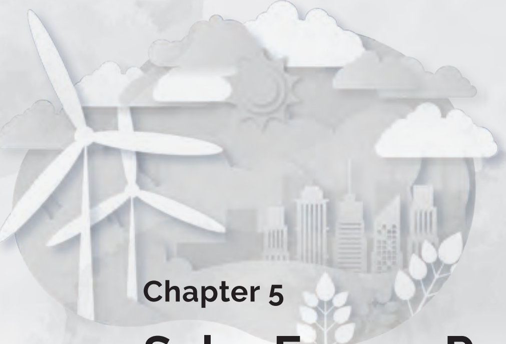

Chapter 5

Solar Energy Potentials and Opportunity of Floating Solar PV in Indonesia

David F. Silalahi & Denny Gunawan

A. Overview of the Rapidly-Growing Solar Energy in Indonesia

Among ASEAN country members, Indonesia has the most abundant solar energy potential. It is measured by considering the areas of land mass and water bodies of Indonesia that can be utilized for solar panel farms. This fact is necessary to be realized by Indonesia because Indonesia is growing rapidly as the COVID-19 pandemic begins to become endemic. The growth of Indonesia will be associated with a demand for energy to power Indonesia's economy. However, Indonesia is also one of the highest polluters in the world. Thus, it becomes a dilemma for Indonesian growth. On one hand, Indonesia needs to grow its economy. It is expected that Indonesia could become the world's fourth-largest economy by 2050, and energy is a crucial part of it.

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Silalahi, D. F., & Gunawan, D. (2022). Solar energy potentials and opportunity of floating solar PV in Indonesia. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (63–88). BRIN Publishing. DOI: 10.55981/brin.562.c5 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

On the other hand, Indonesia has also committed to tackling climate change and contributing to net-zero carbon emissions. This pledge is written in the 26th Conference of Parties (COP26) in Scotland, 2021. The Ministry of Energy and Mineral Resources has also laid out the plan to reach net-zero carbon emission by 2060 in Indonesia, which includes investments in renewable energy.

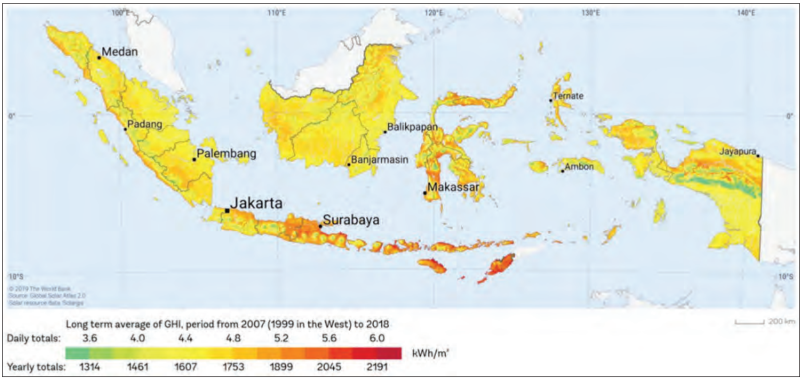
Indonesia is blessed with renewable energy. Based on the National General Energy Plan, it is suggested that the renewable energy potential in Indonesia is 443 GW, while 208 GW of it is from solar energy. This potential is huge and able to power Indonesia if it can be extracted. Indonesia's share of renewable energy is only 9.2% by 2019, far from Indonesia's target of the renewable energy mix, which is 23% by 2025.

Some efforts need to be performed to extract renewable energy, especially solar energy potential in Indonesia and increase Indonesia's renewable energy mix. However, solar energy is not always perfect. Technical challenges must be solved to ensure the abundant solar energy potential does not end to waste.

This chapter discusses the potentials and challenges of solar energy. Furthermore, this chapter concludes with an overview of floating solar photovoltaic (FPV) technology that can be a promising investment in Indonesia.

B. Solar Potential

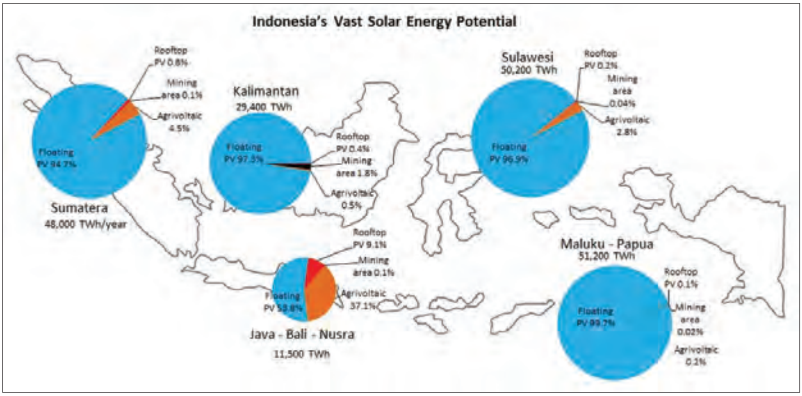
Indonesia is located in the equatorial region which allows the solar irradiation is relatively evenly distributed (Figure 5.1). Indonesia's average global horizontal irradiation (GHI) is 4.8 kWh/m2 per day (Solargis, 2017). According to the Global Solar Atlas PV study (2020), it is higher than the daily average GHI in Germany (2.9 kWh/m^2), Japan (3.6 kWh/m^2), China (4.1 kWh/ m^2), and Singapore (4.5 kWh/ m^2).



Source: Solargis (2017)

Figure 5.1 Indonesia's Global Horizontal Irradiation Map

In the previous Indonesian National Energy Plan (2017), solar energy is suggested to be 208 GW. However, recently the potential has been updated to 3,294 GW (Antaranews, 2022). Institute of Essential Services Reform (2021) studied Indonesia's solar potential reaching 7,715 GW. Vidinipoulous et al. (2020) reported that Indonesia could generate 2,5431 TWh per year. A study by Silalahi et al. (2021) shows that the solar potential is much more immense. By locating the panels on rooftops and defunct coal mine sites, agricultural sites, and floating on the calm equatorial inland sea, Indonesia could harvest 190,000 TWh per year. The breakdown of the potential with a significant fraction of floating PV potential is shown in Figure 5.2.



Source: Silalahi and Blakers (2021)

Figure 5.2 Indonesia's Solar Energy Potential for Its Regions

The potential is much higher mainly because Indonesia has a sufficient calm maritime area considering floating PV potential. Figure 5.3 compares the reported potential in the terawatt hour unit. The estimates are different in number, but all the studies agreed that Indonesia's solar potential is vast.

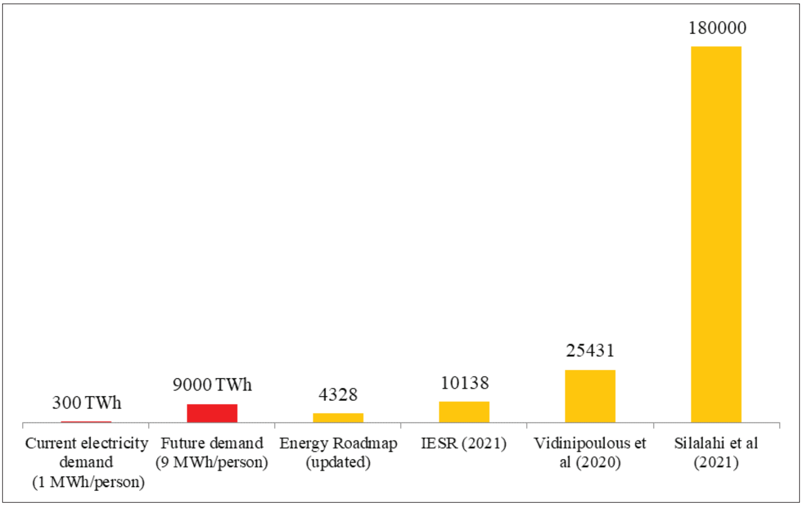


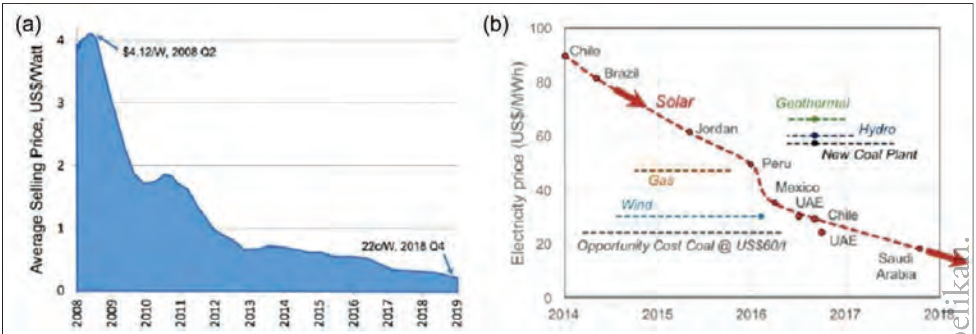
Figure 5.3 Indonesia's Solar Energy Potential Estimation in Recent Studies

C. Challenges of Solar Energy

As one of Indonesia's most prominent renewables solar energy is a great opportunity to act as an effective alternative to conventional energy sources. Harnessing abundant sunlight to provide on-demand energy would be vital to meet Indonesia's climate targets. However, several challenges to the growth of solar energy utilization exist and must be tackled.

1. High Capital Cost

One of the most common issues about solar energy is its high capital expenditure for solar panels. However, this cost-related problem is likely to be irrelevant now or soon as the price of photovoltaic modules has dramatically reduced over the past decade, as illustrated in Figure 5.4 (a) (Green, 2019). This cost reduction leads to a substantial drop in the levelized cost of photovoltaic-generated electricity (Figure 5.4 (b)).



Note: a. Decrease in the average selling price of multi-crystalline photovoltaic modules; b. Reduction in the Levelized electricity cost over time for photovoltaic and other sources

Source: Adapted from Green (2019)

Figure 5.4 Significant Reductions in Photovoltaic Module Price and Levelized Cost of Electricity

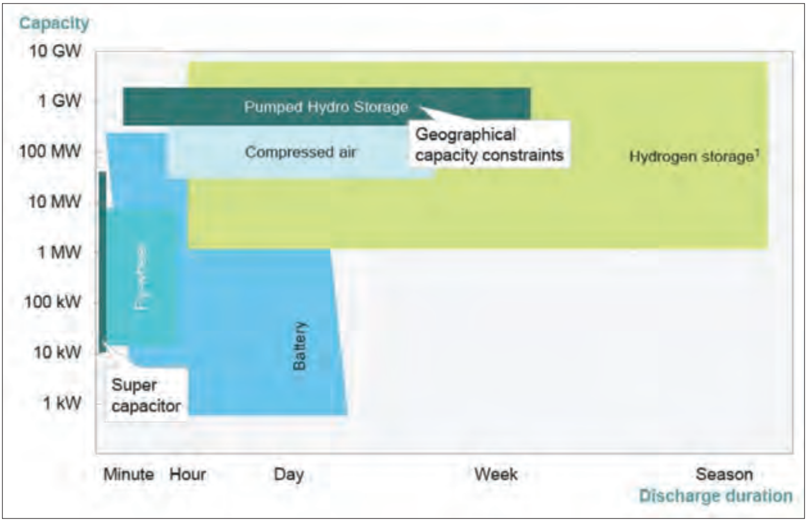
It is important to note that the drop in the levelized electricity cost shown in Figure 5.4 (b) is not solely due to the panel cost reductions but also due to more favorable financing conditions by stakeholders, including industries and the government (Green, 2019). Therefore, healthy investment conditions and supporting incentives are essential to decrease the solar electricity price even further and pursue the advancement of solar technology.

2. Intermittency of Solar Energy

The major problem with solar energy is its intermittency in terms of supply and demand. Solar panels require sunshine to produce electricity. When the irradiation is high, the electricity supply can exceed the demand. When it is not, solar-generated electricity supply cannot fulfill the demand, and therefore, fossil fuels are burned to keep the lights on. The variable nature of solar energy constrains its utilization as baseload power.

Adequate energy storage solutions are required to tackle its intermittency problem and ensure the stability of electricity grid. Numerous storage options with varying power capacities and discharge durations exist, as shown in Figure 5.5. For the short-term, batteries, supercapacitors, and compressed air are among viable storage solutions to support supply-demand balancing. However, they are unsuitable for long-term storage due to limited power capacity or storage timespan.

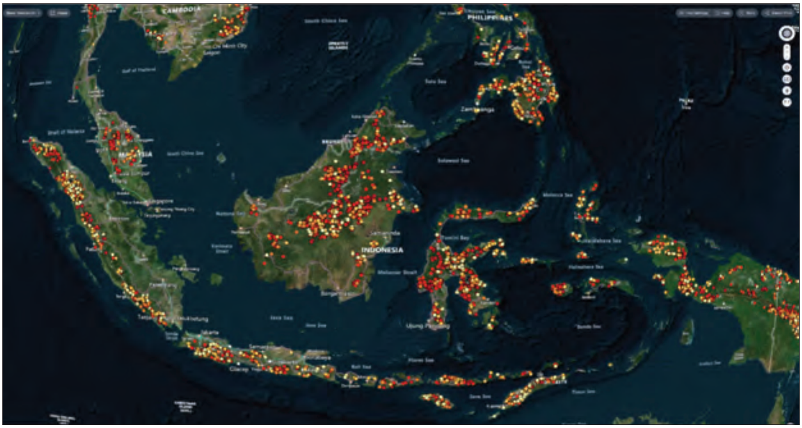
Pumped hydro provides an alternative solution for long-term solar energy storage. Typically, when the electricity supply from solar farms exceeds the demand, the excess energy can pump water from a lower level to a higher one. The stored energy can then be converted back to electricity when the solar-generated power is too little, allowing the water to fall through a hydroelectric turbine into the lower reservoir. This storage method accounts for more than 95% of worldwide power storage.



Source: Hydrogen Council (2017)

Figure 5.5 Options for Carbon-Free Energy Storage Solutions

Indonesia currently has no existing PHES systems. However, this will change soon because Indonesia has included 4000 MW of PHES in its electricity development plan. The 1000 MW Upper Cisokan Pumped Storage project, located in Cianjur, West Java, is currently being financed and approved, and is also planned to operate in 2025 (World Bank, 2021). The Matenggeng pumped hydro storage (943 MW) in West Java is expected to connect to the grid in 2028. The Grindulu pumped hydro storage (1000 MW) in East Java will operate in 2030 (RUPTL, 2021). The state electricity company Perusahaan Listrik Negara (PLN) plans to develop 4x250 MW PHES systems in Sumatera, which are expected to connect to the grid in 2029–2032 (RUPTL, 2021).



Source: Stocks et al. (2021)

Figure 5.6 Potential 150 GWh Greenfield Off-river Pumped Hydro Energy Storage Sites in Indonesia

Based on the Australian National University's Global Greenfield Atlas, 26,000 off-river PHES potential sites are identified in Indonesia (Stocks et al., 2021). The atlas includes eight combinations of storage energy volume (GWh) and storage power capacity, namely 2, 5, 15, and 50 GWh with 6 hours of storage and 5, 15, 50, and 150 GWh with 18 hours of storage. Figure 5.6 depicts the potential of 150 GWh off-river PHES. Indonesia has an enormous combined storage potential of 800 TWh. With so many options, energy planners can afford to concentrate on those with the lowest likely costs per unit of storage. A total of 321 TWh of high-class off-river PHES was identified in Indonesia (Silalahi et al., 2022).

Off-river pumped hydro storage, in contrast to conventional river-based pumped hydro storage, takes up a relatively small area, typically 200 hectares. Off-river PHES avoids the environmental costs of damming rivers, which aids in social acceptance (Silalahi and Blakers, 2021).

Indonesia could also store excess solar energy in a hydrogen form. Hydrogen is a novel way to keep energy in a large power capacity and long storage timespan. The excess solar electricity can be passed through a water electrolyzer to produce hydrogen during an oversupply period. When the power generated from solar farms is underperforming, the stored hydrogen can produce on-demand electricity using a fuel cell or a gas turbine. As a result, hydrogen offers a robust long-term energy storage option to maintain the solar electricity grid stability. More significantly, storing the excess electricity from solar energy as hydrogen can potentially widen the reach of renewable energy for deep decarbonization of hard-to-abate sectors, such as the chemical industry, petrochemical industry, and heavy transport.

Indonesia could build energy storage in the form of off-river PHES or hydrogen infrastructure. With a low daily, weekly, and seasonal variation of solar insolation, Indonesia does not require seasonal solar energy storage. Energy storage need to be only short term, mainly for day-night system balancing (Silalahi et al., 2021).

3. Land-Use Footprint of Solar Energy

Although current land use for solar energy is relatively small, it is predicted that in the future, with a decarbonized electricity grid, solar energy utilization will require significant land areas to be occupied. Defining the minimum efficiency standards for solar panels is essential to reduce land requirements for solar power plants (van de Ven et al., 2021).

On top of that, rigorous environmental and feasibility analysis needs to be conducted to determine where to put the solar panels. Several potential locations for developing solar farms that can minimize the land-use footprint include rooftops, abandoned mine sites, agricultural lands, and floating on suitable water bodies in Indonesia (Silalahi et al., 2021; van de Ven et al., 2021).

Rooftop solar panels do not need extra space and can accommodate the energy demands of residential, commercial, and industrial buildings (Silalahi et al., 2021). Co-locating solar panels in agricultural lands, known as agrophotovoltaic (APV), can be an attractive alternative in Indonesia as one of the world's largest agricultural countries.

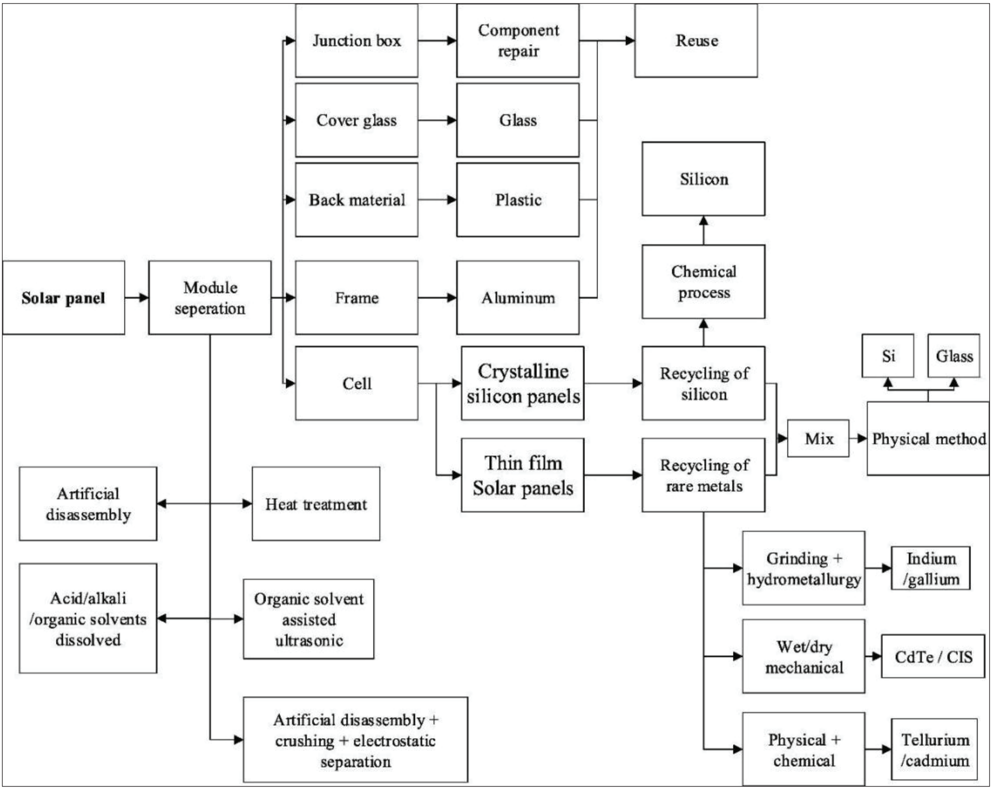
This APV approach could also benefit farmers by providing additional revenue streams (Silalahi et al., 2021).

Putting solar panels on former mining sites has also received significant attention to avoid land competition. With existing transmission lines and infrastructure in the abandoned mining sites, capital expenditure for developing solar power plants can be significantly reduced (Silalahi et al., 2021). Last but not least, floating solar photovoltaic is a promising technological option for Indonesia, with a huge fraction of water bodies, including freshwater and maritime. For instance, lakes and inland seas are suitable for floating solar panels as they typically have low wind speed and relatively calm water surfaces (Silalahi et al., 2021).

4. Hazardous Solar Panel Waste

Every solar panel has particular lifetime (typically around 20–25 years of service life) for its proper performance. After that, solar panels turn into a form of waste that adversely impact humans and the environment. Some photovoltaic cells contain hazardous chemicals, such as lead, selenium, tellurium, and cadmium. As an illustration, it is estimated that 33,205.36 tons of photovoltaic cell waste would create 62.26 tons of hazardous materials that may pollute soil and water, and affect human health (Tasnim et al., 2022). To address this issue, methods to recycle 100% of materials, from the glass, silicon, and metal frame, are required.

Significant efforts have been performed to develop techniques for solar module recycling. Moreover, the research predominantly focuses on silicon extraction and recycling rare metals. Regarding waste processing, there are three solar panel waste processing techniques: component repair, module separation, and recovery of silicon and rare metals (Xu et al., 2018). All those steps can be done using physical, thermal, and chemical processes as summarized in Figure 5.7 (Chowdhury et al., 2020).



Source: Xu et al. (2018)

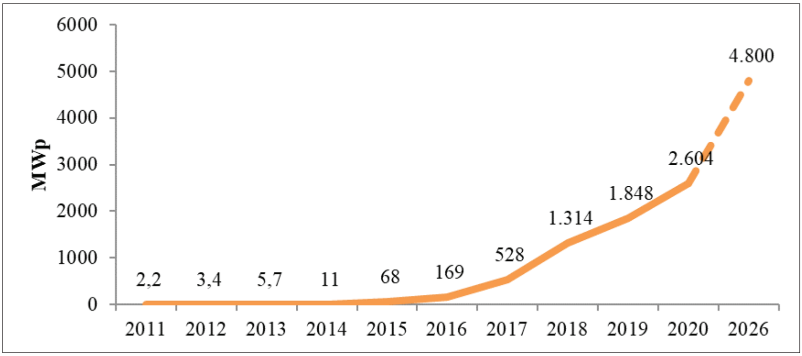
Figure 5.7 Various Recycling Techniques of Solar Panels

Several regulations regarding this matter are necessary as an addition to process the technological development for viable solar panel recycling. Unfortunately, Indonesia has not taken any measures to regulate waste solar panels. A clear recycling industry standard needs to be developed for waste management from solar power plants. The Government must set policies and regulations to encourage recycling and safe waste disposal.

C. Opportunity for Floating Solar Photovoltaic in Indonesia

1. Global Capacity and Cost Overview

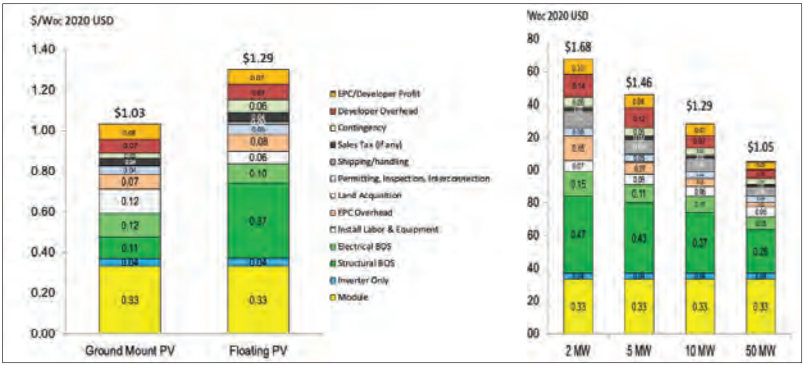
The quick drop in the price of solar photovoltaics (PV) encourages worldwide engineers to look forward to new ways to integrate more PV into power systems. However, the rise in ground-mounted PV installations could put more pressure on land use, particularly in locations where land is scarce and costly. Floating PV (FPV) offers a solution to this land problem and it has gained more attention. The global capacity of FPV systems grew from less than 1 MW in 2007 to 2.6 GW in 2020 (Cox, 2021). Moreover, it is projected to reach 4.8 GW by 2026 (Prnewswire, 2022). The trend of global FPV can be identified in Figure 5.8.



Source: World Bank (2019); Ramasamy et al. (2021)

Figure 5.8 Floating PV Cumulative Global Installed Capacity

NREL reported that the U.S. installed cost of a 10 MW FPV system is $1.29 per watt. It is $0.26 (25%) higher greater than a land-based PV system ($1.03 per watt). It is mainly due to the structural costs related to the floats and anchoring system (Figure 5.9 (a)). However, the larger capacity of the FPV the lower its system costs. The cost of a 50 MW FPV system is close to a 10 MW land-based PV system, as shown in Figure 5.9 (b).



(a) (b)

Note: (a) Cost Comparison of 10 MW FPV System and Ground-mounted PV System; (b) Cost of FPV System with Varying System Sizes
Source: Ramasamy et al. (2021)

Figure 5.9 Solar Panels Cost Comparisons

2. Advantages of Floating Solar Photovoltaic

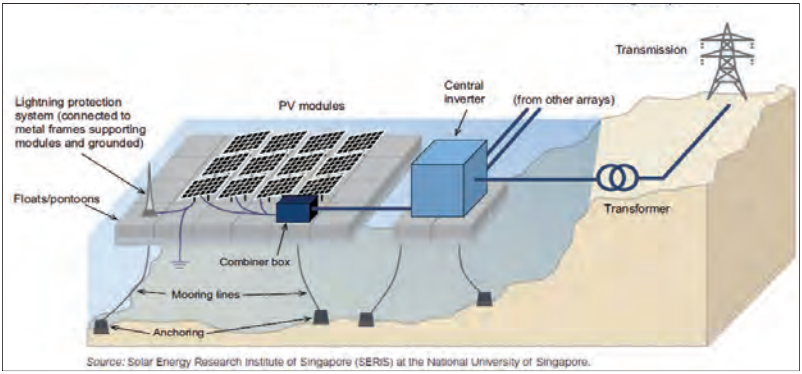
There are several key advantages of floating solar PV compared to land-based solar PV:

1. **No land occupancy.** The most significant benefit of floating solar panels is that the installations do not utilize land space, reducing land-use competition with agriculture or real estate, particularly in locations where land is relatively scarce and expensive.
2. **Higher solar panel performance.** Solar panel performance tends to decrease as temperatures increase. The water around the floating solar installation helps cool the solar panels, enabling the panels to generate electricity with higher efficiency. As reported in studies, the module temperatures are about 3°C to 15°C lower than land-based PV (Reindl, 2018; Liu et al., 2018; Dorenkamper et al., 2021). The performance ratio is 10% to 15% higher than typical rooftop PV systems (Reindl, 2018).
3. **Environmental benefits.** The floating solar panel structure covers the water's surface, reducing evaporation. Advantageous for areas susceptible to drought, as water loss to evaporation, can add up

over time and contribute to a shortage. The shade reduces the growth of algae in water bodies. Lastly, it generates low-carbon electricity.

3. Floating Photovoltaics Technology

Floating solar photovoltaics (FPV) are solar panels mounted on a designed structure to be able to float on a water surface. The design of an FPV is similar to a land-based solar PV system, except that it requires a floating structure to float the panels on the water's surface. The key components of FPV are PV modules, inverters, floating platform, anchoring and mooring system, cabling and combiner box, and transformer. A schematic of typical FPV is shown in Figure 5.10.



Source: World Bank Group (2019)

Figure 5.10 Schematic Diagram of Floating Solar PV System with Its Key Components

The floating structure and anchoring system are the main components that differ from the FPV system to the land-based PV system. This component is worth reviewing to decide on the suitable technology for designated floating PV sites. It contributes up to 30% of the total cost. In this chapter, we only discuss the floating system. There are three major designs of floating. The designs are pure-floats, pontoon and metal frame, and membranes and mat (Figure 5.11,

Figure 5.12, Figure 5.13). Table 5.1 summarizes the advantages and disadvantages of each design.

Table 5.1 Summary of the Advantages and Disadvantages of Pure Floats, Pontoons, and Metal Structure, Membrane, and Mats Floating Technology

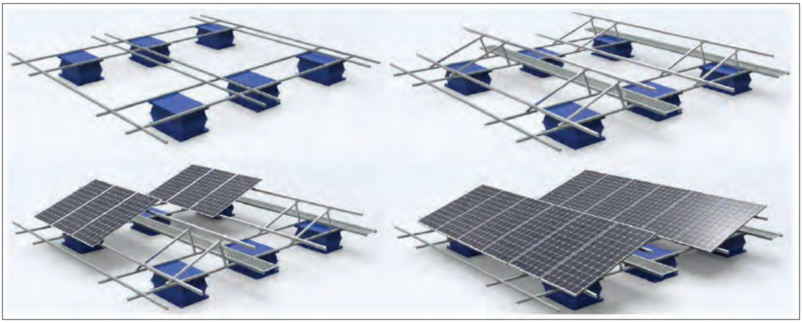
Floating system	Pure floats	Pontoons and metal structure	Membrane and mats
Advantages	• Systems are easy to assemble and install • Systems can be scaled without major changes in design. • Few metal parts are required, minimizing corrosion. • Platform adapts to wave motion and relieves stress.	• The concept is simple. • Floats are easy to make and therefore can be easily sourced locally. • Wave movement between PV modules is less variable, thus reducing wear and tear on module connection components and wires.	• Conceptually simple and provides an easy base for installation and maintenance • being in direct contact with water; heat from sunlight is discharged into the water, thus lowering the operating temperature of the PV modules and increasing energy yield. • possible to float specially designed PV panels directly on water or in a semi-submerged manner • suitable for desert areas to prevent evaporation losses, to cover drinking water reservoir • able to withstand typhoon category 4 • able to withstand water level variation excess of 30 meters

Floating system	Pure floats	Pontoons and metal structure	Membrane and mats
Disadvan-tages	• Modules are mounted very close to water. It reduces air circulation and cooling effect of evaporation. It also generates a high-humidity environment for both PV modules and cables. • It is not cost-effective to transport pure floats over long distances, so they may need to be molded in nearby facilities • Constant movement may cause stress and fatigue to joints and connectors.	• With more rigid structures, waves cause stress to concentrate at certain points. • Structures are more difficult to assemble. • Access for maintenance can be difficult in certain designs. • Possibility of corrosion	• may not be easily scalable • more suitable for smaller-scale systems on reservoirs or irrigation ponds up to around 100,000 to 200,000 m2 in size • Tilting PV panel is not possible

Source: World Bank Group (2018); Ocean Sun (2021)

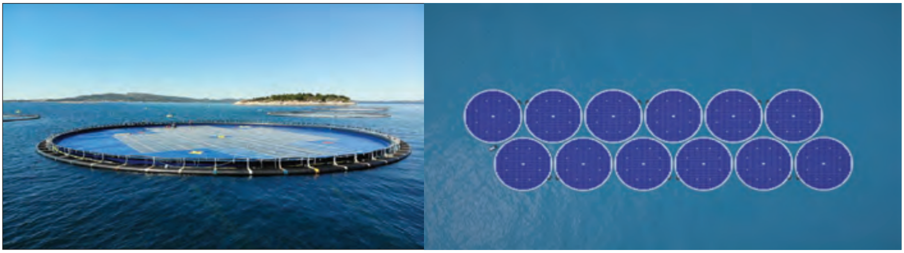
Source: Ciet Et Terre (2021)

Figure 5.11 Pure Floats Design



Source: K-Water Research Institute (2019)

Figure 5.12 Pontoons and Metal Frames Structure by Scotra



Source: Ocean Sun (2021)

Figure 5.13 Floating Solar Technology Based on a Thin Hydro-elastic Membrane

D. Citing Floating PV

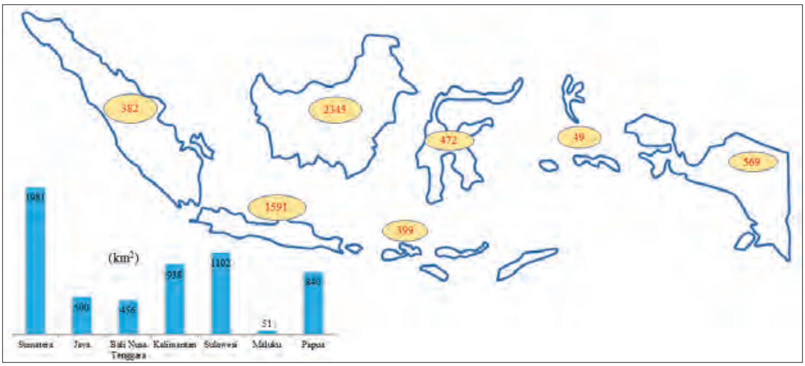
The critical question in discussing the development of a solar energy project is where to locate the solar panels. Is there enough space to host the required solar panels? Table 5.2 shows several recent floating PV projects and how large the area is occupied by each project. The figures vary for each site with an average of 0.8 MW per hectare. This figure might decrease as the efficiency of solar panels improves with the advancement of technology. However, it can be referred to as a conservative figure.

Table 5.2 List of Occupied Area in the Recent Floating PV Projects

Floating PV Projects	Capacity (MW)	Occupied area (hectare)	Capacity per occupied area (MW/hectare)
2021 - Kaohsiung, Taiwan - Ciel et Terre	4.1	8.7	0.5
2021 - Healdsburg, USA - Ciel et Terre	4.8	15.3	0.3
2021 - Xiqian, China - Ciel et Terre	21.6	30.7	0.7
2021 - Changhua, Taiwan - Ciel et Terre	22.8	29.7	0.8
2021 - Changhua, Taiwan - Ciel et Terre	10.3	22.6	0.5
2021 - Marouke Ike, Japan - Ciel et Terre	0.7	2.3	0.3
2021- Yunlin, Taiwan- Ciel et Terre	1.0	1.9	0.5
2021 - Banja, Albania - Ocean Sun	2.0	0.79	2.5

Source: Ciel et Terre (2021) and Ocean Sun (2021)

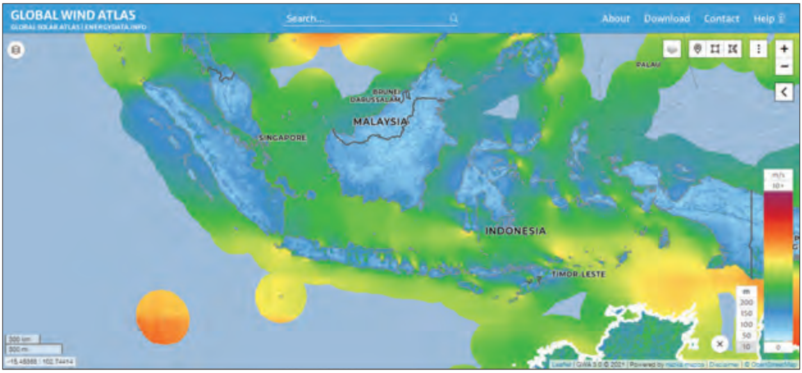
Finding a space for solar PV deployment in Indonesia is easy, with a land area of 1.9 million km^2 and a maritime area of 6.4 million km^2, the country has limitless possibilities to find unused spaces that can be transformed into solar farms (Geospatial Information Agency, 2020). Furthermore, the vast potential of floating PV is available in Indonesia. It could generate 180,000 TWh per year (Silalahi et al., 2021). The vast potential is mainly due to Indonesia having an adequate water surface. Indonesia has 5,800 lakes that can be found with a total area of 5,868 km^2 (Lembaga Ilmu Pengetahuan Indonesia, 2020). It is a vast space to explore for FPV deployment on freshwater.



Source: LIPI (2020)

Figure 5.14 Distribution of 5,807 Lakes with a Total Area of 5868 m^2 in Indonesia

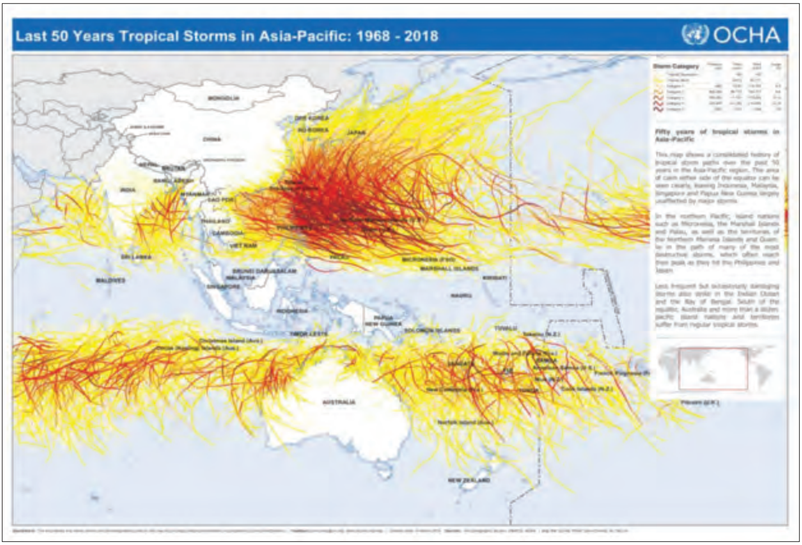
A large portion of Indonesia's maritime territory is protected by Sumatra, Java, Kalimantan, Sulawesi and Papua, as shown in Figure 5.15. A recent study reported that Indonesia has 708,000 km^2 of calm maritime area, with waves less than 4 m and wind speed less than 15 m/s (Silalahi et al., 2021). It is an ample space to host FPV. For example, the sea area along the eastern Sumatra, northern Java, between Kalimantan and Sulawesi, and the gulf in Sulawesi have relatively low wind speeds. As shown in Figure 5.15, the low wind speed at 10 m in the Indonesian maritime area is blue and green.



Source: Global Wind Atlas (n.d.)

Figure 5.15 Indonesia's Wind Speed at 10 M

The absence of tropical storms in Indonesia over the last 50 years raises confidence in the safety of installing solar PV panels (United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA, 2019). Figure 5.16 depicts the paths of tropical storms near Indonesia from 1968 to 2018. None of these storms has significantly affected Indonesia, Malaysia, Singapore, or Papua New Guinea.



Source: UNOCHA (2019)

Figure 5.16 The Last 50 Years of Tropical Storms in Asia-Pacific; 1968–2018

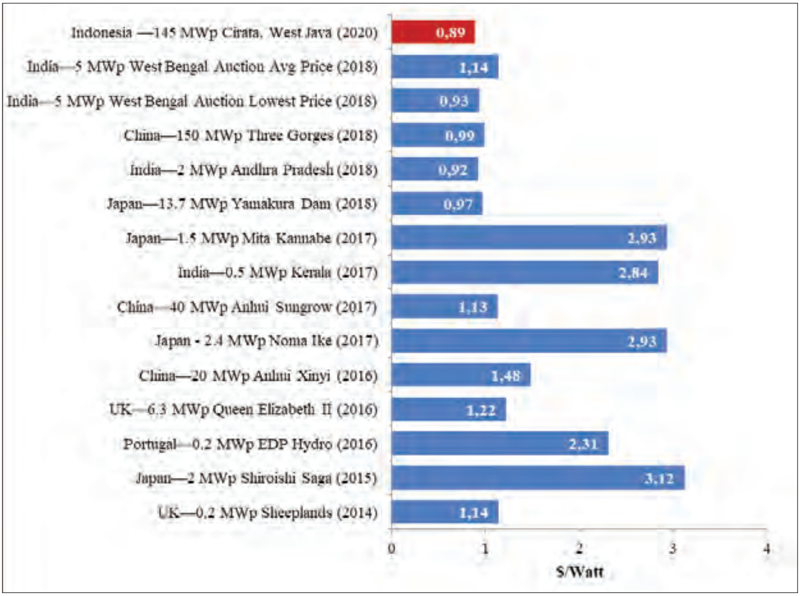
E. FPV Development in Indonesia

Indonesia does not have the facilities for commercial floating PV. However, it is about to change. In early 2020, Masdar (Abu Dhabi-based renewable energy group) and Indonesian energy company PT PJB agreed to build a 145 MW floating PV on a 225-hectare section of the Cirata Reservoir in West Java (PVTech, 2020). It is expected to operate commercially in 2022. In the mid of 2021, Sunseap signed a Memorandum of Understanding with the Batam Island authority to develop a floating PV combined with a battery system on Duriangkang Reservoir (Reuters, 2021). The floating PV is projected to have a capacity of 2.2 GW covering a 1,600 hectares reservoir area, the largest FPV in the world to date. A portion of the electricity will be exported to Singapore via a 50 km submarine cable.

The decreasing price of solar panels has lowered the investment cost significantly. In 2015, the Government set the selling price of solar PV projects up to 25 cents USD/kWh. Yet, the sales price from

Cirata 145 MW floating PV to PLN (Indonesian utility) is 5.8 cents dollar per kWh. Further, the recent bid price for Saguling 60 MW and Singkarak 90 MW floating PV are 3.74 cents USD per kWh and 3.68 cents USD per kWh, respectively (Newsletter, 2021). Saguling is an artificial reservoir (hydroelectric dam) in West Java, while Singkarak is a natural lake in West Sumatra with an existing hydroelectric power plant.

Although floating PV costs might vary due to site-specific design, compared to several projects in different countries, Indonesia's floating solar PV cost is already competitive compared to several projects in different countries. For instance, 129 million USD investment (PJB, 2020) in the 145 MW Cirata project equals 0.89 USD per Watt (Figure 5.17). It is lower than Japan's projects and similar to India's projects. This indicates that the floating PV is a promising way to supply low-carbon electricity for Indonesian.



Source: World Bank Group (2019); PT Pembangkitan Jawa-Bali (2021)

Figure 5.17 Floating PV Investment Costs Worldwide (Real and Auction Results)

F. Strategy for Future Solar Energy Deployment

The capacity factor of solar generation is now the lowest compared to all other forms of energy generation. By genuinely understanding the solar energy limits, we can solve the bottlenecks correctly. We can design our power grid accordingly by knowing the solar nature (no generation during nighttime). On the other hand, solar PV installations are much faster to build than fossil-based power plants and can be completed in months rather than years. It is favorable compared to coal, gas, hydroelectric, and nuclear plants that might take several years to complete.

By deploying at a huge scale (in Gigawatts), the cost of solar PV power in Indonesia is projected to be more competitive. Indonesia has consistently good solar irradiation. Economies of scale will take advantage, and there are large areas where deployment costs (including land access) will be low—particularly in the calm inland sea of Indonesia. It can be started by building floating PV in the safest space, such as existing hydroelectric dams, in the big lakes such as Lake Toba, and finally on the inland sea surface as the technology advances.

Moving towards the 2060 net-zero emissions target, public or business parties must participate. Religious leaders can encourage people about the importance of energy transition to keep the earth safe (Silalahi, 2022). As a breakthrough, the Government could also encourage communities to become involved in the renewable energy project. Community ownership allows high upfront investment sharing and enables more projects to develop. Community-owned projects have a specific purpose: focus on creating social benefits. A community-based renewable energy project has been developed in several countries like the United States and European countries, especially Denmark, Germany, the Netherlands, and the United Kingdom (particularly Scotland). One major benefit of involving the community is that it creates a sense of belonging that makes local people less reluctant to the project (International Renewable Energy Agency, 2020).

G. Conclusion

Indonesia could harness more unexploited renewable energy to achieve carbon neutrality in the future. Despite its challenges, floating PV technology offers a great opportunity to harness untapped Indonesia's solar potential. The abundant freshwater bodies and large calm maritime areas could host the solar panels. Its vast potential offers more opportunities to create green jobs, green energy, increasing Indonesia's role in the region. Not only solar energy for self-consumption but also exporting its energy for helping its neighbor to reduce carbon emissions.

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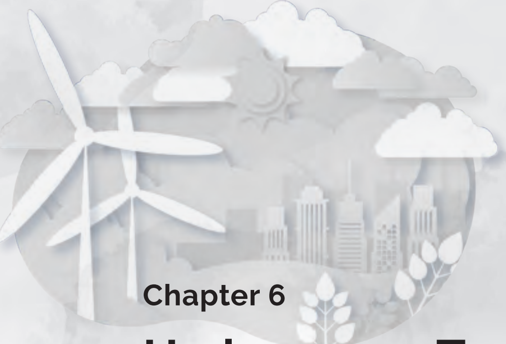

Chapter 6

Hydropower Technology: Potential, Challenges, and the Future

Harun Ardiansyah

A. Overview of Hydropower Technology in Indonesia

As the COVID-19 pandemic started to become endemic, Indonesia's economy has been bouncing back and steadily growing. Indonesia is one of the 20 countries with the largest economy—and is projected to be the fourth-largest by 2050 (Hawksworth et al., 2017). Along with economic growth, economic expansion is inevitable. And economic development needs to be supported by a robust energy infrastructure that will provide 24/7 energy for Indonesia. The electricity demand is increasing for household use, but only for manufacturing and industrial applications. On the other hand, Indonesia is facing a climate change problem. As one of the most polluting countries in

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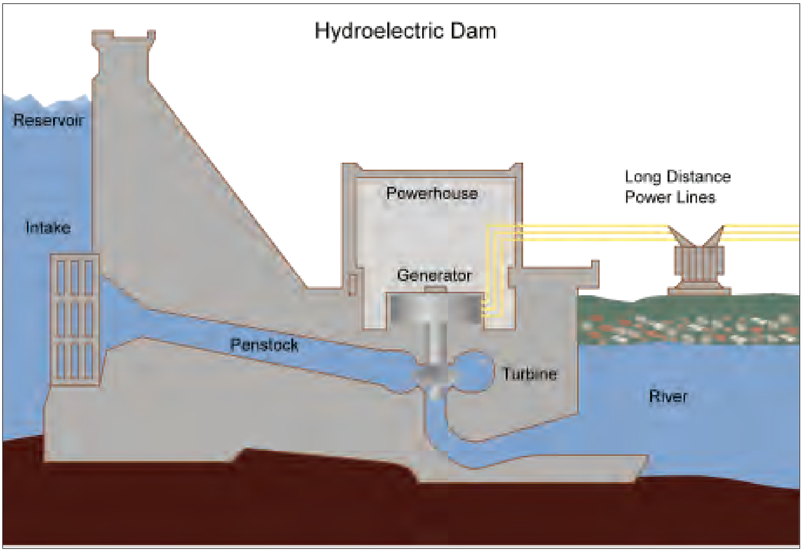
Ardiansyah, H. (2022). Hydropower technology: Potential, challenges, and the future. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (89–107). BRIN Publishing.
DOI: 10.55981/brin.562.c6 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

the world, pressure is mounting for Indonesia to reduce—or even eliminate—its dependence on fossil fuel energy (Ritchie, 2019). As of 2021, Indonesia is still relying heavily on fossil fuel energy. A report by National Energy Council shows that more than 60% of Indonesia's electricity generation comes from fossil fuel energy (National Energy Council of Indonesia, 2020). This motivates the Government to introduce new policies to tackle the increasing demand for energy and electricity and the increasing threat of climate. This includes the introduction of Indonesia's national energy plant (Rencana Umum Energi Nasional-RUEN) by the Ministry of Energy and Mineral Resources (Kementerian Energi dan Sumber Daya Mineral-ESDM) and multiple ordinances of National Electricity Supply Business Plan (Rencana Usaha Penyediaan Tenaga Listrik-RUPTL) by the State Electricity Company (Perusahaan Listrik Negara-PLTN) (Peraturan Presiden Nomor 22 Tahun 2017 Tentang Rencana Umum Energi Nasional, 2017; PT Perusahaan Listrik Negara, 2021). In RUEN, it is stated that Indonesia's target 23% of its energy mix comes from renewable energy by 2025 and 31% by 2050. These targets are backed up by Indonesia's Nationally Determined Commitment (NDC) in COP26 (Humas ESDM, 2021).

These commitments and targets boosted Indonesia's expansion to renewable energy technologies, including hydropower technologies. Hydropower energy means converting the energy of moving water into electricity. This includes both large-scale and small-scale hydropower. In 2020, BP Statistical Review reported that hydropower energy contributes around 7% of all energy mix in Indonesia, constituting almost 20,000 GWh of total electricity production in 2020 (B.P. Statistical Review, 2020). Hydropower energy production has been Indonesia's most significant contributor of renewable energy. The electricity generated from hydropower constitutes more than 50% of the total renewable energy produced in Indonesia. However, this technology is very far from reaching its highest potential. With the geography of Indonesia, hydropower should have been one of the highest electricity sources. On the other hand, every development always comes with a cost. In this case, the ecological price is one of the highest costs that should be paid to develop a reliable hydropower energy infrastructure.

Hydropower has many potential uses for power generation and sustaining crops through irrigation. The hydro dams can also be used for water supply, flood control, and navigation improvement. A typical cross-section of a conventional hydro dam can be seen in Figure 6.1. It contributes to tackling climate change as a renewable energy source by generating low-carbon, reliable energy. In the long term, it can produce electricity at a low cost and adjust electricity demand from the consumer. This chapter explores Indonesia's hydropower potential and what can be done to achieve the goal. Also, this chapter explains the challenges that make hydropower energy is not reaching its highest potential. This chapter ends with two types of technology currently emerging and should be expanded on a larger scale in Indonesia.



Source: Tennessee Valley Authority (2000)

Figure 6.1 Cross-Section of a Conventional Hydroelectric Dam

B. The Current Status of Hydropower in Indonesia

The hydropower resources are primarily abundant in Indonesia and are blessed by divine nature. Indonesia has more than 800 rivers that can be a potential source of hydropower. It is estimated that Indonesia has the potential for 75 GW of electricity from more than 800 rivers (Hasan et al., 2012). These resources make Indonesia the fourth most significant potential for hydropower. However, because of the high capital necessary, only around 34 GW of electricity can be exploited from all the hydropower potential. Hydropower requires massive and complex infrastructures to extract the power from moving water into energy. These massive infrastructures are for the dams' design, construction, and operation. On the other, potential issues may also come up due to social, political, and environmental issues.

Although there is no international consensus on the definition of the scales of a hydropower plant, some suggest that a hydropower plant that produces more than 10 MW of electricity is considered a large-scale hydropower plant. Plants that generate power between 2.5 MW to 10 MW are considered small-scale hydropower plants. Below that range, the mini-hydropower plant produces below 2 MW, micro-hydropower makes below 500 kW, and the pico-hydropower plant has electricity below 10 kW (Erinofiardi et al., 2017).

With all these potentials, Indonesia has built hydropower infrastructures across the country. PT PLN has listed some of the large-scale hydropower stations in some provinces in Indonesia in Table 6.1.

Table 6.1 Some Operational Large-Scale Hydropower Stations in Indonesia

Hydropower Station	Province	Installed Unit (MW)	Installed Capacity (MW)
Cirata	West Java	8 × 126	1008
Saguling	West Java	4 × 175	700
Sulewana-Poso III	Central Sulawesi	5 × 80	400
Tangga	North Sumatra	4 × 79.25	317
Sigura-gura	North Sumatra	4 × 71.50	286

Hydropower Station	Province	Installed Unit (MW)	Installed Capacity (MW)
Sutami/Brantas	East Java	12 × 35 × 3	281
Musi	Bengkulu	3 × 70	210
Sulewana-Poso II	Central Sulawesi	3 × 65	195
Mrica	Central Java	3 × 61.5	184.5
Asahan I	North Sumatra	2 × 90	180
Singkarak	West Sumatra	4 × 43.75	175
Jatiluhur	West Java	7 × 25	175
Larona	South Sulawesi	3 × 55	165
Sulewana-Poso I	Central Sulawesi	4 × 40	160
Karebbe	South Sulawesi	2 × 70	140
Balambano	South Sulawesi	2 × 65	130
Bakaru	South Sulawesi	2 × 63	126
Koto Panjang	Riau	3 × 38	114
Karangkates	East Java	3 × 35	105

Source: PT Perusahaan Listrik Negara (2021)

The Government of Indonesia has planned to increase the cumulative capacity of large-scale hydropower plants in some Indonesia regions. Specifically, the plan includes an additional 20 MW in the east region of Indonesia, 21 MW in the Java-Bali connection, 11 MW in Sumatra, and 18 MW in the eastern part of Indonesia (Erinofiardi et al., 2017).

Besides the large-scale hydropower potential, Indonesia also has some potential to build smaller-scale hydropower by utilizing medium-sized rivers around the country. The utilization of small-scale hydropower has been done since 2005. At that time, 0.45 MW of electricity was generated by small-scale hydropower. Since then, the development is not significant in the coming years. From 2006 to 2010, the electricity generated could only be increased to 0.69 MW (Erinofiardi et al., 2017).

Another example is to utilize micro-scale hydropower. It is estimated that the potential of micro-hydropower is about 459.91 MW. From that number, 20.85 MW of it has been developed by PLN to provide electricity for rural areas (Hasan et al., 2012). Small- and micro-scale hydropower plants might be an excellent option to expand the utilization of hydropower plants, considering Indonesia's distribution of electricity in the islands and the safety of fish and other biotas in the water.

C. Challenges Facing Hydropower

All types of development must come with some risks and costs. Even though in the previous section it is said that Indonesia has about 75 GW of electricity potential from hydropower, it is undoubtedly hard to exploit all those potentials considering the landscape of Indonesia. Any development would indeed have some impact on the surrounding areas. These challenges include the engineering and socio-economic impact of the projects.

1. Geographical Challenges

Although some experts approximated that the hydropower potential in Indonesia is relatively more enormous than in some countries. Undeniably, Indonesia's geography can create challenges that need to be solved or worked around. Indonesia indeed has many rivers that flow across the country. However, the rivers are relatively short. This geographical issue will create problems when a large-scale hydropower plant is constructed. The construction of a large-scale hydropower plant is done by blocking the passage of water to build a dam where the water flow will be directed to the turbines to produce electricity. Creating this dam will also generate a lot of impact on the plant site. In a short river, the construction of large-scale hydropower will be limited to the site constraint (Erinofiardi et al., 2017). It will need an extensive engineering workaround to be able to make the large-scale hydropower dams.

Another problem is related to electricity transmission. As an archipelagic country, Indonesia has more than 17,000 islands. Although some portions of those islands are not inhabited, the inhabited islands need constant electricity transmission to create better-living conditions. Electricity transmission has always been a problem for Indonesia to achieve 100% electrification and balance energy resources. It is well known that as electricity is transmitted among islands, there will be some losses. The losses make the consideration of investing in electricity transmission becomes harder. It also creates gaps in electricity resources in some regions of the country. Right now, most of the manufacturers are on the island of Java. This situation is due to the excessive energy resources accumulated in Java. These gaps will create inequality in the quality of life of the people in the region.

2. Ecological Challenges

Around the world, large-scale hydropower plants have affected fishing activities and fishery production. These effects include direct and indirect impacts of the large-scale hydropower project. The immediate result is that the fish are killed, injured, or physically blocked from their migration. This consequence is likely to happen, especially in large-scale hydropower construction, where dams are the way to generate electricity. Fish can get drawn into the turbines and can injure the fish. Hydropower plants can also alter the habitat upstream and downstream of the river. First, the existence of upstream and downstream will create a barrier effect to the living organisms in the stream. This separation will affect the population of fish and other living organisms. These challenges can be avoided by implementing mitigation measures to the dams. However, it will increase the cost of hydropower plants cost. Upstream, if the condition is not well-maintained, the reservoir can cultivate excess algae and weeds, crowding what has been a challenging environment for the living species in the reservoirs. While downstream, hydropower dams can affect the downstream flow regimes through hydropeaking. Hydropeaking can also alter the upstream habitat as the regime changes from fast-flowing lotic habitat to a slow-flowing lentic habitat (Baumgartner & Wibowo, 2018). Therefore, fish and other living organisms face two types of problems, the existence of dams and turbines create a physical barrier to migration, and the dams alter the flow regimes and habitat availability. Both issues can be mitigated. However, it will increase the cost of building large-scale hydropower plants and make more complicated investments.

For the fish migration problem, some research suggests that the construction of fish passages can be considered to solve the problem. However, some global evidence suggests that the fish passage may cause more harm than good in some instances. Therefore, many considerations need to be taken before constructing a fish passage. If the construction of the fish passage is justified, it will be an excellent way to maintain the river's habitat and maximize the hydropower plants' value.

3. NIMBY-ism (Not In My Backyard Syndrome)

As mentioned in previous sections, the construction of large-scale hydropower plants could dramatically alter the livelihood of all types of organisms, including humans. Some villages might need to be emptied and sunk to construct a dam. This decision will create socio-economic problems for the local villagers occupying the villages from far before the construction. It can make Not In My Backyard (NIMBY) syndrome. NIMBY often refers to intense, frequently emotional, and usually organized opposition to siting proposals that local community residents believe will result in adverse impacts. In this case, if the approach to the local community is not well-communicated, NIMBY is inevitable. NIMBY is a common phenomenon that can be seen in many countries. Furthermore, it does not limit to large-scale power generation projects. NIMBY can also happen for other projects, such as constructing Las Vegas-like Casino construction in Canada or constructing twenty-four homeless shelters in New York City (Wexler, 1996). As a result, it will significantly impact the construction of hydropower plants. It is challenging for the vendor who builds the hydropower plants and the regulators.

D. Current and Emerging Hydropower Technologies

With all the potentials and challenges explained in previous sections, hydropower plants will still considerably affect the landscape of renewable energy in Indonesia. Technologies have been developed in hydropower construction to minimize the ecological effects of hydropower plant construction.

1. Micro-hydropower Plants

As mentioned in previous sections, the geographical landscape is not always suitable for large-scale hydropower plants. Although large-scale hydropower plant is essential to provide baseload from renewable energy, micro-hydropower plants can also be considered to expand to provide reliable electricity for residential purposes. Micro-hydropower plants can also be a decent option for delivering electricity and farming irrigation. Some locations of micro-hydropower plants are shown in Table 6.2.

Table 6.2 Some Locations of Installed Micro-Hydropower Plants

No	Province	Number of Location	Potential Capacity (MW)
1	South Sumatra	1	9.9
2	West Nusa Tenggara	4	2.02
3	East Nusa Tenggara	8	5.8
4	North Sumatra	1	7.5
5	West Sumatra	3	20.5
Total			45.72

Source: PT Perusahaan Listrik Negara (2021)

Of all these potentials, some of them have been built from 2011 to 2014. The micro-hydro power plants that have been constructed are listed in Table 6.3. Some other plants are also built out of data provided in Table 6.3. Some of them are the Van Der Wick irrigation channel in Yogyakarta (11 kW capacity), Rimba Lestari in West Bandung (18 kW capacity), Mendolo hamlet in Pekalongan (22 kW capacity), Pancuang Taba, West Sumatra (40 kW capacity), Muaro Air, Jambi (30 kW capacity), and Koto Ranah, West Sumatra (30 kW capacity). The last three micro-hydropower plants are in Pesisir Selatan, West Sumatra (Erinofiardi et al., 2017).

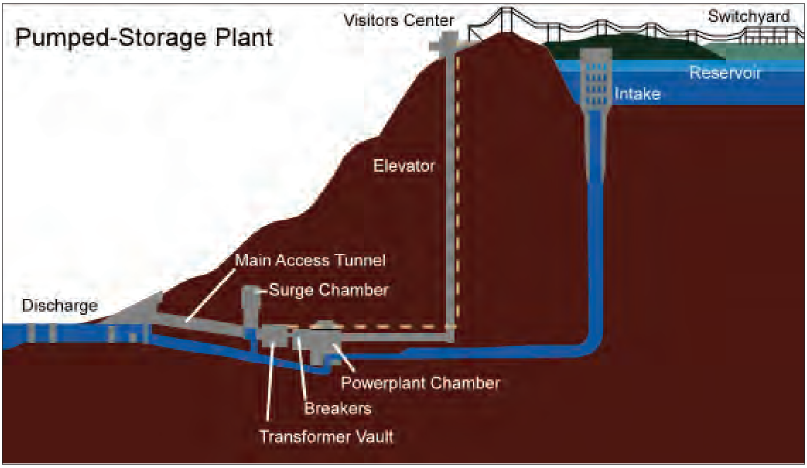
Table 6.3 Installed Micro-Hydropower Plants in 2011–2014

No.	Province	Location	Capacity (kW)
1	North Sumatra	Samosir, South Tapanuli	56.2
2	West Sumatra	West Pasaman, Mentawai, Solok	54
3	Riau	Kampar	8
4	Jambi	Sarolangun	18
5	South Sumatra	South Ogan Komering Ulu, Muara Enim	43
6	Lampung	West Lampung	80
7	West Java	Ciamis	24.4
8	East Java	Situbondo	15
9	West Nusa Tenggara	Lombok, East Lombok, Sumbawa	350
10	East Nusa Tenggara	Ngada, East Manggarai, Central Rote, Central Sumba, South Central Timor	273
11	West Kalimantan	Kapuas Hulu, Landak	450
12	Central Kalimantan	Gunung Mas, Lamandau	48.3
13	North Sulawesi	Sangihe	14.1
14	Gorontalo	Gorontalo, North Gorontalo, Bone Bolango	145.2
15	Central Sulawesi	Lamatoli Morowali	20.6
16	West Sulawesi	Mamasa	120
17	South Sulawesi	North Luwu	40
18	Southeast Sulawesi	North Konawe, North Buton	28
19	Maluku	West Seram	30
20	West Papua	South Sorong, Maybrat, Manokwari	596
21	Papua	Bintang Mountains, Bintuni Bay, Yalimo, Jayapura	186.36
	Total		2,600.75

Source: Kementerian ESDM (2016)

2. Pumped Storage Hydroelectricity Plants

Pumped Storage Hydroelectricity (PHS) Plants use two water reservoirs at two different elevations, as seen in Figure 6.2. PHS offers the flexibility of electricity production based on the electricity demand. When there is low electricity demand or abundant electricity generation from other sources, the plant's power is used to pump up the water from the lower elevation reservoir to the higher elevation reservoir. On the other hand, when the electricity demand is at its peak, the power will be generated through water flows from higher elevations to lower elevations using a turbine. This generated power is then transmitted to satisfy the demand. The loop continues depending on the electricity demand. By this configuration, PHS can balance the demand and supply of electricity and improve the reliability of electricity services in an environmentally sustainable way (Stocks et al., 2019).



Source: Tennessee Valley Authority (2012)

Figure 6.2 Racoon Mountain Pumped-Storage Plant

The concept of PHS is relatively new in Indonesia. As of September 2021, the World Bank has approved a loan to create Indonesia's first pumped-storage hydropower plant. This move aligns with the Government's pledge toward climate change and energy transition. At the same time, the financing will be used to construct Upper Cisokan PHS between Jakarta and Bandung. The expected capacity for this facility is 1040 MW (World Bank, 2022).

PSH offers a unique opportunity to move beyond the first project, especially in Indonesia. PSH can be used to store other renewable energy such as solar PV and wind. PSH is a mature technology that is cheaper than many alternatives for energy storage. Some PSH can be put in remote areas far from rivers and residential areas (off-river). It is possible as PSH can be a closed-loop system and located away from rivers and residential areas. As long as two reservoirs have two different elevations (100–1200 m altitude difference), it is possible to create PSH. The round-trip efficiency is typically about 80%, which is relatively good compared to other renewable energy sources. With Indonesia's topography, PSH can be a good opportunity for reliable electricity storage at a relatively low cost (Stocks et al., 2019).

E. Conclusion

Indonesia has great potential in hydropower. However, those potentials are limited to Indonesia's geography and socio-economic issues. Indonesia's rivers are typically not ideal for constructing a large-scale hydropower plant. Also, the ecological problems due to the possible destruction of the river ecosystem and NIMBY syndrome can affect large-scale hydropower plant projects. Although hydropower plants are necessary to be the renewable energy baseload, the use of hydropower can be expanded in different ways. One way is to reduce the capacity of the hydropower plant and create micro-hydropower plants. Micro-hydropower plants will be an essential addition to residential and farming areas. The other way is to use pumped-storage hydroelectric plants. PSH offers flexibility and reliability to fulfill the supply and demand of electricity that can also be built far from rivers and residential areas. In these ways, hydropower can be a renewable energy backbone for Indonesia.

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Chapter 7

Wind Power in Indonesia: Potential, Challenges, and Current Technology Overview

Taufal Hidayat

A. Wind Power Technical Potential

Wind power has been used for more than two millennia since humans put sails into the wind and continue to grow until now. According to Global Wind Energy Council (GWEC), 2020 was the best year in history for the global wind industry, with 93 GW of new capacity installed, resulting in a cumulative capacity of 743 GW (Lee & Zhao, 2021). China has the largest wind power generation market globally with a total of 206 GW or equivalent to 36% of the global market, followed by the USA, Germany, and India with a total capacity of 96 GW, 2.4 GW, and 2.2 GW, respectively. The wind turbine has supplied almost 6% of the total electricity demand in the world. Some countries have begun developing wind power as their energy resource in

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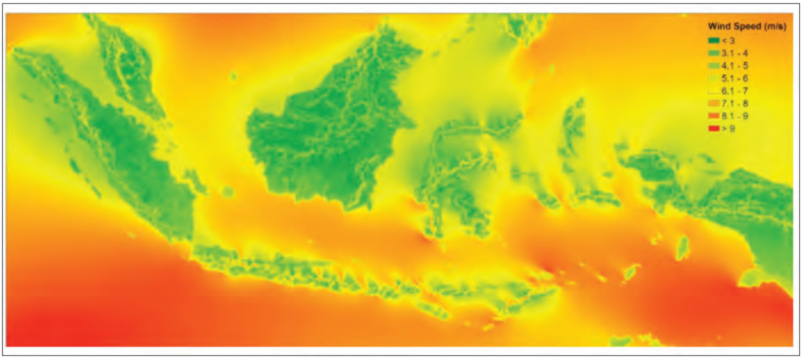
Hidayat, T. (2022). Wind Power in Indonesia: Potential, challenges, and current technology overview. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (109–132). BRIN Publishing. DOI: 10.55981/brin.562.c7 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

Southeast Asia. Vietnam, Thailand, Malaysia, and Indonesia represent 84% of the total installed renewable energy capacity in the Southeast Asian country. Vietnam has the largest capacity with 24,519 MW (34%), followed by Thailand, Indonesia, Malaysia, and the Philippines with 11,860 MW, 9,861 MW, 8,046 MW, and 6,695 MW.

As mentioned in strategic planning in directorate general of new, renewable, and conservation energy, Ministry of Energy and Mineral Resources, 2020–2024, the mean annual speed in Indonesia is only between 3 m/s–6 m/s, only half compared to the country in the northern and southern hemisphere that have wind speed higher than 8 m/s. That low speed happens due to the location of Indonesia, which is on the equator with warm air and low pressure. Based on that wind speed data, the technical potential of wind power notes in the ministry of ESDM is about 60.6 GW, with the utilization being about 0.15 GW until 2020. This utility is still far from the target in RUEN that in 2020, at least Indonesia is already installing 0.6 GW of wind power.

Based on the data from RUEN, Nusa Tenggara Timur have the most significant wind power potential in Indonesia with about 10.18 GW, followed by East Java with 7.9 GW, West Java with 7.03 GW, Central Java with 5.2 GW, and the South Sulawesi with about 4.19 GW. More detailed research shows that the highest wind speed is in Sukabumi, West Java, with about 7 m/s, and Sangihe Island, with 6.4 m/s. Indonesia's largest wind power plant is the District of Sidenreng Rampang, South Sulawesi, with about 75 MW capacity.

Based on the Institute for Essential Service Reform (IESR) (Puspitarini, 2021), wind power potential in each province in Indonesia with hub heights of 50m and 100 m are shown in Table 7.1. From the table, IESR reports that Indonesia has 25 GW wind potential with 50m Height and 19,8 GW with 100m hub height by using a minimum mean annual wind speed of 7.25 m/s at 50 m and 7.99 m/s at 100 m.



Source: Hesty et al. (2021)

Figure 7.1 Indonesia's Global Wind Speed at 50 m Height-Resolution 5 km

Table 7.1 Indonesia Wind Power Technical Potential

Province	Technical potential	
	at 50 m hub height (MW)	at 100 m hub height (MW)
Aceh	1,104.5	1,211.1
Bali	71.5	20.9
Banten	0.0	0.0
Bengkulu	0.0	0.0
DI Yogyakarta	0.0	0.0
DKI Jakarta	0.0	0.0
Jambi	0.0	0.0
Jawa Barat	780.3	418.6
Jawa Tengah	444.4	185.3
Jawa Timur	488.2	205.3
Kalimantan Barat	0.0	0.0
Kalimantan Selatan	120.4	86.7
Kalimantan Tengah	0.0	0.0
Kalimantan Timur	0.0	0.0
Kalimantan Utara	0.0	0.0
Kepulauan Bangka Belitung	0.0	0.0
Kepulauan Riau	36.2	0.0

Province	Technical potential	
	at 50 m hub height (MW)	at 100 m hub height (MW)
Lampung	70.4	0.0
Nusa Tenggara Barat	183.8	34.5
Papua	1,085.2	161.4
Papua Barat	0.0	0.0
Riau	0.0	0.0
Sumatra Barat	11.9	0.0
Sumatra Selatan	15.9	0.0
Sumatra Utara	246.2	38.4
Nusa Tenggara Timur	4,933.0	5,943.8
Sulawesi Utara	0.0	0.0
Sulawesi Tengah	15.2	0.0
Sulawesi Selatan	8,732.7	6,525.0
Sulawesi Tenggara	2.1	0.0
Gorontalo	65.1	9.7
Sulawesi Barat	107.2	0.0
Maluku	6,391.7	4,857.6
Maluku Utara	20.9	0.0
Total	24,926.8	19,698.4

Source: Puspitarini (2021)

B. Wind Power Problem

Although the potential of wind power as a renewable energy source in Indonesia is growing steadily, there are some problems following the installation and development of wind power.

1. Noise

Wind farms can cause mechanical and electrical noise. Some reports and research studies show that the wind farm can produce noise at sound pressure levels that cause negative emotion, insomnia, and various symptoms.(Mar et al., 2020; Mittal et al., 2017; Yamani et al., 2018) According to ISO, the allowable noise level in residential areas is 45 dB, and for an industrial area up to 50 dB (ISO, 1996).

In certain circumstances, wind turbines can cause electromagnetic interference with television signal reception or microwave transmission for communication. The height of the wind turbine is determined by analyzing wind turbulence and wind strength data. Aerodynamic noise is a function of many factors such as propeller design, rotational speed, wind speed, and inflow turbulence.

Moreover, aerodynamic noise is also the main problem caused by the wind farm. Some scientists argue that the wind kinetic energy of large-scale wind farms can affect local and global climate change. Therefore, it is essential to limit the speed of the wind turbine rotor to below 70 m/s.

2. Ecological Problem

Wind farms also potentially affect the animal population, mainly bird and bat populations. Some studies reveal that wind farms can disrupt bird and bat migration. Moreover, the construction of wind farms also potentially affects soil quality and the surrounding land.

3. Visual Impact

The wind farm requires a large installation area, which is impossible to hide. The minimum distance of a wind farm is five times the rotor diameter, which means that for a standard 2 MW wind turbine with a 40 m blade diameter, the required area is 40 km^2 for one turbine. The critical area can disturb the view and reduce the agricultural land.

C. Wind Power Challenges in Indonesia

The prospect of wind power development is relatively high despite several obstacles. In Indonesia, there are several obstacles or challenges, such as:

1. Low Wind Velocity

As a tropical country, Indonesia has a low annual wind speed between 3 m/s–6 m/s. The minimum wind speed required to spin the blade of a wind turbine is 5 m/s, so as the mean annual wind speed in Indonesia, the wind energy potential in Indonesia is low. Referring to the report from IESR (Puspitarini, 2021), compared to solar photovoltaic with 7,714.6 GW potential, wind power has only 194 GW potential for both onshore and offshore. Therefore, it requires further research to optimize the wind energy potential, especially regarding the type of blade that can spin at lower wind speed.

2. High Investment Cost.

The initial investment for a new wind farm is high. In 2017, the initial investment for the wind farm was around USD 0.02/kWh (Lee & Zhao, 2021). The primary investment comes from the area and turbine cost. Therefore, further research is vital to reduce the cost of wind farm energy.

D. Wind Power Technology

Various researches have been developed to increase performance and mitigate the problem possibly caused by wind power resources. Some related research can be adopted to answer the challenge of implementing wind turbines in Indonesia. In this chapter, three prominent technologies are detailed in terms of some research done by the researcher. The researchers can implement the technologies to improve the performance of wind power and mitigate the problem caused by the implementation of wind power resources.

1. Wind Turbine Design

As mentioned in the previous chapter, low wind speed is one challenge to wind power resources in Indonesia. The average wind speed in Indonesia is around 3–6 m/s, which is not suitable for all types of blades. The wind turbine will spin at the wind speed called cut-in speed. For standard wind blades (HAWT), the cut-in speed is 6 m/s which means that the wind turbine will not spin and start to produce power below that speed. Scientists have developed some new blades designed to reduce the minimum wind speed. For example, the implantation of the vertical axis wind turbine can reduce the minimum wind speed to only 2 m/s, which is more suitable to implement in Indonesia. To discuss the recent technology related to blade design, the classification of wind turbines should be detailed first. The wind turbine design can be classified in the following ways.

As seen in Figure 7.2., wind turbines can be classified into two main parts: horizontal axis wind turbine (VAWT) and horizontal axis wind turbine (HAWT). VAWT is a popular type of wind turbine utilized in many wind farms globally. The blades of this wind farm have a vertical direction or are perpendicular to the land, while in HAWT, the edges are parallel with the ground. The comparison of both types of wind turbines is explained in detail in Table 7.2.

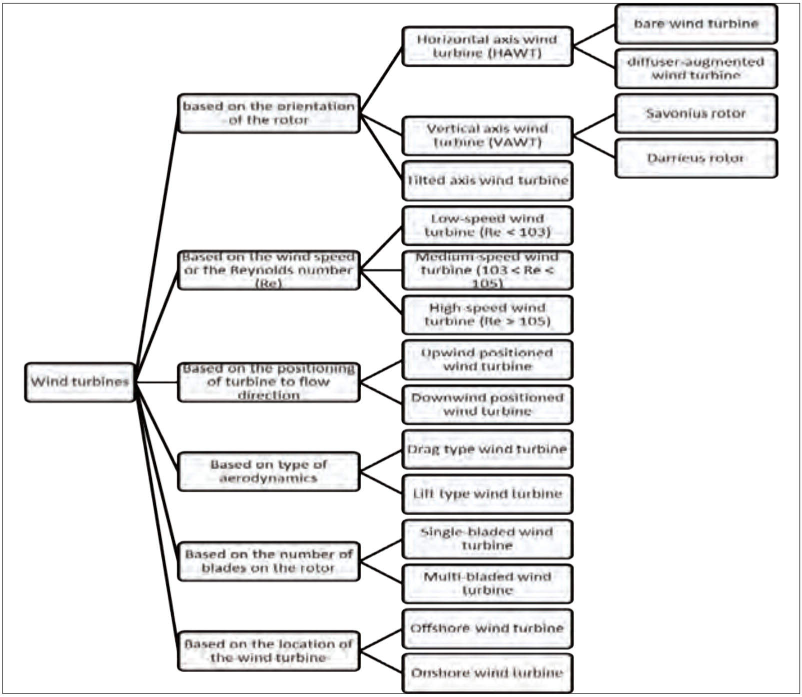


Figure 7.2 Wind Turbine Classification

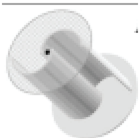
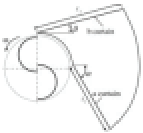
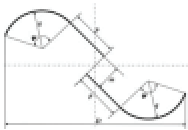
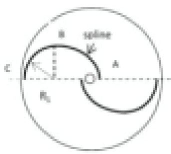
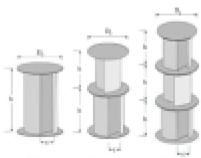
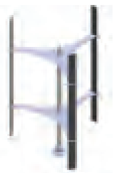
Table 7.2 The Comparison of HAWT and VAWT

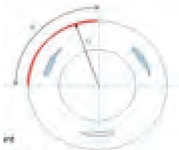
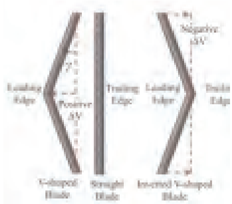
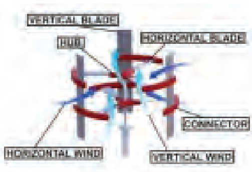
Characteristics	HAWT	VAWT
Rotor orientation	Horizontal	Vertical
Weight	Heavier	Lighter
Wind direction	Specific wind direction	All win direction
Wind speed range	6–25 m/s	2–65 m/s
Environmental impact	Higher chance of bird collision	Lower case of bird collision
Noise level	Higher	Lower
Starting function	Self-starting with high starting torque	Not-self-starting with lower starting torque
Cost and construction	Higher	Lower
Power produced	Higher	Lower

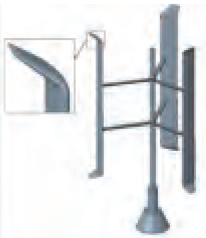
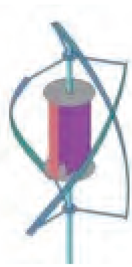
HAWT and VAWT have pros and cons, so the implementation of both should consider the installation area's requirements and conditions. The standard VAWT should be more suitable for Indonesia with low wind speed due to the low cut-in rate, but the energy produced is also lower. Therefore, the researcher should elaborate more research on improving VAWT to increase the energy produced by the wind turbine. Based on the literature review, VAWT can be classified into two categories: Savonius-Rotor and Darrieus rotor. Numerous researchers have also modified each of these types to increase performance. The detailed configuration of this type of VAWT is detailed in Table 7.3.

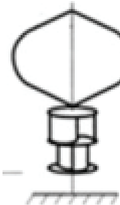
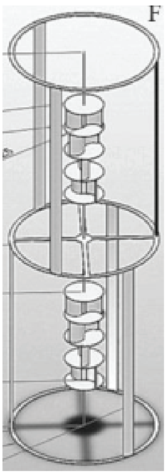
Darrieus rotors have excellent aerodynamic overall performance. However, typically they are not self-starting simultaneously as the Savonius rotors are self-starting but have low aerodynamic overall performance. The Savonius rotors will feature with drag forces. A mixture of them or in different hybrid Savonius-Darrieus rotors will assist in resolving the self-starting venture for the Darrieus rotor and the low aerodynamic overall performance of the Savonius rotor.

Table 7.3 The Modification of VAWT

Type	Modification	Model	Benefit	Drawback
	Conventional (Menet & Rezende, 2013)		Low starting torque; Low angular velocity,	Drag device; Low efficiency
	Conventional with curtain (Altan & Atilgan, 2010)		Increasing power coefficient	Fixed wind direction; Drag device; Low efficiency
	Without shaft (Kamoji et al., 2009)		Higher maximum power coefficient	Negative torque coefficient; Drag device; Low efficiency
Savonius VAWT	Elliptical blade (Sanusi et al., 2016)		Higher maximum power coefficient	Drop-in performance in the use of endplates linking shaft
	Double wind tunnels (Promdee & Photong, 2016)		Higher voltage	Limited wind angle range
	Multiple stages with twisted blade (Saha et al., 2008)		A higher power coefficient compares to two blades	Consume More material
Darrieus VAWT	Three straight-bladed Darrieus rotors with upper and lower surface connectors (Raciti Castelli et al., 2011)		Exceed Betz limit 3 times during one rotor revolution.	Lower average power coefficient

Type	Modification	Model	Benefit	Drawback
	Straight-bladed Darrieus rotor with upstream deflector. (Stout et al., 2017)		Higher maximum power coefficient	Specific wind direction; Specific deflector angle
	Three V-shape blade Darrieus rotor (Su et al., 2020)		higher maximum power coefficient	energy loss on the blade tip region
	Darrieus Phi rotor (eggbeater/curved rotor) (Islam et al., 2013)		Cost-effective	Rotor height limitation; Uneven wind velocity on the rotor blades
	Cross axis helical Darrieus rotor (Muzammil et al., 2017)		Collect wind energy from horizontal and vertical Directions. Suitable for low wind speed areas	Not suitable for high wind speed areas. Suitable for small-scale wind turbines
	Helical twist Darrieus rotor (Patel & Sapariya, 2017)		Lower noise	Lower max. power coefficient

Type	Modification	Model	Benefit	Drawback
	Straight blade Darrieus with wing tip devices (Mishra et al., 2020)		Aerodynamic efficiency; Decrease the induced drag.	Trailing vortices weaker; increase the total drag.
	J-shaped straight Darrieus (Zamani et al., 2016)		Improves self-starting ability; Less turbulence and noise.	Change the optimum TSR
	Darrieus Phi rotor (Hilewit et al., 2019)		Higher max power coefficient; Higher TSR range Lesser cost	Reduce blade wake interactions
Hybrid Savonius - Daerrius	Two-bladed Savonius with three-bladed straight Darrieus (Nemati, 2020)		Low TSR; It can function at low wind speed.	Complex geometry.
	Two-bladed Savonius with three-bladed helical Darrieus (Pallotta et al., 2020)		Less starting speed; Self-starting	Lower energy produced compared to Darrieus rotor

Type	Modification	Model	Benefit	Drawback
	Double stages two-bladed Savonius with egg beater Darrieus (Wakui et al., 2005)		Self-starting.	Lower output power compares to the Darrieus rotor
	Double stages two-bladed Savonius with two, three, and four-bladed straight bladed Darrieus (Ahmedov, 2016)		Better efficiency; Self-starting.	Lower power coefficient
	Three-bladed Savonius and thirteen-bladed Darius (Belmili et al., 2017)		Self-starting; Better performance compared to Darrieus rotor	Complex geometry; Costly
	Combined Bach-type and H Darrieus rotor (Hosseini & Goudarzi, 2019)		Self-starting	Complex model and higher cost

2. Optimization in Wind Power Generation

a. Optimization Algorithm

Wind Farm Layout Optimization (WFLO) usually refers to placing a wind turbine (WT) inside a particular area to maximize or minimize the objective function while meeting various constraints and considerations. However, the optimization process in WFLO is not an easy task due to the complexity of the problem, so it cannot be solved by using classical analytical optimization techniques. Researchers have developed many optimization methods to solve the problem, including heuristic, meta-heuristic, and other evolutionary algorithms—the primary method described in Table 7.4.

Table 7.4 Optimization Method Algorithm

Algorithm	Reference
Genetic Algorithm (GA)	Abdulrahman & Wood (2017); Emami & Noghreh (2010); Gao et al., (2020); Grady et al., (2005); Parada et al., (2017); L. Wang et al., (2015)
Greedy Algorithm	Chen et al., (2016); Ozturk & Norman, (2004); Chen et al., (2013); Changshui et al., (2011)
Particle Swarm Optimization (PSO)	Asaah et al., (2021); Chowdhury et al., (2013); Pso et al., (2021); Wang, S. M. G., (2014)
Ant Colony Algorithm (ACO)	Eroĝlu & Seçkiner, (2012)
Random Search Algorithm (RS)	Feng & Shen, (2015)
Evolutionary algorithm (EA)	(Gonzalez et al., 2010; Kusiak & Song, 2010; Li et al., 2017; Mora et al., 2007; Pso et al., 2021; Y. Wang et al., 2018)

b. Objective Function

Several objective functions can be defined in WFLO programming, some works of literature use a single objective, and others use multi-objective. The most widely used metrics are the wind farm Annual Energy Production (AEP), the instantaneous power conversion, and the Cost of Energy (CoE).

Power Conversion and Annual Energy Production

Four metrics equivalents to the AEP and the instantaneous power conversion were found in the literature, such as (1) the wind speed reaching each WT in the wind farm (to be maximized); (2) the wind speed deficit at each WT (to be minimized); (3) the wind farm capacity factor (to be maximized); and (4) the wind farm efficiency (to be maximized), defined as the ratio of the wind farm power conversion to the ideal wind farm power conversion (if no wake and turbulence effects are taken into account).

AEP can be modeled as cited from Lackner & Elkinton, 2007; Manwell & Mcgowan, 2014:

$$AEP = 8766 \sum_{m=1}^{N} \int_{0}^{360} \int_{0}^{U_{max}} \left[\frac{1}{2}\rho A U^3 C_p(U,\rho)\right] p_\theta(\theta,m) \left[\left(\frac{k(\theta,m)}{c_{eff(\theta,m)}}\right)\left(\frac{U}{c_{eff}(\theta,m)}\right)^{k(\theta,m)-1} e^{-\left(\frac{U}{c_{eff}(\theta,m)}\right)^{k(\theta,m)}}\right] dU\, d\theta \tag{7.1}$$

Cost of energy (CoE) and Levelized Cost of Energy (LCoE)

The cost of the energy (CoE) wind farm is the cost divided by the total power production, as shown in Eq. 7.2:

$$CoE = \frac{Cost}{AEP} \tag{7.2}$$

The wind turbine cost is a function of the number of wind turbines that can be modeled in Eq. 7.3 (Mosetti et al., 1994)

$$Cost = N_{wt}\left(\frac{2}{3} + \frac{1}{3}e^{-0.00174 N_{wt}^{2}}\right) \tag{7.3}$$

Two equivalent definitions to the CoE that were identified in the literature are (1) the Levelized Cost of Energy (LCoE) and (2) the Levelized Production Costs (LPC). In addition, different definitions of Financial Balance (FB) (or economic profits) were identified in the literature. The main difference between FB models resides in which costs are considered. Some works did not implement any performance metric, as their objective was to treat a specific issue of the WFLO problem (e.g., review assignments, derivation of mathematical approximations, etc.). LPC can be formulated as:

$$LPC = \frac{C_{INV}}{a\,E_a} + \frac{C_{O\&M}}{E_a} \quad (7.4)$$

$$E_a = A_f \left[\sum_{i=1}^{N} \left(E_{WT,i} - E_{Loss,wake,i} - E_{Loss,col,i} \right) - E_{Loss,trans} \right] \quad (7.5)$$

Sales Revenue, Profit, and Financial Balance (FB)

The formula is given as cited from Réthoré et al. (2014):

$$FB = WB - C_D - C_{O\&M} - (C_F + C_G)\left(1 + \frac{r_c - r_i}{n_L}\right)^{T(n_L)} \quad (7.6)$$

Where Wp is the sales revenue of the expected electrical energy conversion over the wind farm operational lifetime, C_D is the accumulated cost of components degradation, $C_{O\&M}$ is the cost of overall operation and maintenance, C_F and C_G represent variable investment costs of foundations and electrical infrastructure, r_c [%] is the interest rate, r_i [%] is the inflation rate, n_L is the number of times interests of loans have to be paid in a year, and T is the wind farm expected operational time in years

Net Present Value (NPV)

The Net Present Value (NPV) is a widely used financial metric in discounted cash flow analysis. It is a standard method implementing the idea of the time value of money to appraise long-term projects, such as wind farms. The NPV is similar in definition to the FB. It is the sum of present values of individual cash flows over finite periods

Formulation of NPV can be given as cited from Gonz & Pay (2012):

$$NPV = \sum_{k=1}^{T} \frac{N_K}{(1 + r_i)^k} - C_{INV} + V_R \quad (7.7)$$

Where N_k represents the net income (or profit, which is the value of the energy sales revenue minus all variable costs such as O&M costs) produced by the wind farm during the *k*th year, r_i represents the equivalent discount rate or interest rate [%], which is an indicator of the opportunity cost of capital goods (e.g., the higher the discount rate, the lower the present value of the future cash flows), C_{INV} represents all the current capital investments during the expected operational lifetime. V_R represents any present residual income/outcome after the project's lifetime.

E. Wind Farm Design Variables and Constraints

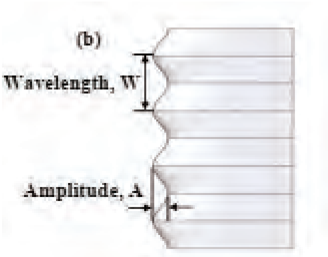
The WFLO problem aims at defining the best value of the following set of variables: (1) WTs emplacement locations; (2) WTs type (e.g., the technology including the control/operation strategy); (3) WTs size (e.g., capacity); (4) number of WTs; (5) WTs hub heights; (6) type of tower, sub-structure, and foundation; and (7) type, size and capacity of auxiliary infrastructure (e.g., auxiliary roads, power collection systems (i.e., transformer number/type/size/capacity and other electric devices), electrical interconnection layout and capacity (i.e., power lines type and length), repeater stations, etc.).

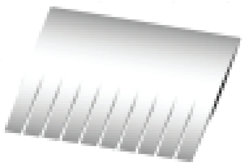
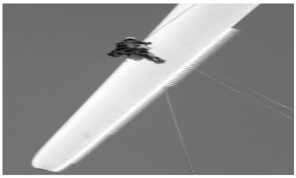
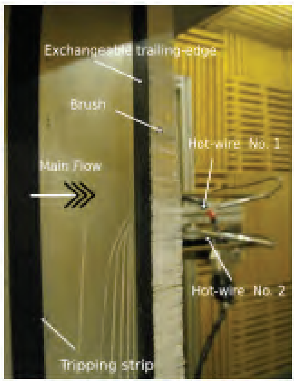
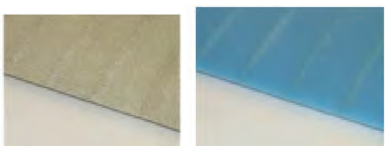
All variables are naturally bounded and constrained by physical factors: (1) the WTs emplacement locations are bounded by the considered wind farm site area and constrained by local terrain aspects, and environmental and climatological characteristics (e.g., land use, restricted areas, geotechnical capacity, setback constraints, obstacles, etc.); (2) the available technology constrains the WTs type; (3) the size and (4) the number of WTs are constrained by the actual power system capacity and the expected demand from the energy consumers. In addition, the theoretical maximum number of WTs can be coarsely calculated as the ratio of the wind farm site area to the individual WT area of $\pi R2$, assuming that two or more WTs cannot be located within an area of $\pi R2$; otherwise, blade collisions would occur. In practice, the maximum number of WTs is much lower due to geometrical and geographical constraints; (5) the minimum and maximum WT heights are constrained by the rotor radius (R), the national aviation regulations, and the available technology, respectively; (6) the type of foundation is a function of the water depth (in the case of offshore wind farms), the bearing capacity of the terrain, the expected loading and the available technology; and (7) the auxiliary infrastructure design, often considered an embedded optimization problem, is constrained by all described variables and the current electric, civil engineering, and communication system capacity.

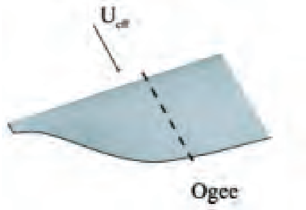
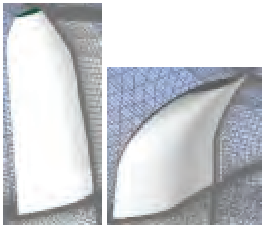
F. Noise Reduction

Noise is the next problem of wind power generation that should be tackled. Numerous experimental and numerical techniques have been developed for noise mitigation by using the knowledge of the noise mechanisms, which offer a perception of the aero-acoustic characteristics of wind turbines. Some techniques and related research that can be implemented to reduce the noise is shown in Table 7.5

Table 7.5 Noise Reduction Techniques for Wind Turbines

Technique	Method	Design
Reduction of influx turbulence noise	Used a sinusoidal leading edge to reduce tonal noise components (Hansen et al., 2010)	
	Bio-inspired leading-edge serrations based on adaptations of the barn owl (Chaitanya et al., 2016)	

Technique	Method	Design
	Sinusoidal leading edge based on adaptations of the barn owl (Chaitanya et al., 2016)	
	Leading-edge slits over serrations for the reduction of aerofoil interaction noise (Paruchuri et al., 2018)	
Reduction of trailing part noise	With trailing edge serration (Oerlemans et al., 2009)	
	Trailing edge brushes over serration (Finez et al., 2010)	
	Porous trailing edge (Geyer et al., 2010)	

Technique	Method	Design
Reduction of tip noise	Ogee type tip shape using acoustic analogy (Geyer et al., 2010)	
	Reference tip and shark tip (Maizi et al., 2018)	

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Chapter 8

Biomass Energy

Matthew Hardhi

A. Overview of Biomass Energy

Biomass energy is one of Indonesia's forefront options of renewable energy. Unlike fossil fuels, the net CO_2 emission of bioenergy use is close to 0 as, theoretically, the released CO_2 can be reabsorbed during the biomass growth stage. This condition makes bioenergy a very lucrative source of efficiently utilized renewable energy. On top of this, Indonesia is blessed with large forested areas, allowing differing options for optimizing biomass production capacity to produce biomass-based energy. In this chapter, we will look at the definition of biomass energy, how it is utilized, available sources, and its suitability as one of Indonesia's pillars of renewable energy to reach the target energy mix in 2045.

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Hardhi, M. (2022). Biomass energy. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (133–158). BRIN Publishing. DOI: 10.55981/brin.562.c8 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

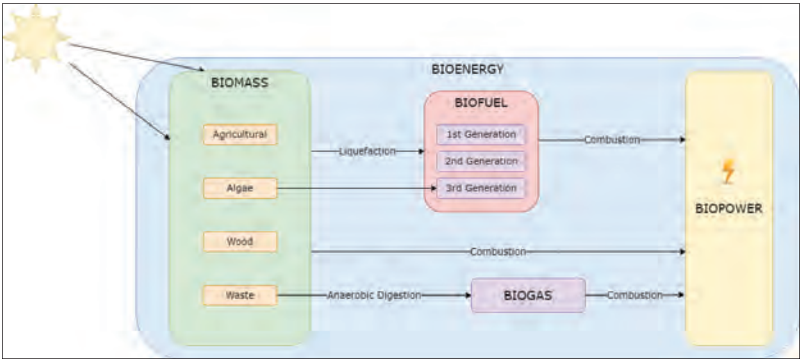
B. Definitions

The terms biomass, bioenergy, biopower, and biofuel are frequently used when describing this particular form of energy. Biomass is defined as living or dead biological material and its by-products, in the form of solid organic matter, which can be burned to provide heat, electricity, or both (*Are Biofuels Sustainable? First Report of Session 2007-08*, 2008; Bajpai, 2020). Biomass components may include lignin, celluloses, hemicelluloses, lipids, proteins, starches, water, ashes, and other compounds.

Therefore, bioenergy is the renewable gas, liquid, or solid energy product derived from biomass (Dahiya, 2020; Nyoman & Kumara, 2020). It falls into renewable energy because biomass absorbs the sun's power in its growth, converting CO_2 into carbohydrates through photosynthesis and storing them as chemical energy. Historically, civilizations had heavily relied on biomass to provide them with energy, usually for heating by burning wood. Today, it is the largest source of renewable energy use, accounting for 70% of the total world renewable energy supply and 10% of the total primary energy supply in 2017 (International Renewable Energy Agency, 2020).

Biofuels are liquid fuels mainly produced from food and fodder crops. This type of fuel is classified as the first generation of biofuels and can be differentiated into biodiesel or bioethanol. Biodiesel is made from oils of palm fruits and rapeseed, while bioethanol is produced from the fermentation of feedstocks containing high sugar or starch content. Wheat, barley, sugarcane, and maize are the common feedstocks used in bioethanol production.

Biopower is the electricity generated from biomass combustion (Dahiya, 2020), either the sole fuel or combusted with coal, natural gas, or other fuels. This joint combustion is termed co-firing. Biopower plants use biomass feedstocks as fuel for the boiler, which is burned to heat, passing water into steam, rotating the turbine, and producing electricity. The steam produced can also be directly used for process heating in industries. A graphical representation of how all these terminologies interact can be seen in Figure 8.1.



Source: Author documentation (2021)

Figure 8.1 Definitions of Biomass Energy-Related Terminologies

Bioenergy has several advantages compared to traditional fossil fuel usage. Firstly, biomass burning to produce energy does not release harmful gases such as sulfur dioxide or lead oxide (Bajpai, 2020). Burning biomass merely releases the CO_2 absorbed by the biomass in its growth to the environment. As long as the amount of CO_2 released as a fuel matches the amount absorbed during its development, it is carbon neutral. For further measures, bioenergy can be used in tandem with Carbon Capture and Storage (CCS) to create a net harmful emission of CO_2. In contrast, burning fossil fuel releases the CO_2 absorbed a long time ago back into the environment, contributing to the greenhouse effect.

Secondly, the utilization of biomass fits within the circular economy scheme. Bioenergy is just one form of biomass that also supplies humans with various uses such as food, feed, fiber, fertilizer, and so on (International Renewable Energy Agency, 2020). Production and processes of this biomass lead to wastes and residues. These wastes are usually disposed of due to not having any economic value. These wastes can be used as a potential bioenergy source, allowing to extract all of the potential energy contained within the wastes, reducing the number of wastes released. An example of this would be methane emission from the wastes, which could be refined into biomethane through anaerobic digestion or syngas through gasification (Ardolino & Arena, 2019).

Biomass energy offers the option to decarbonize many sectors. For example, biofuel can be used as an alternative to fossil fuel in the transport sector. Bioenergy can power the district heating systems in housing and building sectors instead of traditional coal boilers. In some industry sectors, biomass may replace fossil-based feedstocks (International Renewable Energy Agency, 2020).

C. Feedstocks

Once biomass has been processed through heating, microbial activities, chemicals, or any combinations of these processes, it will be termed "bioenergy feedstock." Biomass needs to be converted to feedstock as aside from direct combustion. Biomass cannot be directly converted to electricity. Biomass has a relatively low value in bulk density (weight per volume) (McKendry, 2002). This means for the same amount of volume, biomass has a relatively low energy value than other energy sources. Thus, we need to process more volumes of biomass to obtain the same amount of energy as the traditional energy source, like fossil fuel. Still, more logistics are also required to transport the biomass, which translates to higher costs.

Therefore, it is necessary to convert raw biomass into logistically feasible forms to transport. There are three processing steps: aggregation, densification, and palletization. Aggregation gathers up harvested biomass into easily handled units (such as bales). Densification is the process of increasing the feedstock's density through pressure and other means to create a condensed feedstock. Finally, palletization is the densification of feedstock into pellets. All of these are standard methods of increasing the energy density of biomass.

D. Generation of Biofuels

Biofuels can be classified as primary or secondary biofuels based on production. Primary biofuels are obtained from biomass in their natural forms (wood pellets, firewood, wood chips), while secondary biofuels are obtained after biomass processing. These secondary biofuels can be classified into first, second, or third-generation biofuels. First-generation biofuels are obtained from fermenting edible feedstocks (crops high in sugar content) to produce mostly bioethanol or biobutanol. Since they are obtained from edible food crops, the production of first-generation biofuels directly competes with increasing food demand in many parts of the world.

Second-generation biofuels are obtained from mostly inedible biomass through thermochemical and biochemical processes. Bioethanol and biobutanol are synthesized from non-food, lignocellulosic biomass. Since the main source of biomass is not food crops, second-generation biomass suffers no competition from increasing food demands. Lastly, third-generation biofuels are sourced from aquatic biomass. Commonly used biomass includes microalgae, seaweed, or other microorganisms to synthesize biodiesel and bioethanol. The advantage of this biofuel generation is low land usage, the high lipid content of the biomass, and high atmospheric CO_2 uptake. This means they have more potential to become a carbon-neutral energy source.

In the future, we might obtain biofuels from the fourth-generation biomass, sourced from genetic modification of third-generation biomass. However, this type of biofuel is still in the research and developmental phase. Table 8.1 lists a detailed explanation and description of the various generations of secondary biofuels, bioethanol.

Table 8.1 Generations of Bioethanol

Generation	Source	Examples	Processing Methods
1	Crops with high sugar and starch content	Corn sugarcane, Molasses, and Tapiocas	a. Direct fermentation with microorganisms (generally with the yeast Saccharomyces cerevisiae) into ethanol (7–10%) b. Distillation (up to 96%) The theoretical yield is 0.51 kg ethanol.kg glucose.
2	Cellulose	Bagasse, EFB, Corn pulp, and Rice husks	a. Simultaneous saccharification and fermentation (SSF) b. Batch/Fed-batch c. Separate hydrolysis and fermentation (SHF) d. Consolidated bioprocessing (GST)
3	a. Microalgae Rapid growth, Requires relatively smaller production area b. Bacteria Rapid growth, The metabolic pathway can be genetically engineered	Potential Microalgae Species: *Chlorella vulgaris* *Spirulina maxima* *Botryococcus* sp. *Chlamydomonas* sp.	a. Harvesting (flocculation + centrifugation) b. Extraction (homogenization + hexane solvent) c. Biodiesel production with transesterification

Source: Amrullah & Hambali (2021)

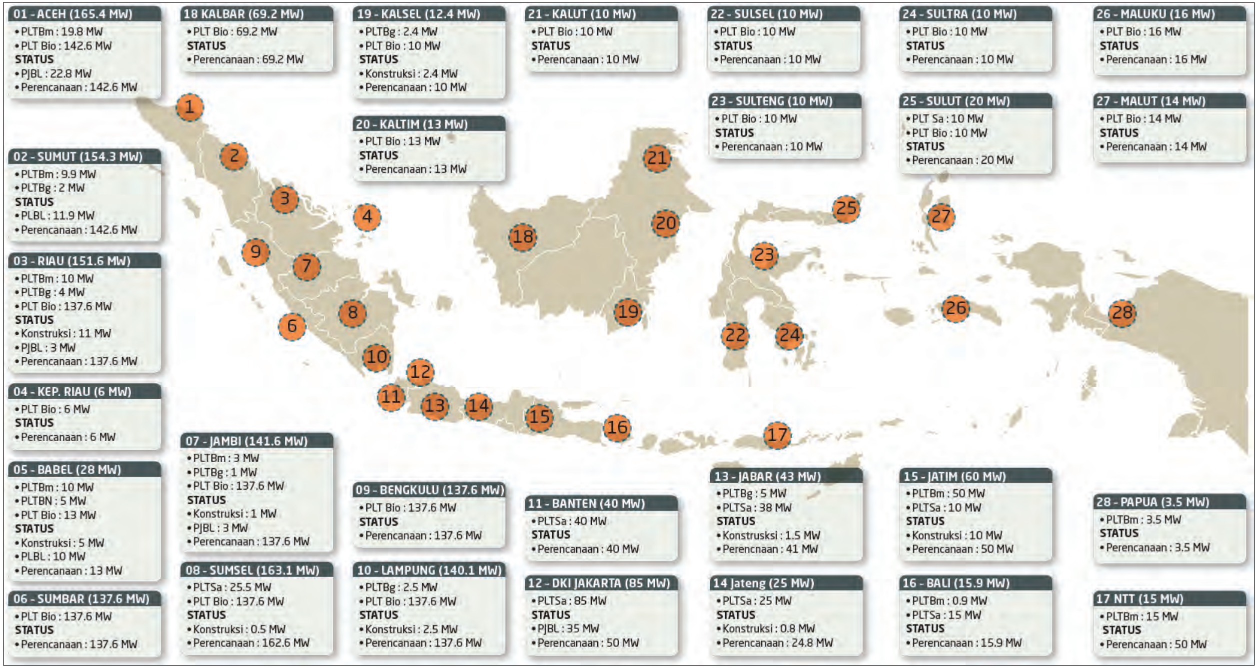
E. Current Conditions in Indonesia

According to the latest National Energy General Plan (RUEN) (Presidential Regulation No. 22/2017), Indonesia plans to achieve a 31% energy mix from New and Renewable Energy (NRE) in 2050. Just last year, the National Development Planning Agency (Bappenas) plans to achieve a 70% NRE mix in 2050 to meet the goal of a carbon-neutral Indonesia in 2060, where 100% of energy resources are projected to come from NRE (CNN Indonesia, 2021). In contrast, the NRE mix reached only 11.2% of the total energy mix in 2020. Naturally, concerns were raised due to several challenges that complicate the implementation of such directives in Indonesia. As follows:

1. Shortage of available land for production of NRE;
2. Relatively high investment costs in NRE still deter investments in the sector;
3. Government subsidy makes fossil fuels cost cheaper, hence slowing the transition to NRE;
4. Lack of knowledge and research in NRE technology, as well as lack of human resources;
5. High-interest rate from the banking sector for NRE investments due to high risk associated;
6. Intermittent energy supply from NRE power plants demands an efficient energy storage facility.

However, despite these facts, numerous efforts have been made to integrate more biomass sources into the total energy mix. The Ministry of Energy and Mineral Resources' 2020–2024 Strategic Plan (Ministry of Energy and Mineral Resources, 2021a) had set several directives as follows:

1. Develop bioenergy power plants with a total capacity of 1,295 MW in the five years between 2020 and 2024, utilizing crude palm oils (CPO) (Figure 8.2).
2. Implement co-firing method in existing coal-based steam power plants, where the co-firing feedstocks would come from garbage pellets, wood pellets, and wood chips (Figure 8.3).
3. Develop small-scale biomass power plants (with a capacity ranging from 20–200 kW) to be distributed strategically. Biomass wastes used as fuel include palm fibers, rice husks, and sugarcane bagasse.
4. Develop bio-based Compressed Natural Gas (CNG) utilizing >95% purity biogas consisting of methane (CH_4) to replace fossil-based natural gas.
5. Develop the market for waste-to-energy power plants.
6. Implement the B30 program to increase biofuel mixture in diesel fuel (30% instead of the previous 20%) to reduce imports.



Source: Ministry of Energy and Mineral Resources (2021a)

Abbreviations are as follows: PLTBm-biomass power plant, PLT Bio-bioenergy power plant, PLTBg-biogas power plant, PLTSa-waste-to-energy power plant, PLTBn-biofuel power plant

Figure 8.2 Bioenergy Power Plants Projects Based on National Electricity Supply Business Plan (RUPTL) for 2019–2025

Source: Ministry of Energy and Mineral Resources (2021b)
Co-firing is predicted to contribute as much as 18 GW to steam power plants in 2024.

Figure 8.3 Steam power plants implementing co-firing method commercially with 1–5% biomass portion.

Indonesia comprises 188.20 million hectares of land area with various soil and climate types in terms of land use. Agricultural farming of different kinds of valuable plant commodities is possible, including bioenergy plants such as palm oil, sugarcane, cassava, and others. According to Hambali et al. (2016), around 76.40 million hectares are suitable for growing these valuable crops, which gives plenty of potential for biomass utilization. However, efficient biomass utilization requires the maintenance of a stable feedstock supply.

An established supply chain of biomass feedstock can be selected by having local governments construct roads in rural areas. Currently, farm roads exist within biomass plantation areas for in-plant transportation needs. However, they are seldom connected to district arterial roads. Connected routes will allow easier transport of biomass feedstock into a centralized refinery location (Zhou et al., 2020). Both national and local governments must work on logistics laws to build better road infrastructures. These will assist in reducing the cost of biomass production, in which transportation and pre-processing can make up to 43% of the total production cost (Labriet, 2013).

F. Biomass and Indonesia

Due to being an archipelago with many scattered, isolated islands, perfectly distributed energy access is difficult due to technical issues related to electrical transmission and distribution (Haryana, 2018). As such, small islands in remote areas need to be equipped with the capacity to self-produce and supply their energy demands. As fossil fuel reserves are not available to most islands, biomass energy becomes a suitable source of energy resources. It is relatively simpler to process (combustion is sufficient) and is located near the equator; the year-long solar irradiation allows the year-long cultivation of biomass sources.

Therefore, as biomass sources are accessible even to households and small-scale farms, it is an important energy resource for Indonesia. One accessible option for biomass utilization is processing the biomass of agricultural residues, either wood waste or crop waste (herbaceous, fruit, etc.) (Brunerová et al., 2018). Currently, this waste biomass utilization in developing countries is relatively low, representing an untapped sector that could be developed further to fill the total energy demand (Brunerová et al., 2017).

As such, utilizing biomass as an energy source is an attractive proposition, especially considering the potential to reach a net-zero emission from its utilization, as long as the amount of carbon absorbed equals or is less than the amount emitted from its usage. While crop residues are large and have a significant energy potential, many residues must be left on-site to protect soil productivity and prevent erosion (Scarlat et al., 2010), ranging between 15–60% for most crops. However, the remaining amount still leaves a potential for further processing and use.

1. As with other Southeast Asian countries, Indonesia is one of the top producers of agricultural commodities. These commodities include rice, sugar, cane, palm oil, coconut, and rubber, with the most promising residues for biomass energy being rice husk, sugarcane bagasse, oil palm residue, and wood residues. Cur-

rently, applicable technologies to extract this energy source are direct combustion/biomass co-firing: direct heat and electricity production (Tun et al., 2019).

2. Anaerobic digestion: For animal wastes to produce biogas (methane/CH_4).
3. Pyrolysis: For bio-charcoal, gas, and oil production.
4. Gasification: For agricultural waste and woody residues (sawdust, wood chips, etc.)

The following table (Table 8.2) represents the total potential of biomass energy in Indonesia as of 2019.

Based on this data, there are ten total types of biomass sources in Indonesia, with palm oil dominating the potential for energy production. According to Nyoman & Kumara (2020), the meat and kernel of palm fruits can be converted to biodiesel oil, while their shells can be used as fuel in co-firing coal power plants (PLTU). We could extract methane from livestock waste, landfill garbage, and palm oil mill effluent to power biogas plants (Figure 8.5).

Until 2019, the total installed capacity of bioenergy power plants amounts to 1,890 MW (Ministry of Energy and Mineral Resources, 2021a). The estimated total potential for biomass in Indonesia is around 32 GW (Figure 8.4). Therefore, the gap between actual capacity and estimated potential can still be utilized to increase Indonesia's NRE energy mix.

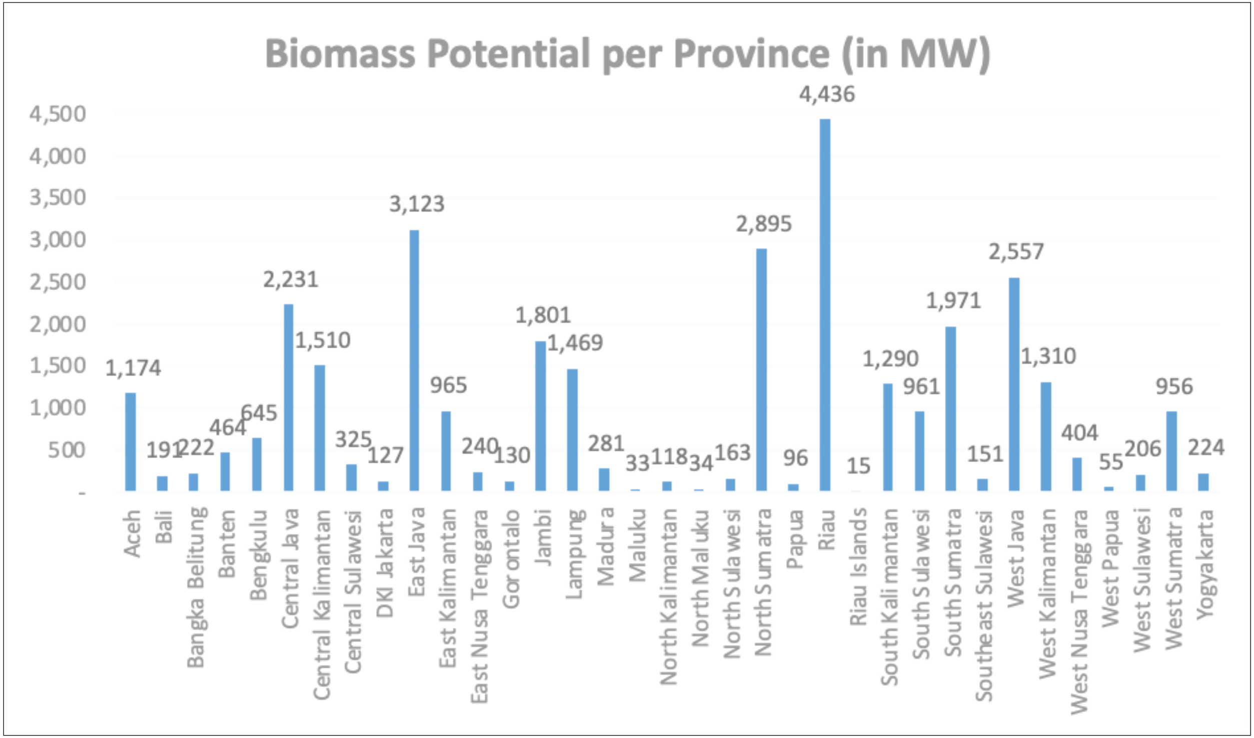
The rest of the biomass types, namely sugarcane bagasse, non-producing rubber tree trunks, coconut shells and fibers, rice husks, corn cobs, and cassava stems, can be converted into biofuel power plants. In general, as long as the waste biomass is plenty, possesses good sugar content, and comes from easy-to-grow crops (Amrullah & Hambali, 2021), it can be a potential source of biofuel production.

Table 8.2 Potential of Biomass Energy in Indonesia

Province	Energy Potential (in MW)										
	Palm Oil	Sugar Cane	Rubber Wood	Coconut	Rice Husk	Corn	Cassava	Wood	Livestock	Garbage	Total by Province
Aceh	646	-	233	3	240	13	1	-	17	21	1,174
Bali	-	-	-	4	131	10	1	-	23	22	191
Bangka Belitung	214	-	-	-	3	-	-	-	-	5	222
Banten	41	-	-	3	297	3	1	-	2	117	464
Bengkulu	434	-	108	-	79	11	1	-	4	8	645
Central Java	-	138	-	10	1,431	262	39	3	70	278	2,231
Central Kalimantan	1,234	-	140	4	99	1	2	18	2	10	1,510
Central Sulawesi	117	-	-	11	158	18	1	1	8	11	325
DKI Jakarta	-	-	-	-	1	-	-	-	-	126	127
East Java	-	630	-	11	1,476	460	35	4	140	367	3,123
East Kalimantan	837	-	43	1	58	2	1	5	3	15	965
East Nusa Tenggara	-	-	-	3	90	64	17	18	28	20	240
Gorontalo	-	20	-	3	42	54	-	-	7	4	130
Jambi	840	-	687	6	96	4	1	148	4	15	1,801
Lampung	179	326	114	6	448	217	89	6	27	57	1,469
Madura	-	-	-	3	120	90	5	-	32	31	281
Maluku	-	-	-	4	13	2	1	3	3	7	33
North Kalimantan	118	-	-	-	-	-	-	-	-	-	118
North Maluku	-	-	-	14	9	2	1	1	2	5	34
North Sulawesi	-	-	-	15	88	45	1	-	4	10	163

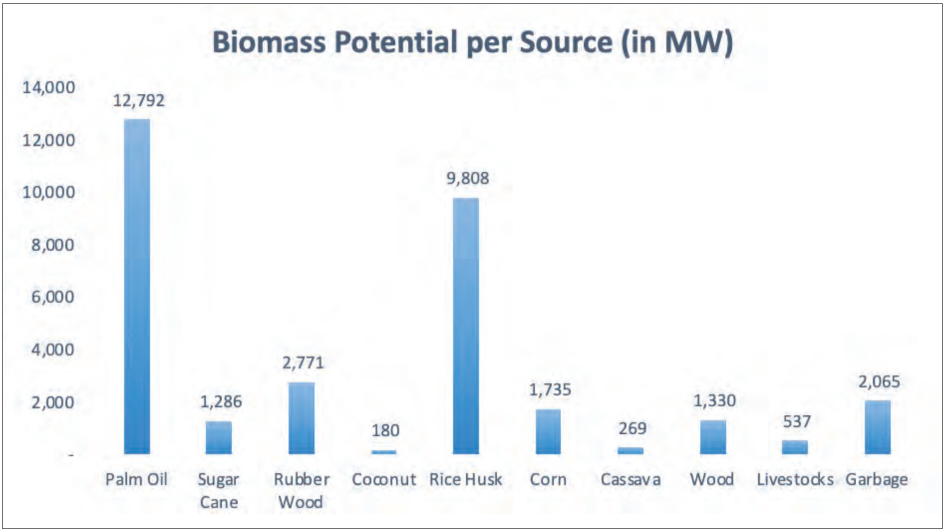
Province	Energy Potential (in MW)										
	Palm Oil	Sugar Cane	Rubber Wood	Coconut	Rice Husk	Corn	Cassava	Wood	Livestock	Garbage	Total by Province
North Sumatra	1,927	30	220	5	472	111	11	4	16	99	2,895
Papua	42	-	-	13	16	1	1	9	2	12	96
Riau	2,888	-	430	24	88	5	1	962	6	32	4,436
Riau Islands	10	-	-	1	-	-	-	-	1	3	15
South Kalimantan	574	-	386	2	281	9	1	13	5	19	1,290
South Sulawesi	25	22	-	5	696	119	7	18	36	33	961
South Sumatra	1,187	43	70	3	492	10	4	91	9	62	1,971
Southeast Sulawesi	47	-	-	2	69	11	3	1	8	10	151
West Java	22	62	-	6	1,772	90	28	4	15	558	2,557
West Kalimantan	758	-	285	4	205	19	3	7	6	23	1,310
West Nusa Tenggara	-	-	-	3	315	31	1	1	25	28	404
West Papua	33	-	-	1	4	-	-	12	3	2	55
West Sulawesi	134	-	-	2	56	5	1	-	3	5	206
West Sumatra	485	-	55	5	337	36	2	1	12	23	956
Yogyakarta	-	15	-	3	126	30	9	-	14	27	224
Total by Type	12,792	1,286	2,771	180	9,808	1,735	269	1,330	537	2,065	Total Potential: 32,773

Source: Nyoman & Kumara (2020)



Source: Nyoman & Kumara (2020)

Figure 8.4 Biomass Potential per Province



Source: Nyoman & Kumara (2020)

Figure 8.5 Biomass Potential per Type

As of 2019, the provinces of Riau, East Java, and North Sumatra ranked top three for potential biomass energy production. This is because Riau province possesses many palm oil plantations, contributing to a potential of 2,888 MW production. In East Java province, widespread rice farming contributes to the prospect of 1,476 MW out of 3,123 MW total potential. Lastly, for North Sumatra province, 1,927 MW out of 2,895 MW can be attributed to palm plantations. Palm oil and rice husk dominate Indonesia's potential energy production resource.

A very productive crop, the palm can produce oil seven times higher than rapeseeds and eleven times higher than soybean (per hectare) (Hambali & Rivai, 2017). Fresh fruit bunches (FFB) are harvested and converted into crude palm oil (CPO), producing an abundant amount of waste such as empty fruit bunches (EFB), mesocarp fiber (MF), palm kernel shell (PKS), palm kernel meal (PKM), and palm oil mills effluent (POME). The amount of waste is significant as palm oil plantations can be found in 65% of the provinces in Indonesia and, therefore, are a substantial source of biomass.

POME, for example, can be used as a feedstock for biogas production. The remaining liquid waste from this activity can still be used as a fertilizer and medium for microalgae growth as it is still rich in nutrients. Both mesocarp fiber (MF) and palm kernel shell (PKS) can still be utilized as boiler fuel to produce process heat in the palm oil mill, while PKS can also be processed as bio-pellets to be used as fuel. Empty fruit bunches (EFB) and tree trunks can be utilized as mulching material to help maintain soil humidity, inhibit weed growth, compost raw material, and be a source of fiber for various composite products. These qualities make the utilization of palm oil wastes an interesting proposition.

G. Suitable Biofuels for Indonesia

Simply under volume alone, as represented by the data in the previous section, rice husks and palm oil are seemingly the prime candidates for valorization into biomass energy sources. Rice husk can either be fermented into bioethanol or converted to solid biofuels, while palm oil wastes can be converted into solid or gaseous biofuel. POME can be treated before being discharged into the environment to produce biogas. Palm waste's mesocarp fiber (MF) and palm kernel shell (PKS) can be converted to solid biofuel.

Based on current challenges facing NRE implementation in Indonesia, the source of biofuels must meet several criteria for successful implementation, which can be seen in Table 8.3 below.

Table 8.3 Author's Concerns and Implications Toward Types of Biofuels

Concerns	Implications
Shortage of available land	It must be sourced from abundant sources without requiring extra land clearance.
High investment costs deter investors	Biofuel production processes selected must be relatively cheap.

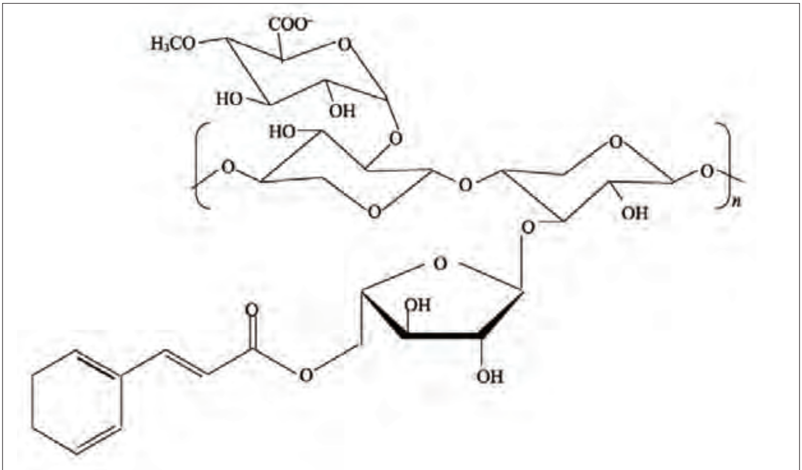
Concerns	Implications
Government subsidy on fossil fuels	The biofuel selected must be common and well-known to ease the transition from fossil fuel subsidy to NRE subsidy. A well-known biofuel type among the public will help ease implementation and integration.
Lack of research and human resources	Biofuel production processes must be kept simple. The processes must not require too high of an expert to run and rely on too specialized technology.
High-interest rate from finance sectors for high-risk technology	Technology for biofuel production must already be on commercial-scale. It must also already be established for a long time.
Intermittent energy supply requires an efficient energy storage facility	The biofuel must always be readily produced without delay.

H. Rice Husks

Rice husk is the main biomass by-product of rice harvesting, amounting to almost 20% of the total cereal production in the rice industry (Cacua et al., 2018). It has a low density at around 122 kg/m^3. Currently, rice husks possess close to zero economic value and are often thrown away post-rice harvesting. Rice husks waste contributes to a significant part of total biomass waste generated from rice cultivation. Moreover, rice husk contains low nutrients yet a high level of silica. Thus, it is not suitable to be processed as fodder. Instead, it is commonly used to produce porous sorbents, concrete with rice husk ashes, solid fuel, and feedstock in biofuel production (Nanda et al., 2020). Unlike corn grains- (starch) or sugarcane- (sucrose) based bioethanol (first-generation), rice husk is inedible, lignocellulosic biomass. It is not used as a food source and thus does not compete with the increasing demand for food in many parts of the world (Madu & Agboola, 2018).

However, Brunerová et al. (2017) and Bakker (2000) found that rice husks possess significant ash content (19–21%), alkali, and potassium which cause agglomeration fouling and melting in the components of boilers during combustion. High ash level is also reflected in the low calorific value of rice husks at around 14–16 MJ/kg. A high ash content leads to clogging in combustion device grates due to the presence of bottom ash, obstructing the pathway for combustion air (Malaťák & Passian, 2011).

Furthermore, its components (cellulose and hemicellulose) are hard to ferment/degrade biologically into ethanol. Proper pre-treatment methods and enzyme selections for the saccharification and fermentation steps are required to convert bioethanol from rice husk efficiently. The reason for this is that rice husks contain a combination of cellulose (28.6–41.5 wt%), hemicellulose (14–28.6 wt%), and lignin (20.4–41.5 wt%) (Nanda et al., 2020). Together, they form a stable 3-dimensional structure known as lignocellulose in the cell walls, making the individual monomers difficult to separate (Figure 8.6). The stability of these structures impedes access of cellulolytic enzymes to hydrolyze cellulose, the carbon source that will be fermented to ethanol by yeast. Therefore, the lignocellulose needed to be delignified by pre-treatment processes that available in various ways, including physical, physicochemical, chemical, and biological pretreatment.



Source: Goodman (2020)

Figure 8.6 3D Representation of Hemicellulose Linking to Cellulose and Lignin

Pre-treatment of biomass is usually done to alter its physical and chemical properties to aid in processing and transport. Preliminary pre-treatment steps usually taken include size reduction, leaching (washing), compaction (agglomeration), briquetting, and palletization (Nanda et al., 2020). They increase the low density of untreated rice husks complicating the transportation and subsequent biomass utilization.

Altering the chemical properties of the rice husks, i.e., the lignocellulosic structure, requires physical, physicochemical, chemical, or biological pre-treatment methods. All the pre-treatment processes have their specific advantages and disadvantages. Chemical pre-treatment is very accessible as no specialized equipment is required in the process, and the chemicals used are usually acid, alkali, sulfur dioxide, ammonia vapors, and lime (Nanda et al., 2020). Alkali-based treatments are the most effective because they break the ester bonds between lignin, hemicellulose, and cellulose (Goodman, 2020). However, chemical-based pre-treatment is relatively more expensive. Biologically based pre-treatment is often slower, while environmentally pre-treatment tends to be inefficient. All these pre-treatment processes have been extensively studied and can be applied commercially.

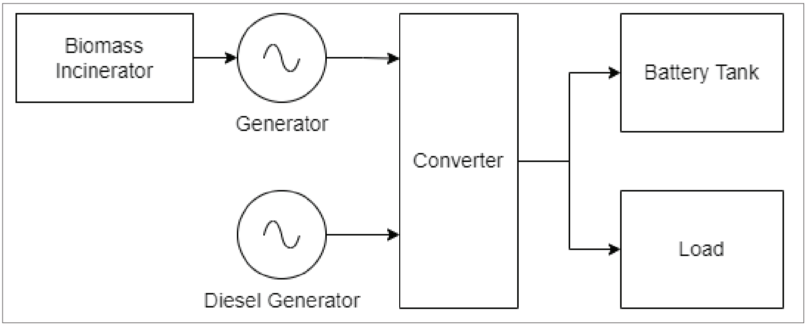
I. Re-evaluation of Investment and Subsidy Priority

As stated in previous sections, one of the major hurdles in utilizing the maximum potential of Indonesia's biomass energy resources lies in the lack of interest in the financial and economic sectors. Skepticism from investors, banks, and entrepreneurs toward renewable energy projects contributes to the relative lack of interest in transitioning to NRE. While regrettable, these concerns are valid due to the government's lack of incentives and push towards funding NRE projects. Currently, the Government is occupied with recovering economy hits by the pandemic. The amount the government plans to subsidize towards fossil-based energy rises to 134 trillion Rupiah in 2022, compared to 128.5 trillion Rupiah in 2021 (Ridwan, 2021). This huge number of investments can be partitioned to boost incentives towards NRE utilization, for example, by subsidizing biofuel prices in the market to become more competitive than fossil-based fuels.

However, the issue related to government subsidy is more than just a reluctance towards transitioning towards NRE. The 134 trillion Rupiah subsidy planned for 2022, for example, comprises a 77.5 trillion-rupiah subsidy towards LPG (3-kg) and fuel oil prices. These subsidies are meant to alleviate the rise in oil prices, impact the economy due to the pandemic, fluctuations of the currency exchange rate, and improve the livelihood of many people. All layers of society use fuel oils for various economic activities, and thus, disruption towards the price would impact heavily, thus explaining the need for subsidy for fuel oil. The same applies to LPG (3kg); they are a typical household and economic goods used by most societies. These include households, small-and-medium businesses, and street vendors. The subsidy is warranted to ensure that people's livelihood tied to this goods is not affected, which will impact the economy in various ways (increased LPG price would increase the price of goods too, reducing incentives of doing economic activities).

Therefore, subsidy allocation is sensitive and requires prudent planning from many sectors and stakeholders. Looking from a pure energy or environmental viewpoint would be tantamount to folly. However, considering only the welfare of the general society without feeling the burden the subsidy puts on the State Budget is also unwise. As of 2022, state spending exceeds state income by 868 trillion Rupiah, or about 4.5% of the GDP of Indonesia (Tim Kementerian Keuangan, 2022). To bring the deficit below 3% of the GDP in 2023, there is a limit on subsidies that can be allocated from the state budget.

An interesting point would be to discuss the remaining fraction of the 2022 energy subsidy, in which a 56.47 trillion-rupiah subsidy has been allocated towards assisting electricity costs. As of June 2021, out of 73.341 MW installed power plant capacity in Indonesia, coal-based steam power plant still dominates electricity production at 47% of total installed capacity (Indrawan, 2021). This implies at least half of the total investments are allocated to lowering the cost of electricity produced from coal power plants. Suppose this amount is instead redirected towards reducing the electricity price from NRE sources. In that case, this will help keep the electricity price affordable to the general public, while increasing the incentives for investments in NRE-based power plants. While the burden on the state budget may stay similar, the overall carbon emission would be reduced due to relying on carbon-neutral/carbon-negative NRE to produce electricity.



Source: Jena (n.d.)

Figure 8.7 Direct Biomass Combustion-Diesel Hybrid Power Generation System

A lucrative investment option would be small-scale power generation in rural communities situated in Indonesia's archipelago's remote, scattered part. Utilizing the cheap yet abundant agricultural wastes commonly produced on rural farms, biomass-based power plants can be alternative to diesel power generators widely used in remote areas. The biomass can be processed into electricity through direct combustion, gasification, or anaerobic digestion. All are well-known commercially mature technologies. A micro-gas turbine will be coupled with a generator to produce the required electricity. From the environmental side, the utilization of agricultural residues does not heavily affect the food supply in the region and can contribute to a net-zero CO_2 emission. The biomass generator system could even be coupled with a diesel generator to form a biomass-diesel hybrid system. When the electricity demand rises during peak load times, diesel generators could be activated to meet the extra demand from residents.

The main advantage of this setup of a hybrid system is the reduction in the Levelized Cost Of Electricity (LCOE) production from biomass resources. LCOE represents the average revenue per unit of electricity generated required to recover the building costs and operate a generating plant during an assumed financial life and duty cycle. The higher the LCOE, the higher the price required to produce said electricity. A techno-economic study regarding biomass-diesel hybrid system implementations was done by Dejucos et al. (2019) on thirteen off-grid islands in the Philippines. This study is fascinating as the area they surveyed was more or less similar to the numerous remote islands not connected to the electricity grid. They found that the LCOE of such a hybrid system can achieve an average reduction of 4.57%. Up to 25% reduction is possible in the case of low energy demand and high biomass availability and a moderate decrease in diesel fuel consumption of 5%. The LCOE of the hybrid system is lower than a purely diesel-based power generation system, implying the cost of producing electricity with an integrated biomass utilization is cheaper. With a high biomass availability in the individual islands due to farming activities and low energy demand due to low population density and lack of energy-intensive infrastructures, this hybrid system can be the solution for powering remote areas in Indonesia.

Aside from the reduction in LCOE, there are at least four non-technical advantages to implementing said systems. Firstly, we avoid connecting every island to the national electricity grid by producing locally on each remote island. This represents a major saving in costs. Secondly, implementing such systems gives extra stimulus to the local economy. By providing a value for the wastes produced from farming activities, we can increase the total income made by the locals by paying them a price to deliver their agricultural biomass for electricity production use. Thirdly, local electricity production alleviates locals' need to rely entirely on the national electricity grid. A localized electricity production means an uninterrupted supply of electricity as all the electricity produced by the plant, assuming sufficient generation capacity, is only used for the localized area. Excess electricity usually sent to the grid can be stored in storage systems (batteries) used in emergencies. Lastly, directly related to the reduced LCOE of the hybrid system, electricity prices would go lower, thus ensuring that electricity is available for all parts of the population, improving their life quality. By building numerous energy-independent remote areas, we could reduce the state budget required to subsidize electricity use in these areas and thus alleviate the economic burden caused by energy subsidy.

The last point of discussion would be to benchmark the current investment climate abroad toward green funding projects. Looking at France as one of the forerunners among EU countries toward a net carbon emission, there are at least three central institutions related to climate commitments in the French financial sectors: banks, insurers, and asset management companies. All banks and insurers, with the majority of asset managers, have adopted a thermal coal exit date in 2030 for OECD countries and 2040 for the rest of the world. In addition, an increasing number of participants are now excluding the financing of companies developing new coal projects. In contrast, for oil and gas projects, the financial actors are still reluctant to complete the phase-out from oil and gas financing (ACPR & AMF, 2021). While improvement in commitments is still warranted from these financial actors, some entities like La Banque Postale, one of the prominent banks in France, have decided to stop financing oil and gas projects by 2030. Another major bank, Société Générale, has also signed an agreement with the European Investment Bank for a collective risk-sharing and funding participation for a total of EUR 240 million dedicated to supporting renewable energy projects. Such agreement is an example of financial institutions' commitments toward energy transition.

Taking note of the above example, it is natural that Indonesia's financial sectors need goodwill to follow suit with their actions. To support the commitment toward clean and renewable energy transition, it is imperative to concentrate investments, loans, and projects in the NRE sector, leaving behind a portfolio of fossil-based energy. While a radical change is warranted, progress can be made in small steps. This change includes improving the attitude against NRE projects, from one that is purely economical and cost/benefit concentrated to a more holistic approach. That is to say, to have a future for everyone, it is dire to switch to NRE as soon as possible, and that means looking beyond mere investment returns.

In closing this chapter, it is also essential to consider the need for talented human resources and researchers to fully integrate biomass energy into the national energy mix. Fresh graduates, professionals, and academic researchers all contribute to successfully implementing a feasibility study, all the way into the commercial application of biomass energy. When we all work together, united under a common cause of alleviating climate change, we can achieve our goal of sustainable clean energy accessible to all Indonesians. Therefore, academic lecturers need to ensure that young students and fresh graduates are aware of the urgency of climate change. Without haste, there will be no incentive for action.

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Chapter 9

Geothermal Energy in Indonesia

Ghibran Fahreza Dipayana & Rahmat Agung Ramadhan

A. Overview of Geothermal Energy in Indonesia

Many countries have committed to decreasing fossil energy consumption and transforming their energy mix into cleaner and more sustainable energy. This means that the use of renewable energy is going to rise significantly. Indonesia has signed and joined other countries in Paris Agreement. However, some questions remain. The most common question can be the type of renewable energy suitable for Indonesia's geological and geographical conditions. Arguably, the answer to that question is geothermal energy. Geothermal is classified as renewable energy because no emissions are released during production. Geothermal energy is derived from the flow of the Earth's internal thermal energy to the surface, which includes

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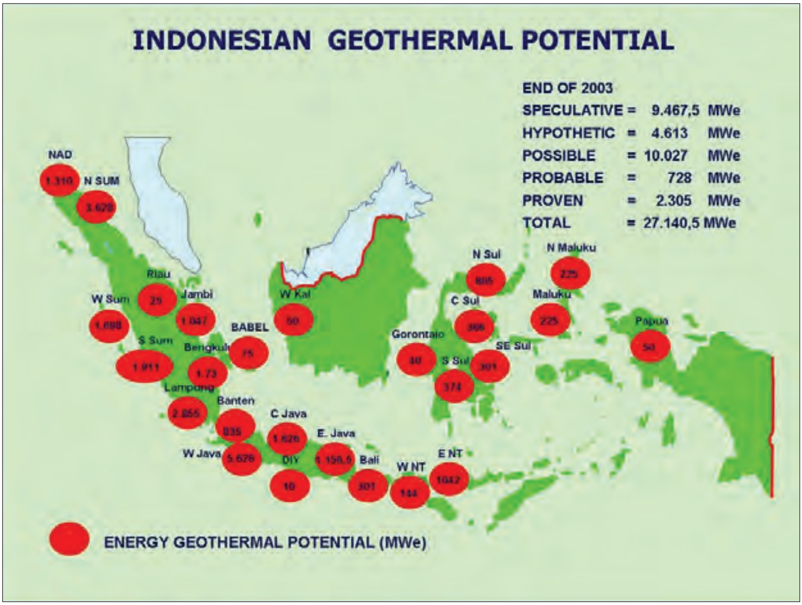
Dipayana, G. F. & Ramadhan, R. A. (2022). Geothermal energy in Indonesia. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (159–180). BRIN Publishing.
DOI: 10.55981/brin.562.c9 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

thermal energy from the original formation of the planet and the heat-producing radioactive decay of elements in the Earth's mantle and crust (Berrizbeitia, 2014). Indonesia is located among three active tectonic plates, leading to Indonesia's strategic position as one of the wealthiest countries in geothermal energy. To produce heat below the surface, Indonesia needs to build a production well and integrate it with other infrastructures such as steam gathering facilities. Finally, the subsurface heat can be easily transferred to the surface with a fracture system.

From a geological point of view, Indonesia has 76 historically active volcanoes, making Indonesia one of the countries with the most significant number of active volcanoes (Volcano Discovery, 2022). The data also shows that the heat flow of geothermal energy in some regions of Indonesia to the surface is up to 100% greater than the average heat flow at the surface at around 120 milliwatts per square meter compared to the usual value of 60 milliwatts per square meter (Southeast Asia Research Group/SEARG, 2002). This potential provides excellent conditions for developing geothermal energy. Indonesia is listed as one of the wealthiest countries in geothermal energy. Almost 40% of geothermal resources are in Indonesia, according to mapping done by several institutions. These resources and geothermal reserves can be one solution, among others, to eliminate fossil energy as a baseload as it is estimated equal to 219 million BEO and can generate almost 27.00 GW of electricity (Suharmanto et al., 2015). The Minister of Energy and Mineral Resources of the Republic of Indonesia has published data on geothermal sites in Indonesia, with almost 80% of geothermal sites in Indonesia located in isolated active volcanic systems such as Sumatra (81 locations), Java (71 locations), Bali and Nusa Tenggara (27 locations), Maluku (15 locations), and North Sulawesi (7 locations). There are also some regions with active non-volcanic environment: Sulawesi (43 locations), Bangka Belitung (3 locations), Kalimantan (3 locations), and Papua (2 locations). The total composition of the geothermal potential of 252 locations in

Indonesia is 27,357 MW, which is consisted of 14,007 MW of resources with 13,350 MW of reserves (Wahyuningsih, 2004).

Indonesia has made a long history of developing the geothermal industry. The first main project was built and started at Kamojang, West Java, in 1983 (Radja, 1995). Pertamina and PLN, the state-owned electricity company, have constructed 140 MW of steam gathering facilities and power plants. The first private contracts were signed in 1982–1984. Afterward, several companies also signed contracts on joint operations with Pertamina for ten contract areas between 1994 and 1997. As a result of these contracts, geothermal energy generated an additional 480 MW in regions such as Salak (220 MW), Wayang Windu (110 MW), Darajat (90 MW), and Dieng (60 MW) in Java. Pertamina also developed other geothermal working areas in Indonesia at Sibayak (2 MW) in North Sumatra and Lahendong (20 MW) in North Sulawesi (Fauzi et al., 2005).



Source: Suharmanto et al. (2015)

Figure 9.1 Indonesia Geothermal Potential

Geothermal possesses many advantages compared to other fossil energy sources; an example can be found in the reliability of electric power generated from geothermal energy that can be sustained as a long base (more than 30 years). In general, the capacity factor of geothermal power plants may reach 90% per year if we look at the examples of PLTP Kamojang (93% capacity factor), Tiger Puppet (94% capacity factor), and Darajat (93% capacity factor). So, geothermal energy can be used as a baseload in electricity systems at a higher capacity than other energy sources, especially since geothermal energy is available steadily throughout the year. The productivity of geothermal resources is relatively unaffected by climate change, making it different from renewable energy sources such as wind or solar and the annual hydropower season. Another advantage of geothermal energy is that it does not require large tracts of land.

The use of geothermal energy can reduce our dependency on fossil fuels significantly. To illustrate the comparison of geothermal to other powers, 1 kWh generated electricity assumption requires 0.28 liter of fuel, or 1 MWh requires 280 liters or approximately 2 barrels.

B. Drilling

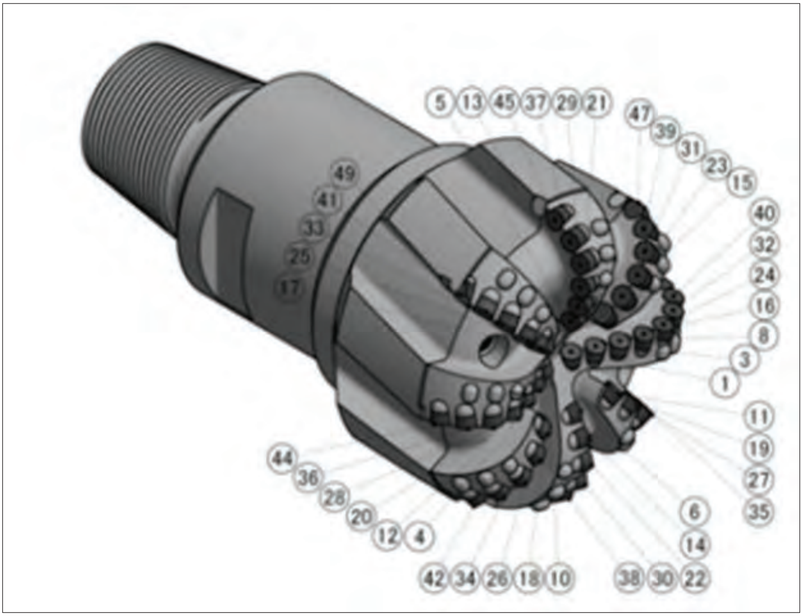
The first step in developing geothermal resources is exploration activities. This activity aims to confirm the size of reserves below the surface or in a reservoir. One of the most critical activities is exploration drilling. Many data have shown that exploration drilling costs almost 40% of the total investment in the project or capital expenditure of a company for a new high-temperature geothermal project (Kipsang, 2013). The data from historical drilling costs show that the depth of the well is the main reason and parameter explaining its overall cost. It is calculated that 56% of the investment costs of geothermal wells are linked to depth (Cedric, 2010). The data also shows that many factors must be considered during drilling operations, such as the well configuration and duration. Almost all geothermal sites are located in deep and ultra-deep wells; the deeper the target we want to reach, the more problems we may face. These problems are ultra-high temperature, high pressure, high sulfur, multiple pressure systems, poor drillability, and impurities contents, making it more difficult to reach the target and bringing more challenges to the exploration stage (Wu et al., 2020). There are a few challenges regarding drilling and completion engineering of exploration. They are (1) high-temperature instrumentation and seals; (2) Geothermal logging instruments and tools must be modified regarding the high temperature in geothermal wells; (3) Due to high temperature, thermal expansion is possible, affecting the buckling and collapse of the casing; (4) The property of drilling fluids and mud coolers. Mud coolers are one of the most important parts during drilling operations; they can prevent bad things such as high mud temperature; (5) The loss circulation of geothermal. This phenomenon happens in geothermal and oil and gas; the reason is similar due to faults associated with the zones.

There are two fundamental physical requirements for producing geothermal power from the subsurface. These are high geothermal heat flow and high permeability of the geothermal fluid for its migration to the surface (Raymond et al., 2012). The basic principles of a drilling operation in the geothermal industry are the same as oil and gas. However, there are differences in some aspects. Almost all geothermal fields consist of complex layers or hard abrasive rocks such as granites and volcanic or metamorphic rocks. However, some geothermal reservoirs consist of soft layers or rocks such as sedimentary or carbonate rocks.

Consequently, a drilling bit degrades shortly due to large loads and impacts in such severe geological conditions. A high-performance drilling bit commonly has a high drilling speed and high durability (Miyazaki et al., 2019). There is a project on geothermal drilling wells that tested two off-the-shelf polycrystalline diamond compact (PDC) bits in a geothermal drilling project in the Chocolate Mountains of Southern California. It is reported that the PDC bits exhibited higher drilling speeds and longer lifetimes than those expected with roller-cone bits (Raymond et al., 2012). Another experiment tried to evaluate the effects of the cutter geometry, material composition, and processing conditions of PDC drag cutters on the drilling efficiency, abrasion, and impact performance in hard rocks. There are many reasons to explain the failure of the drill bit to drill the geothermal formation, but the main reason is the cutters of the drill bit are challenging to face the complex abrasive rock formation. The forces on the drill bit are unevenly distributed during drilling, leading to poor working stability and abnormal vibration (Wise et al., 2005). To increase the PDC bit stability and cutter density, selecting cutter types is essential to improve the wear resistance of drill bits.

Japan Oil, Gas, and Metals National Corporation (JOGMEC)has focused on drilling techniques and established a research and development project on the PDC bit with both high drilling efficiency (speed) and long drill length (durability) in 2015 (Imaizumi et al., 2019). In the project, they studied the manufacturing technique of PDC cutters and have succeeded in developing ones with high wear resistance and impact toughness. The process of manufacturing PDC cutters has been accomplished by sintering diamond powder on a cemented carbide substrate with cobalt as a binder by applying high pressure and high temperature (HPHT) to the component**.** The cutters have been developed by using coarse diamond grains to increase impact toughness and abrasion resistance using fine diamond. They have used PDC bits with eight blades to place as many PDC cutters as possible on the bit to face hard abrasive rocks with heterogeneous geological fractures and to reduce the load (reaction force) on individual PDC cutters. It was confirmed that the reaction forces were ever-increasing outward from the bit center, but those on the adjacent cutters were almost equal.

Cost is another thing that needs to be considered by the engineer during drilling operations on geothermal wells. The associated costs in Turkey are the cheapest amongst the costs of wells in Australia, France, Germany, Iceland, Kenya, Netherlands, and the United States (Gul & Aslanoglu, 2018). There are many reasons why Turkey is listed as one of the countries with the lowest cost for drilling geothermal wells. First, they have successfully reduced the daily operating costs of rigs and third-party services since Turkey's labor costs are more affordable



Source: Imaizumi et al. (n.d.)

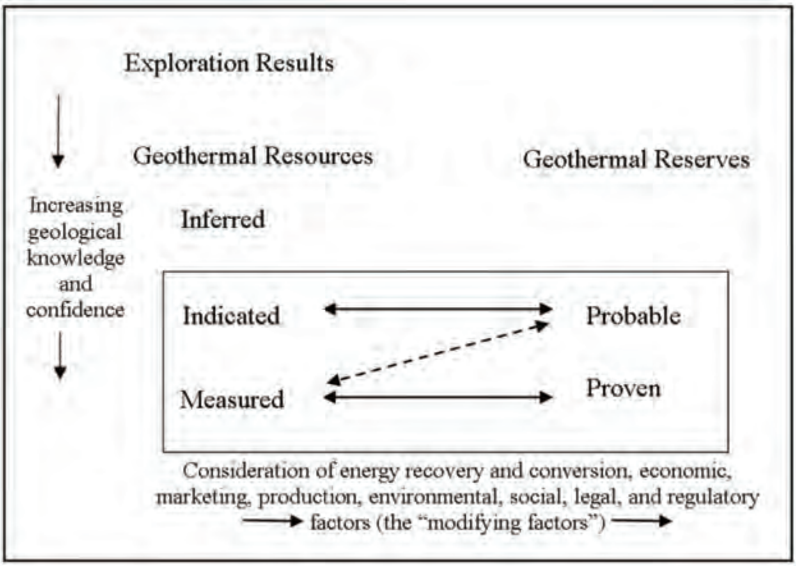
Figure 9.2 D CAD Modeling for 8-1/2" PDC bit

than other countries. Second, the most critical equipment of the wells, the casings, are chosen from the lowest cost option. Third, Turkey has more competence and experience in drilling activities, resulting in a competitive market producing better-optimized wells with shorter project lead time (Gul & Aslanoglu, 2018). From data published by Baker Huges, as of January 2017, almost 40% of total drilling rigs in the world are used in Turkey for geothermal well drilling. Turkey is also the leader in the drilling activity, with 32 of 98 drilling activities in Europe located in the country (Huges, 2017). The geothermal gradient in Turkey ranges between 8.33°C/100 m to 11.10°C/100 m in thermally active regions (Njolnbi, 2015). Therefore, Indonesia may copy Turkey's strategy to operate geothermal wells by reducing daily drilling costs since the associated costs have affected the total project investment or capital expenditure. It also can be concluded that Turkey is currently a market leader in geothermal drilling activities, thanks to a very low-cost operating strategy.

C. Technical Data

The Australian code has been used in many countries and has gained international acceptance. This code includes three key principles: transparency, materiality, and competency. These three principles are important as a guide for determining the success of the geothermal project. Exploration practitioners in Indonesia need to adopt the Geothermal Play Fairway Analysis method. The United States Department of Energy developed this method to decrease uncertainty during geothermal exploration activities. The method evaluates a range of geological, technical, and socioeconomic factors, which are subsequently integrated to narrow a basin or regional-scale area down to smaller areas of interest for further study and prospecting (Garchar et al., 2016). There are many differences between Indonesian and Australian codes. The Australian codes explain and consider not only the technical aspects (geosciences or engineering), but also socioeconomic aspects related to marketing, legal, regulatory factors, and environmental. While it may be questioned whether the Australian/ Canadian codes are applicable to Indonesia, the fact remains that they have been employed in three geothermal feasibility studies at Lumut Balai, Ulubelu, and Tompaso (Adams et al., 2011). To conclude, there are lacks in quantity and quality of data provided by the Indonesian government that needs to improve.

Indonesia needs to make a database that can be accessed by companies participating in regular tender conducted by the Government. Indonesia can also implement an open-data policy in geothermal exploration, which has been instigated in Indonesia's oil and gas industry with membership schemes for providing more accessible data and developers also can analyze not only in one basin but also regional. A further principle in the code is the demarcation of a reserve instead of the resource, considering commercial viability. A 'Geothermal Resource' is a Geothermal Play that exists in such a form, quality and quantity that there are reasonable prospects for eventual economic extraction (Williams et al., 2010). A 'Geothermal Reserve' is that portion of an Indicated or Measured Geothermal Resource which is deemed economically recoverable after considering both the Geothermal Resource parameters and Modifying Factors (Williams et al., 2010) The classification between these two terminologies' reserves and resources is important because it provides explicit understanding. The Indonesian standard codes also use resources classification called '*Cadangan Terduga*'. This word usually is meant as Contingent Reserves. However, the criteria do not include well testing and drilling wells. Reserves are used as the highest classification of petroleum and mineral exploration. For comparison, the Australian code enters well deliverability as one of the obligations to declare "reserves" and also different sources such as Joint Ore Reserves Committee Mineral code require an economic analysis such as bankable feasibility study to declare "Reserves.". The Geothermal Reporting Code recognizes three levels of Geothermal Resource (Inferred, Indicated, and Measured) based upon increasing levels of geological knowledge and confidence (Williams et al., 2010)



Source: Williams et al. (2010)

Figure 9.3 Relationship between Exploration Results, Geothermal Resources, and Geothermal Reserves

In addition, many entities have won bids with insufficient technical and financial capacity (Asian Development Bank, 2015). There are many alleged deficiencies, including a lack of technical ability of the tender committee (resulting in poor prequalification screening), tiny bid bonds, and performance bond requirements that are not imposed (Asian Development Bank, 2015). There is a requirement for posting their bid bond based on their total investment project rather than just their exploration budget for first-year and no less than US$ 10 million. The bid bond also should reflect the company's work and program funding (WP&B), and can be converted into a performance bond as evidence of exploration activities or drilling. The tender process should also follow the best international practice for more investments from domestic and multinational companies. There are no possibilities to reach the target the Government has made on geothermal without the participation of international or foreign developers and practitioners in the geothermal industry.

Some specific issues with the current version of the Indonesian standard are as follows (Asian Development Bank, 2015):

1. The Indonesian standard uses an anumerical simulation process, but there is no guidance on how that simulation can be used to determine the capacity of the resources.
2. Many investors and developers use a probabilistic approach or estimates. This method is used for determining stored heat estimation. However, in the Indonesian standard reporting code, there are no explanations regarding this method without considering this method. Indonesia is in a position by the recommendation that World Bank has given.
3. The Indonesian standard permits using the volumetric method (stored heat) and numerical simulation to estimate reserves and resources, which is appropriate. For stored heat, the 2000 revision of the standard lists preferred or defaulted single values (within broad reservoir temperature bands) for various parameters such as recovery and conversion factors at diverse resource and reserve categories and does allow the use of other values. It does not guide how those values should be selected. In contrast, for example, the Australian code lexicon provides default values.

D. Policy

1. Analysis of Geothermal Policy in Indonesia

Geothermal developments in Indonesia have fluctuated due to legal uncertainty for entrepreneurs, accompanied by an economic crisis impacted by COVID-19 and others that affect the commercial aspect, thereby increasing the risk of investing. Other factors related to geothermal power development include capital intensive, risk of security in the country, the floating Rupiah payment system, low basic electricity tariff, low public purchasing power, fiscal policy, consistent contract sanity, and strict sanctions. From these parameters, we still find things that have not been realized in the field or irregularities that often occur.

Indonesia has several policies in managing geothermal resources from 1974 to 2009 until finally, the Indonesian government in 2003 issued the first law that provided a robust legal basis for the development of geothermal energy, which is the issuance of Law Number 27 of 2003 and its derivative rules. Law Number 27 of 2003 is a regulation that regulates all geothermal exploitation activities. This law states that the flow of geothermal exploitation in Indonesia consists of five stages: a preliminary survey, exploration activities, feasibility studies, exploitation activities, and optimal geothermal utilization.

Law Number 27 of 2003 states that local governments have full authority regarding licensing and geothermal legislation. With this authority, local governments can create and provide quality human resources in geothermal processing, from technical to administrative capabilities. This authority can significantly impact local communities where their abilities are increasing. These qualified human resources aim to present accurate and detailed data and information related to the potential of geothermal energy in their area to developers who can facilitate the research process by themselves. This can affect the price quote for geothermal steam or electricity and plans for future geothermal energy projects.

The Indonesian Government has issued many policies related to geothermal energy. However, in the field, we still find some problems. Problems that usually arise are the quality of the human resources of the regional auction committee, which is not yet competent enough. There are many cases where the existing workers cannot handle this job. Resolving the problem requires an increase in the competence of human resources. This increase can be in education, training, or certification activities from related parties. The role of the Government and educational institutions is vital to creating quality human resources.

The next problem is the overlapping boundaries of the allocated geothermal working area. Most of the geothermal working areas are in conservation forests. This issue has been the subject of much debate. The Government responded to this issue by issuing PP (Government Regulation) Number 28 of 2011, which explains that geothermal is an environmental service business so that geothermal activities can be carried out in conservation forests. In implementing this regulation, it is necessary to coordinate with several parties, such as the Ministry of Energy and Mineral Resources with the Ministry of Forestry and other parties involved, so that it will not produce big questions about the placement of the geothermal working area.

Furthermore, recently there have been many permits for geothermal energy development, from the inventory of geothermal working areas to the commercial. The geothermal business licensing process takes a long time; for exploration, it takes about 2 to 3 years; for exploitation activities up to commercial, it takes 3 to 5 years. So, the total time required is about 5 to 7 years from initial inventory to operation. With this problem, to shorten the time required, regulations are needed regarding the certainty of licensing times from the relevant ministries and the Government so that many developers are interested in developing the existing geothermal potential.

Lastly is the problem of inter-sectoral coordination, which is still constrained. A more detailed and precise clarity of authority is needed between the central government, provincial governments, and local governments related to geothermal development. Articles 5, 6, and 7 of Law Number 27 of 2003 have stated the authority regulation, but it is not detailed and can cause confusion. The problem in the field is the emergence of disorder about which party is responsible for solving a problem. Therefore, more detailed and clearer derivative regulations from existing regulations are needed.

2. Geothermal Policy Analysis in the United States, New Zealand, and the Philippines

The trend of developing clean, renewable energy is hotly discussed worldwide. One of the renewable clean energies that can be produced at any time regardless of time and has excellent potential is geothermal energy. In some countries, this potential is utilized as much as possible to create clean and sustainable energy. The efforts carried out by governments in the world vary widely from financial support, technology transfer between countries, training related to geothermal processing and utilization, and geological surveys supported by the Government. The trend of geothermal development, which is constantly increasing drastically, has made countries serious about utilizing it, such as the efforts made to form policies and regulations regarding the use of geothermal energy.

Table 9.1 Top 10 Countries Developing Geothermal Capacity in 2021

Rank	Country	Installed Capacity (MW)
1	United States	3,722
2	Indonesia	2,276
3	Philippines	1,918
4	Turkey	1,710
5	New Zealand	1,037
6	Mexico	963
7	Italy	944
8	Kenya	861
9	Iceland	754
10	Japan	603

Source: Pristiandaru, D.L. (2020)

Countries in the world included in the global top 10 in developing geothermal energy and have high innovation related to geothermal processing are the United States, New Zealand, and the Philippines. In this part, we will discuss the existing policies in those three countries that can be compared with those policies in Indonesia.

a. Geothermal Policy in the United States

The United States has the most installed capacity of geothermal energy globally. The amount of installed capacity of geothermal energy is high, so the United States has a detailed policy stated in the legislation. The United States government has two of the most important laws that govern the authorization and guide the Department of Energy (DOE) in managing and conducting geothermal energy research. The two laws are the Energy Independence and Security Act of 2007 and the Geothermal Energy Research, Development, and Demonstration Act of 1976, which contain regulations for geothermal exploitation such as on mineral lands and mining, project management, loan guarantees, until the protection against environment on geothermal energy management.

In addition to these two crucial laws, other policies are applied in the United States in the management of geothermal energy, such as tax incentive policies, geothermal energy research, development policies, financial incentive policies, and geothermal energy policies regarding leasing and resource management laws.

Geothermal Energy Association (GEA), an association of US companies engaged in geothermal energy, which supports the development of geothermal energy and geothermal energy resources around the world to generate electricity from geothermal energy, issued several priority policies to support geothermal energy development in 2012.

The first policy is to provide tax incentives for a longer term to support geothermal energy development and industrial stability. The second is to facilitate the permission and construction of the transmission capacity needed to support geothermal energy development. Third, minimizing delays in geothermal energy contract permits that has been a challenge in geothermal energy development. Fourth, the policy is aimed to issue new national regulations to support the exploration, quantification, and development of geothermal energy projects. Lastly, it supports energy policies for developing geothermal energy through the clean energy base standard mechanism set by the Government. The sixth policy is to help GEA member companies to collaborate to create geothermal energy and increase their contribution to the global market.

b. Geothermal Policy in New Zealand

Geothermal utilization is proliferating in New Zealand, as evidenced by the increasing number of geothermal installed capacities in this country. With the expanding number of geothermal plants, the New Zealand government has a policy to regulate geothermal exploitation. The first policy made by the New Zealand government to control geothermal energy was The Geothermal Energy Act of 1953. Still, it was replaced through the regulation of The Resource Management Act (RMA), 1991. RMA 1991 integrated environmental management regulations into one statute for managing natural and physical resources, including air, water, land, geothermal, minerals, and coastal area resources up to 12 nautical miles. The purpose of establishing the RMA 1991 is to promote the sustainable management of natural and physical resources. RMA 1991 applies rules and governance to exercise control over resource use by delegating decisions and planning and resource management policies to the regional council until the new district council in New Zealand. RMA 1991 explains that geothermal management is further integrated into control and water permits, which are an inseparable part of development planning and regional policies within an integrated development framework. If the regional council cannot yet manage geothermal energy, the central government can assist in geothermal management (Hollroyd & Dagg, 2011). To facilitate the central government in managing geothermal resources following the scale, capacity, and designation for national energy development, the regional council that cannot yet manage geothermal resources must make plans to divide geothermal potential into five categories. It includes the geothermal can be developed, limited development, research, protection, and small geothermal systems.

Other policies governing the exploitation and management of geothermal energy in New Zealand are the Building Act (BA) 1994, which regulates building work, establishes a licensing regime for building practitioners, and sets building performance standards. The following policy is the Electricity Industry Reform Act (EIRA) 1998, which was implemented in the renewal of the New Zealand national electricity policy. The electricity supply is hoped to be managed efficiently process to provide outstanding long-term benefits for consumers (IEA, 2011). The last is Regional Policy Statements and Plans (RPSP), which is a regional council policy instrument under RMA 1991 that explains regional resource management and basic guidelines for environmental management in each region (EMSL, 2011).

c. Geothermal Policy in the Philippines

The Philippines, the third largest country that uses geothermal energy in the world, has regulated the management of renewable energy, especially geothermal energy. The first policy is the Geothermal Service Contract Law, Presidential Decree 1442, issued in 1978, regarding the control and regulation of exploration, development, and utilization of geothermal energy. The second policy is Executive Order 215, published in 1990, which effectively eliminates the NPC monopoly system and allows private sector participation in the construction, ownership, and operation of geothermal power plants. The third policy is the 2008 renewable energy law, which benefits developers, including a 7-year tax holiday, a tax-free carbon credit program, and a standard for meeting domestic electricity needs of 60%. The fourth policy is An Act to Promote the Exploration and Development of Geothermal Resources 1978 regarding incentives. The fifth policy is the Resource Management Act 1991 regarding managing resources such as land, air, and water for sustainable use.

From the Philippines' existing policies in attracting geothermal development, the Philippine government provides an example to the world, which was supporting investment in equipment capital and the entry of foreign experts, as well as sending Filipino workers abroad to learn about geothermal development. Then depreciation of capital equipment over ten years. Next is recovery from operating costs that come from government funds. Then, the service fee is up to 40% of the net result. Next is the exemption from all taxes, except individual liability income tax and the exemption from payment of duty rates and compensation tax on geothermal energy operational equipment.

d. Summary of Policy Analysis

In conclusion, the policy analysis between Indonesia has been compared to the United States, New Zealand, and the Philippines. Considering all the policies from the countries mentioned above, the first step is to improve the laws and regulations governing geothermal utilization and management so that they can provide certainty more comprehensively while not conflicting with other laws and regulations. This will make the geothermal business environment more conducive and attract investors to invest in geothermal development.

Furthermore, the Government's role must be expanded from policy discourse to a more concrete and implementable policy commitment to pique investors' interest. This solution can be done through research and development financing incentives, incentives for reducing or eliminating duties and taxes related to the pre-construction process, and incentives for installation construction.

Lastly, the requirement is clarity of authority in applying rules and governance to exercise control over geothermal utilization and management through delegation and division of power between central and regional governments, while maintaining a balance between local and national interests in allocating appropriate resources. These rules should be exist in a way that is both sustainable and environmentally.

E. Conclusions

Geothermal industry development is still facing many challenges, primarily related to the participation of international or domestic companies in investing their money and taking a risk in Indonesia's geothermal sector. The characteristic of the geothermal industry is high-risk, high capital, and high technology, which means there are no possibilities to reach the target that Indonesia's government has made without the support from international companies. There are many recommendations for encouraging the development of the geothermal industry in Indonesia:

1. Applying and implementing a new fiscal term to support the economic viability of the project called cost recovery in the upstream development of the geothermal industry. These fiscal terms also have been used in Indonesia's oil and gas industry and have proven their success in accelerating the industry development. There are many reasons for these issues because of many similarities between geothermal and oil and gas.
2. Indonesia needs to adopt or use Australia's standard reporting code to accommodate investors' interests because many international companies have used those codes and gained international recognition.
3. More investigations and studies are necessary to get proven and mature data, especially exploration drilling. Indonesia needs to conduct a Government Drilling Program; based on advice given by investors, the lack of quality and quantity data is one of the concerns and needs improvement. By presenting the Government Drilling Program or offering it through auctions or regular tender, the Government can provide more attractive and proven data. Thus, the climate of investment in Indonesia's geothermal industry will be more attractive because the Government has successfully decreased the uncertainties by providing proven, mature drilling data, which is one of the most important things.

4. Indonesia should decrease the total investment of project or capital expenditure by selecting and applying new technologies suitable for geothermal layers or lithology formations and characteristics of the geothermal reservoir. The geothermal building is known for hard rocks such as metamorphic or volcanic rocks. It means many instruments and tools need to be modified the drilling bit significantly by applying Polycrystalline Diamond Compact (PDC) bit to replace the conventional roller-cone bit. The data have proven that the PDC bit results in higher drilling speed and longer lifetimes, and it can reduce large amounts of the total investment in the geothermal project.
5. It is necessary to improve the laws and regulations related to geothermal utilization and management so that it is more comprehensive and does not overlap with other rules. The Government must also play a more active role from just policy discourse to a more concrete and implementable policy that can attract investors, as well as more clarified authority in applying rules and governance to control the utilization and management of geothermal.
6. To boost the development of the geothermal industry in Indonesia, one of the most important parts is the electricity price. By implementing the regulation called Feed-in tariff, the producers will be able to sell the electricity they generate at a cost set in advance by the government under a long-term contract; also, these policies can support the economy of geothermal power generation in the downstream industry.

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Chapter 10

The Case for Nuclear Energy

Harun Ardiansyah

A. Nuclear Energy, The-Once-Antagonist

Nuclear energy is not something that is particularly new in Indonesia. Indonesia is one of the first few countries that ratified the International Atomic Energy Agency (IAEA) Statute, legalizing the establishment of IAEA as the world's nuclear watchdog. Mr. Soedjarwo Tjondronegoro served as one of IAEA's first board of governors (IAEA Statute, 1956). Since then, Indonesia has progressed so well in nuclear technology. Indonesia has three research reactors, namely TRIGA Mark II in Bandung, Kartini in Yogyakarta, and G.A. Siwabessy Multipurpose Reactor in Serpong. These reactors have served public interests since their first operation (Sugiawan & Managi, 2019). However, after the three reactors were built, advancements somehow stopped in terms

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Ardiansyah, H. (2022). The case for nuclear energy. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (181–208). BRIN Publishing. DOI: 10.55981/brin.562.c10
ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

of nuclear reactors, especially to construct of nuclear power plants for energy mix. There is no significant progress in Indonesia in pursuing nuclear energy as part of its national energy mix (Cho et al., 2021). On the other hand, the urgency of using nuclear energy has grown significantly over the last five years. Nuclear energy can be part of Indonesia's energy mix as the baseload, to fulfill the fluctuations from wind, solar, and other renewable energy sources. This chapter will explore the concept of nuclear energy, how it works, unresolved topics in nuclear energy, misinformation surrounding nuclear energy, and how nuclear energy can significantly help Indonesia tackle climate change.

B. Brief History of Nuclear Energy

Nuclear energy has been around for more than seventy years. Since the first nuclear fission reaction happened in Chicago Pile-1 (the first self-sustaining nuclear reactor on December 2, 1942), nuclear energy has transformed how humans can extract energy from the tiniest things in the universe (Atomic Heritage Foundation, 2016). However, the first "official introduction" of nuclear energy to the world came when Hiroshima and Nagasaki in Japan were bombed with atomic bombs in 1945, creating devastation and prolonged misery in the cities of Hiroshima and Nagasaki. This "introduction" creates a horrible perception of nuclear energy (Rhodes, 2012).

As the follow-up of the Manhattan Project—the project that created atomic bombs but was dismissed in 1946, the United States government created an Atomic Energy Commission. The mission of this organization was to develop nuclear energy further so that it could be used for peaceful purposes. Subsequently, these efforts started to come to reality as the Experimental Breeder Reactor-1 (EBR-1) in Idaho managed to produce electricity for the first time in 1951. This started a chain of rapid developments of nuclear reactors not only in the United States, but also around the world (Michal, 2001).

Seeing the progress of nuclear energy, President of the United States Dwight Eisenhower called for the use of "atoms for peace".

He delivered the speech at the UN General Assembly of 1953. This move was then propagated until 1957, when the IAEA was established. The wave of support for nuclear energy continued when the Nuclear Nonproliferation Treaty (NPT) was ratified in 1968 (United Nations, 1968). This marked the wake of the "nuclear golden age" when nuclear reactors were developed very rapidly around the world (Hewlett & Holl, 1989).

The first sign of the "nuclear golden age" is the Obninsk Nuclear Power Plant (NPP) startup in the Soviet Union. Established in 1954, the Obninsk NPP was the first commercial nuclear power plant operated in the world (Semenov, 1983). This story continued with the establishment of more than 150 nuclear power plants in 20 years. The peak of the golden age was in 1974 when the Prime Minister of France, Pierre Messmer, launched a new initiative to build more nuclear reactors in France. This initiative was implemented as the answer from France to tackle the oil crisis that haunted Europe in the 1970s (Funding Universe, 1996).

Source: United States Postal Service (n.d.)

Figure 10.1 U.S. Postal Service Stamp to Commemorate "Atoms for Peace" Speech

Then the tables turned. On April 26, 1986, a devastating disaster happened in the Chernobyl Nuclear Power Plant. This accident was the biggest nuclear accident in the world up until now. The Chernobyl plant was a graphite-moderated, pressure tube of channel-type boiling water reactors (BWR) of the RBMK (*Reaktor* Bolshoy Moshchnosty Kanalny)-1000 design with a large core (12 m x 12 m) cross-sectional area and height of 7m. The accident happened during a test of turbogenerator coast down, which was to provide power to feedwater pumps and the emergency core cooling system (ECCS). This type of experiment was not an urgent case to be done. The decision to perform a non-nuclear-focused test on a large civil power reactor facility reflected the lack of safety culture (Ripon et al., 1986).

The Chernobyl accident shocked the nuclear industry and the whole world. Calls to improve or even shut down nuclear reactors grew in public. This resulted in public perception of nuclear energy hitting its lowest point. As an effect, mistrust from the public created project delays in many reactors around the world, causing the cost of nuclear energy to skyrocket and not economically feasible to build new reactors. Nuclear energy entered its "dark age" due to all the pushbacks that came to the industry. In early 2000, after 16 years without any accident, nuclear energy started to gain its footing again with the emergence of Generation-III, III+, and IV reactors. Generation-III, III+, and IV reactors are new types of nuclear reactors that employ new safety features for better and safer nuclear reactors. Research and development have been growing for this new type of reactor that was told to be the future of nuclear reactors.

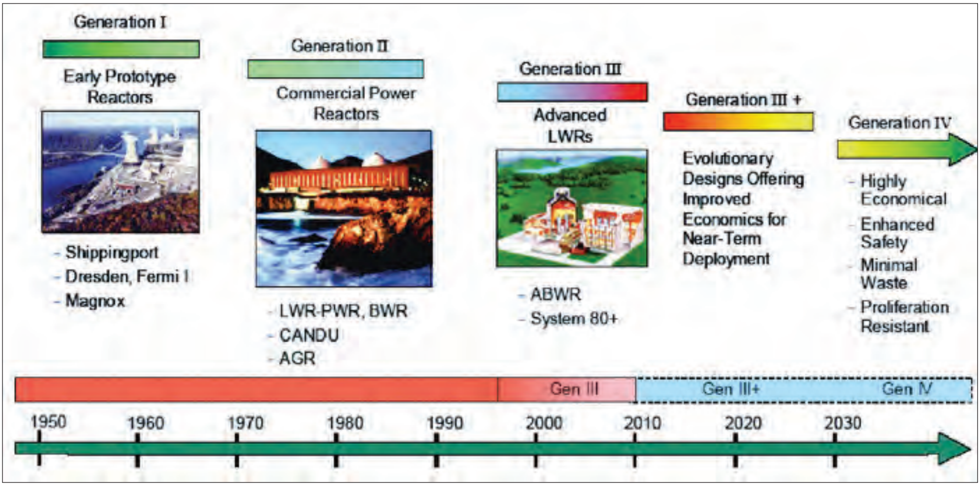
The rapid progress is again facing an obstacle after another accident happened on March 11, 2011. A 9.0-magnitude earthquake shocked the east coast of Japan. This event was followed by a tsunami with waves around 10 to 14 meters. In the Fukushima Prefecture, a nuclear reactor complex was operated by Tokyo Electric Company, Co. (TEPCO) called the Fukushima Daiichi Nuclear Complex. This complex consisted of 6 BWRs of General Electric design and started operation between 1971 and 1979 with power between 439 to 1067

MWe. Seconds after the earthquake, reactor units 1, 2, and 3 were directly shut down as expected. It was followed by the trip of the turbo generator and the main steam valve was closed. Then the tsunami waves hit the nuclear complex causing the electrical diesel generator to malfunction resulting in a station black-out (SBO) for units 1 through 4. Some additional batteries were still used to cool down the reactors. However, as time passed, the batteries started to be depleted and the core temperature started to increase. Eutectic reactions of fuel and zirconium also melted the fuel rod and eventually damaged the core. A significant number of radionuclides were also released into the atmosphere (Japan Nuclear Emergency Response Headquarters, 2011).

After the Fukushima accident, the nuclear industry once again went into another dark age. Public perception of nuclear energy was hit once again to an all-time low. From an engineering view, this pushed innovation towards better safety and the ability to passively remove the decay heat, which drives more support for nuclear energy. The existence of climate change and its effect on future generations also prompted younger generations to support nuclear energy to tackle climate change. Much research done by non-governmental and intergovernmental organizations shows that nuclear energy can help tackle climate change effectively and efficiently. This is an ongoing pursuit, especially since some organizations are still indecisive on nuclear energy. On the other hand, support for nuclear energy is growing larger, reaching more audiences, especially in Europe and Asia (Lovering et al., 2016).

C. Generations of Nuclear Reactors

Since the existence of nuclear reactors in the 1950s, innovations have driven the nuclear industry to produce electricity at the highest capacity (Figure 10.2). Innovations and improvements of nuclear reactors are made to reach better cost, safety, security, and fuel cycle, among other things. These improvements are classified into several "generations" of nuclear reactors.



Source: Goldberg & Rosner (2011)

Figure 10.2 Generations of Nuclear Reactors

1. Generation I

The first generation of nuclear reactors, usually referred to as Generation I, refers to the prototype and power reactors that launched civil nuclear power. This generation of reactors consists of early prototypes of commercial reactors that started commissioning in the 1950s and 1960s. These reactors were early proof that the concept of nuclear reactors was validated and could operate safely. Examples of reactors in the generation I category are Shippingport (1957–1982) and Dresden-1 (1960–1978) in the United States, and Calder Hall-1 (1956–2003) in the United Kingdom (UK) (Figure 10.3). The last remaining commercial Gen I plant, the Wylfa Nuclear Power closed on December 30, 2015, after nearly 45 years of successful and safe operations. This closure marked the conclusion of Magnox reactor generation in the UK (Goldberg & Rosner, 2011).

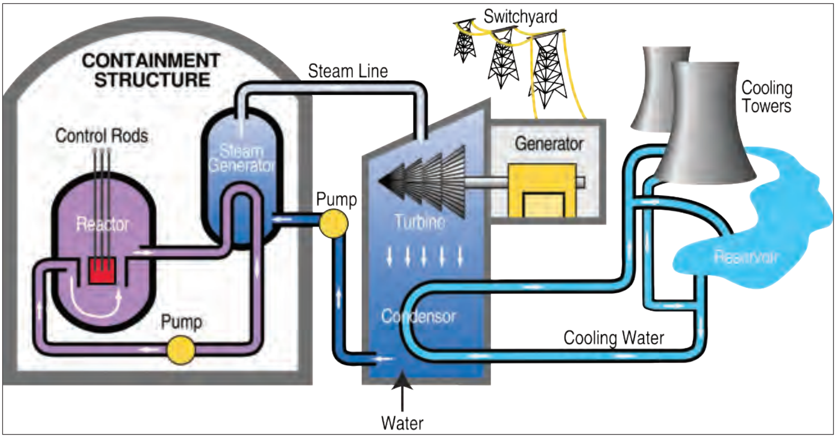
Source: U.S. Department of Energy (n.d.)

Figure 10.3 Calder Hall Power Station in the United Kingdom

2. Generation II

Generation II refers to a class of commercial reactors mainly deployed around the 1970s to 1980s. After proving that nuclear reactors were reasonably deployed, engineers, and designers innovated to create more economical and reliable nuclear power plants. These reactors were typically designed to be operated for forty years. Regarding technical aspects, Generation II reactors have matured some critical components on safety-related issues. For example, active and passive safety features are used to operate the reactors safely and function without operator control or loss of auxiliary power. Generation II reactors include pressurized water reactors (PWR) (Figure 10.4), Canada Deuterium Uranium reactors (CANDU), boiling water reactors (BWR), advanced gas-cooled reactors (AGR), and Vodo-Vodyanoi Energetichesky Reactors (VVER) (Goldberg & Rosner, 2011).

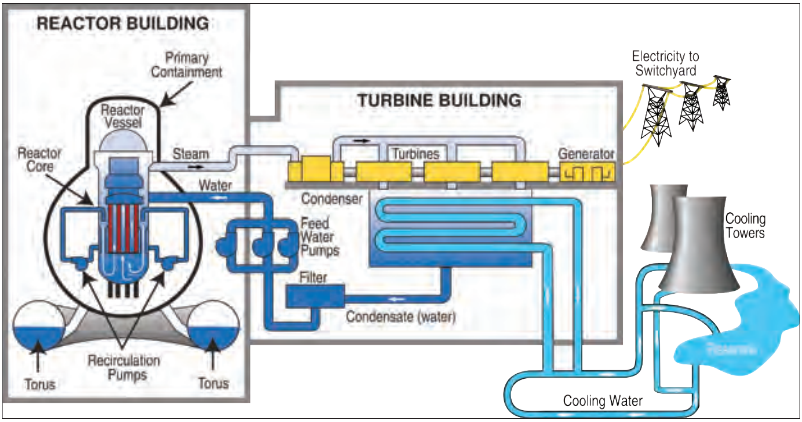
Until now, Generation II reactors have the largest fleet in the world, especially PWR and BWR. PWR is by far the most common civilian nuclear reactor in the world. This type of reactor was originally developed for nuclear submarines. Water is circulated in a pressure vessel to cool the reactor core and extract the heat from the core. The pressure inside the pressure vessel is around 150 bar. Thanks to the pressure, the water stays in its liquid state even at a high temperature. Water passes downward through an annulus between the reactor core and the pressure vessel and then flows up over the fuel elements. It then leaves through a series of pipes to the steam generator. In the steam generator, hot water from the reactor core passes through a heat exchanger. Current PWR technology commonly uses four loops of steam generators to maximize the steam generated in the system. Water at lower pressure is fed to the other side of the heat exchanger. The exchange of heat creates steam that is then passed to the turbine, then to the condenser (Hewitt & Collier, 2000).



Source: United States Tennessee Valley Authority (n.d.)

Figure 10.4 Pressurized Water Reactor Schematic Diagram

BWR is the world's second most common civilian nuclear reactor (Figure 10.5). BWR differs from PWR, where the steam generation process is done directly on a single cycle. BWR generates steam directly with the core without a separate steam generator. The pressure inside the core is about 70 bar. Water passes through the core, and about 10% is converted into steam. The steam is then separated from water molecules in the upper region of the core. The separated water is pumped back to the core using a circulating pump. Then, the steam goes to the turbines and condenser and the water goes back to the core to continue the cycle (Hewitt & Collier, 2000).



Source: United States Tennessee Valley Authority (n.d.)

Figure 10.5 Boiling Water Reactor Schematic Diagram

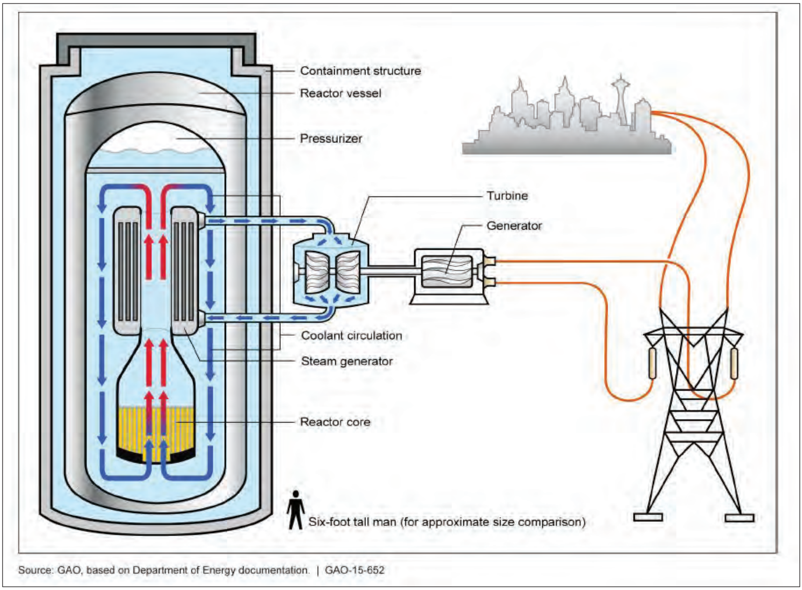
3. Generation III

Generation III reactors are technologically similar to Generation II reactors. However, evolutionary state-of-the-art design improvements are added to the reactors. These measures are added to prevent Fukushima-like accidents from happening. Improvements are added in fuel technology, thermal efficiency, modularized construction, passive safety system, and standardized design. These improvements aim is to extend the operational lifetime of a nuclear reactor up to sixty years without compromising the safety and security of nuclear reactors (Goldberg & Rosner, 2011). Generation III reactors include the Westinghouse 600 MW Advanced PWR (AP-600), GE Nuclear Energy's Advanced Boiling Water Reactor (ABWR), and Enhanced CANDU 6. These technologies are not massively employed around the world yet.

4. Generation III+

In between Generation III and Generation IV, Generation III+ reactors are designed as a development from Generation III reactors, providing more significant safety improvements. The most significant improvement is the passive safety features that do not require any active controls and only rely on gravity and natural circulation to mitigate the impact of abnormal events. Generation III+ reactors include South Korea's Advanced Power Reactor (APR), European Power Reactor (EPR), Japan's Advanced Pressurized Water Reactor (APWR), Russia's VVER-12000, and the United States' AP-600 and AP-1000 (Juhn et al., 2000).

Small and modular reactors (SMR) is one of the nuclear technologies in this category (Figure 10.6). IAEA defined SMRs based on the power and size of the reactors. SMRs typically produce up to 300 MWe (International Atomic Energy Agency, 2014). However, the smallness of its size is not the only advantage of SMRs. SMRs are designed to be modular, which means that the reactor consists of standardized units that are easy to be constructed. It is important that each individual component can be altered or replaced without any significant effect on the overall system. The modularity of nuclear reactors will solve one problem: the inability to standardize any design to simplify reproducibility. Ultimately, this innovation will lead to cheaper and faster construction of nuclear power plants (Hussein, 2020).



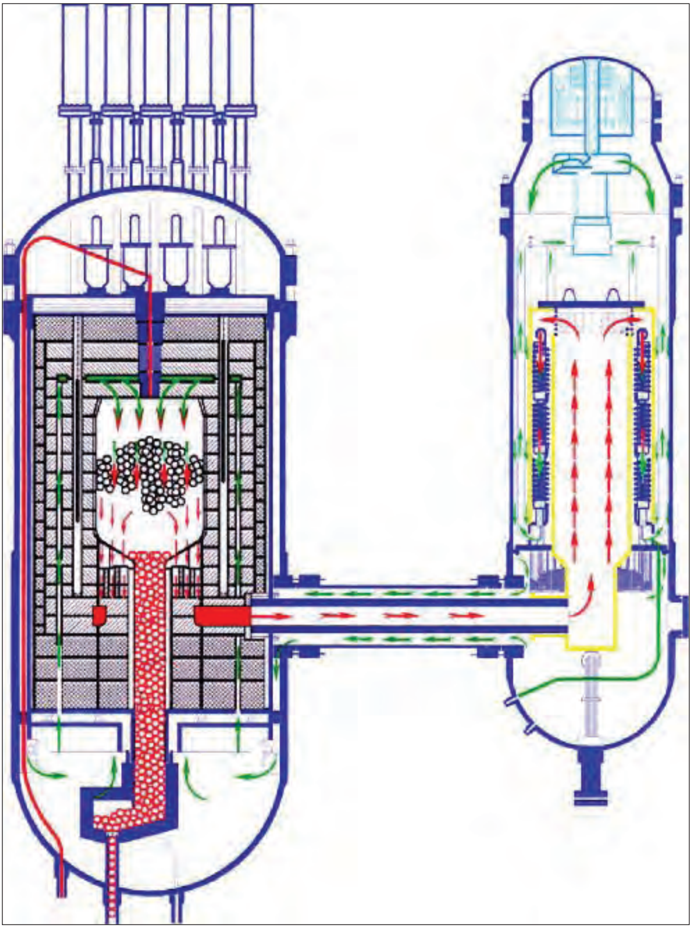
Source: U.S. Government Accountability Office (n.d.)

Figure 10.6 Schematics of Light Water Small Modular Nuclear Reactor

5. Generation IV

The next generation of nuclear reactors, Generation IV, is a brand-new generation that expands nuclear power technology. All Generation IV technology identified by the Generation IV Forum (GIF) is currently in the development phase and seeks to be deployed shortly (The Generation IV International Forum & U.S. DOE Nuclear Energy Research Advisory Committee, 2002). Generation IV offers major improvements in some key areas: economics, safety, sustainability, and proliferation resistance. There are six new nuclear technologies with the potential to fulfill these goals and are currently under development in many countries. Those reactors are the high-temperature gas-cooled reactor (HTGR), the sodium-cooled fast reactor (SFR), the gas-cooled fast reactor (GFR), the lead-cooled fast reactor (LFR), the molten salt reactor (MSR) and the super-critical water-cooled reactor (SCWR) (Abram & Ion, 2008).

HTGRs and MSRs are leading the innovation of Generation IV reactors (Figure 10.7). Multiple startups and companies have designed a lot of new nuclear reactors to be deployed in the near future. For HTGRs, the Chinese HTR-PM reactor, a 2 x 210 MWe HTGR, has been generating electricity since late 2021. This is significant progress to prove that Generation IV reactors are coming sooner or later (World Nuclear News, 2021).



Source: Zhang et al. (2009)

Figure 10.7 High-Temperature Gas-Cooled Reactor Schematics

D. Benefits of Nuclear Energy

Nuclear energy has a lot of benefits to society. Not only as a clean energy source, but also for the livelihood of people around nuclear energy. This part will explain some features to argue that nuclear energy benefits the future.

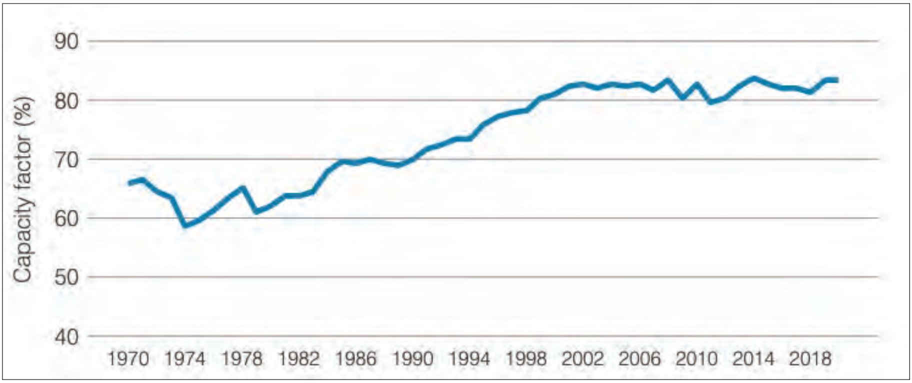
1. Energy Density

Energy density is the amount of energy produced per unit volume of fuel. Nuclear energy is the densest energy source in the world. A comparison by IAEA stated that a chicken-egg-sized amount of uranium fuel provides more than enough power for a lifetime of energy use for an average person. This is because each individual atom of Uranium-235, the isotope commonly used for thermal fission inside a reactor core, can produce energy as much as 200 MeV (equivalent to 3.2044×10^{-11} Joule) in every fission reaction (Lamarsh & Baratta, 2001). Though the number seems very small, 200 MeV is energy produced by each atom in a single fission reaction. This equates to around 85,000,000 MJ/kg, compared to other energy sources such as coal (24 MJ/kg) and natural gas (50 MJ/kg). A nuclear power plant that generates 1,000 MW of electricity will only consume around 3.5 kg of Uranium-235 per day. This means that electricity can be generated using considerably fewer resources than any other source of energy (Williams, 2016).

2. Capacity Factor

The capacity factor is the ratio of actual energy output over the maximum possible electrical energy output in a given period. This measure shows how often the energy source is running at maximum power and is used to measure the reliability of an energy source. The capacity factor is a unitless ratio and usually computed over a year. In 2019, the capacity factor of nuclear energy was 83.1%, which means that on average, nuclear power plants produce 83.1% of their maximum possible energy output in a year. Nuclear energy has maintained a capacity factor of around 80% for the last twenty years (World Nuclear

Association, 2021). This value is the largest among other renewable energy sources such as hydropower (40.2%), solar energy (13.4%), wind energy (25.9%), and geothermal energy (79.9%) all in 2019 (International Renewable Energy Agency, 2020).

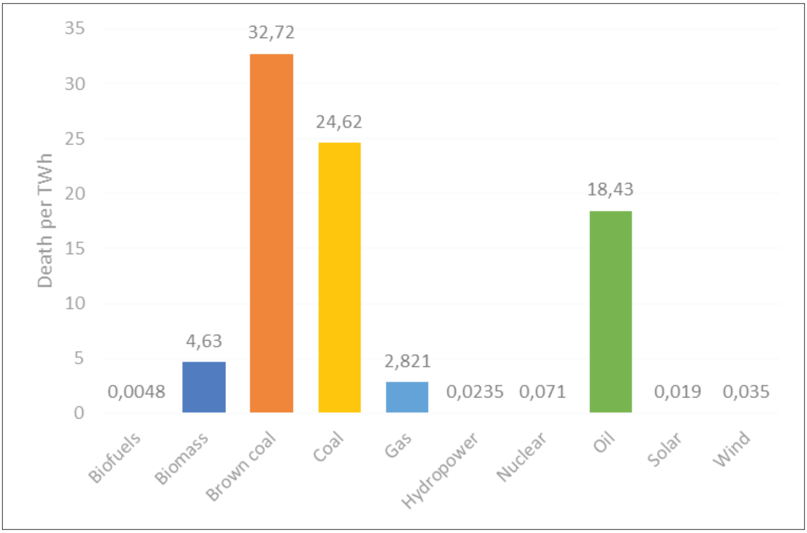


Source: World Nuclear Association, IAEA PRIS (2021)

Figure 10.8 Global Average Capacity Factor of Nuclear Energy

3. Health Effects of Energy Production

Numerous measures can be used to measure the safety of energy production. One parameter that can be used is the health effects of energy production, measured in the number of deaths per energy produced by a given energy source. From this perspective, nuclear energy is among the safest energy sources. The death rate from nuclear energy is 0.07 death per Terawatt-hours (TWh) of energy produced (Markandya & Wilkinson, 2007). This calculation already included death estimation from the Chernobyl disaster (4,000 deaths), death estimation from the Fukushima disaster (one worker death, and 573 indirect deaths from the stress of evacuation), and death estimation from mining and milling activities. This value is very close to renewable energy sources such as wind energy (0.04 death per TWh), hydropower (0.02 death per TWh), and solar energy (0.02 death per TWh) (Sovacool et al., 2016). This shows how nuclear energy can be used worldwide as a safe electricity source.

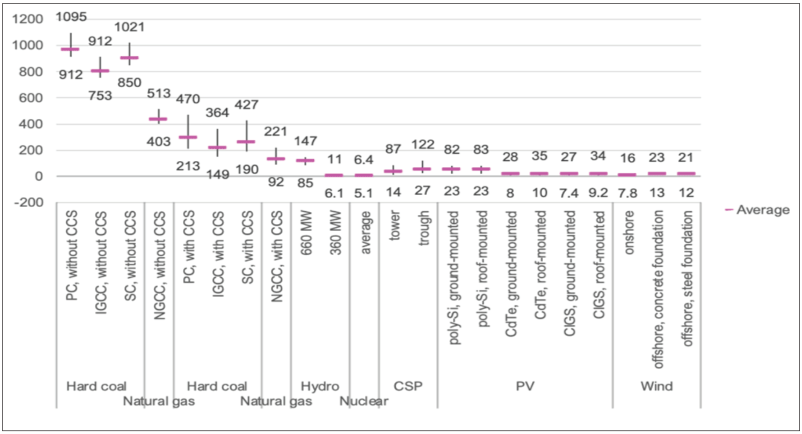


Source: Our World in Data (2020)

Figure 10.9 Death Rates from Energy Production per TWh

4. Greenhouse Gas Emissions

The United Nations Economic Commission for Europe (UNECE) examines the carbon lifecycles of multiple technologies to produce electricity. The report shows that nuclear energy has the lowest greenhouse gas emissions among all electricity sources. Nuclear energy produced on average 5.5 g CO_2 eq./kWh of greenhouse gas. Greenhouse gas is mainly produced during the front end of the nuclear fuel cycle, which includes mining, milling, and fuel fabrication processes. Nuclear energy is among the lowest in other categories such as freshwater eutrophication, human toxicity, land occupation, and fuel resources. This shows that nuclear energy is important to balance the increase in energy demand with greenhouse gas reduction (Gibon et al., 2021).



Source: Gibon et al. (2021)

Figure 10.10 Lifecycle Greenhouse Gas Emission Range for Assessed Technology

5. High-Paying Jobs

The nuclear energy industry has created long-lasting, high-paying jobs for future generations. In the era of post-COVID-19 recovery, the nuclear energy sector has supported economic recovery, keeping the pace of energy transition, creating jobs, and leading the effort towards a more sustainable future. For example, the refurbishment of six reactors by Bruce Power in Canada will provide low-cost, reliable, and carbon-free energy until 2064. These reactors will also provide long-lasting 22,000 jobs during their operation of the reactors (NEA Policy Brief, 2020). A technical report by World Nuclear Association shows that nuclear energy provides about 25% more employment per unit of electricity than wind energy. Nuclear employment also includes comparatively good-paying, long-term job security, and a high degree of localization in the host country (Emsley, 2020). These jobs are not only high-skill technical jobs, but also secondary jobs such as sales and administrative support, construction, management, business and financial occupations, cleaning and maintenance, production, health care, transportation, installation, maintenance, and repair (Berkman & Murphy, 2015).

E. Unresolved Problems in Nuclear Energy

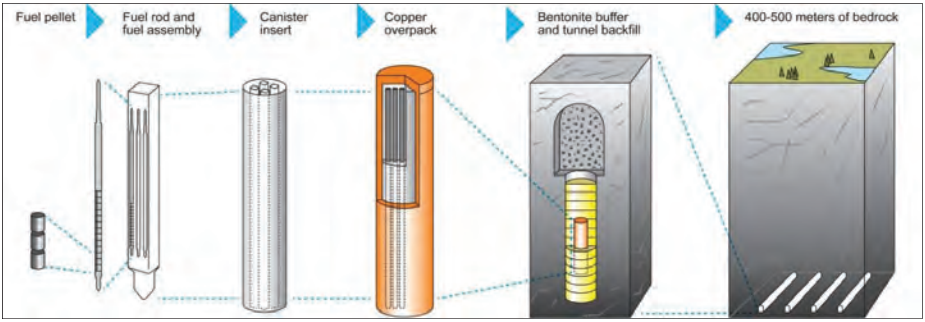
Like technologies, nuclear energy kept improving in many aspects, such as safety, security, and safeguard. However, two particular aspects of nuclear energy considered unresolved until now, namely nuclear waste and cost and time of construction. These aspects are considered unresolved due to technical and engineering problems or policy and political problems as discussed below.

1. Nuclear Waste

Nuclear waste is the most common topic when nuclear energy is being discussed. Some would argue that nuclear waste is why nuclear energy should not be implemented, due to the high level of radioactivity and radiological impact on the future. However, some information and news about nuclear waste might need to be clarified.

Nuclear energy waste is generally classified into three categories: low-level, intermediate-level, and high-level waste. These categories are divided based on how radioactive the waste is. Low-level waste is waste that is exposed to low-level of radiation. These are generally common things that can be found not only in a nuclear facility, but also in laboratories. For example, gloves, laboratory coats, and laboratory equipment. Low-level waste contributes up to 90% of all nuclear waste, yet it can be disposed in near-surface repositories without having any consequences on the nearby environment (IAEA, 2018)

Intermediate-level waste has a higher level of radioactivity compared to low-level waste. This waste is usually found in the form of chemicals, fuel cladding, and some amounts of concretes surrounding the reactor core. About 7% of total wastes from nuclear power plants are accounted for as intermediate-level waste. This type of waste might have some heat deposited within. Should the heat deposit occur, it must be contained in a specific container that can cool down the waste's temperature. The container is specifically designed to maintain its integrity in any situation. The container has multi-barriers to prevent radioactive waste leakage. This type of technology has already been implemented in all nuclear power plants worldwide.

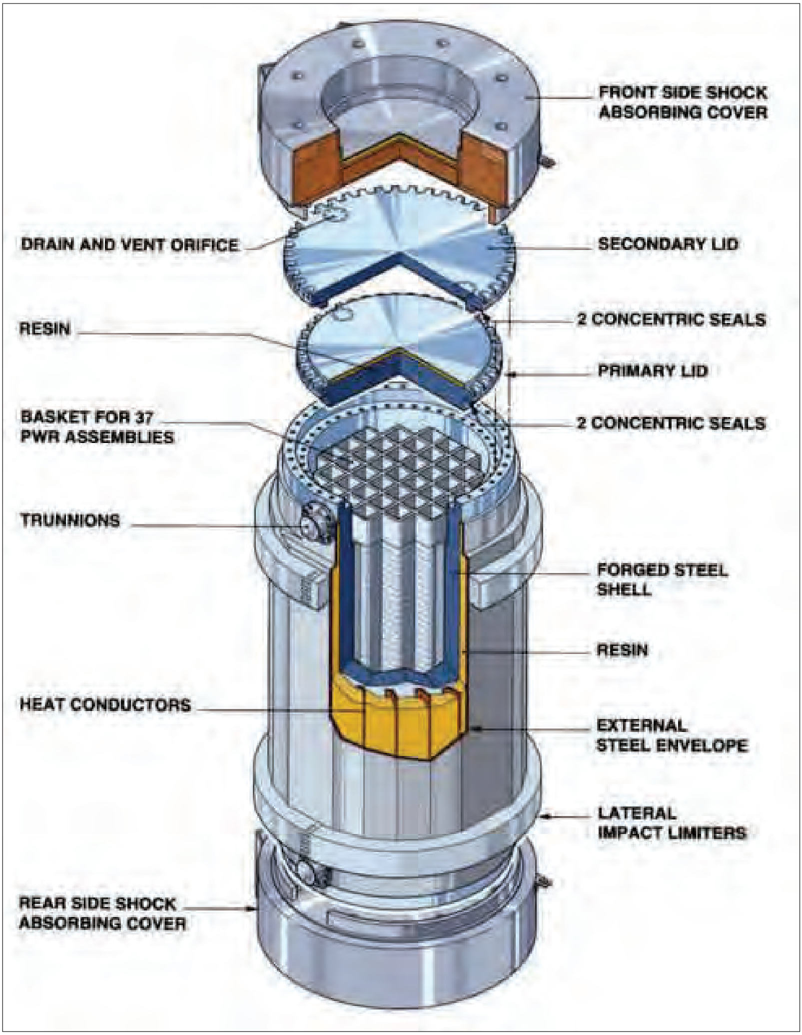


Source: Posiva (2014)

Figure 10.11 Concept of Multi-Barrier Disposal Concept

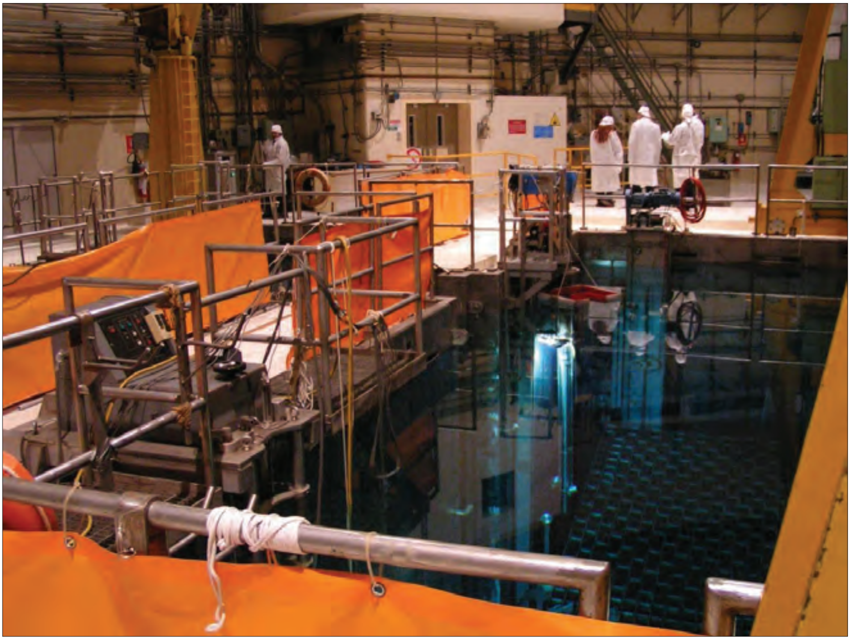
Lastly, high-level waste is the spent nuclear fuel. Spent nuclear fuel is the most radioactive material inside the core. It still generates heat due to delayed fission. Therefore, special treatments are necessary for spent nuclear fuel. After the spent nuclear fuel is taken out of the reactor core, it is placed in a special spent fuel storage pool for about five years. This pool serves two purposes, to cool the spent nuclear fuel and to reduce the number of radioactive materials through the decay process. This process reduced up to 95% of the radioactivity from short-lived isotopes. After five years, the spent nuclear fuel is compacted and placed in a special container. This method of containment has been designed to sustain any type of disturbance. The spent nuclear fuel remains in the container forever (IAEA, 2018).

Although the engineering side of handling nuclear waste is considered resolved, there many debates on where to permanently store high-level wastes. So far, the spent nuclear fuel that has been cooled and contained is placed within the nuclear power plant area. However, it is not considered a long-term solution for high-level nuclear wastes. A deep geological repository, a facility deep down the Earth to store all the containers of high-level nuclear wastes, is the ideal solution. However, debates on this topic are harsh. In the United States, a deep geological repository was proposed in Yucca Mountain, Nevada in early 2000, but it is still not approved (Bowen, 2021). A sign of hope



Source: Orano TN (n.d.)

Figure 10.12 TN24 Cask Produced by Orano TN (Formerly Areva TN)



Source: World Nuclear Association (n.d.)

Figure 10.13 Caorso Nuclear Power Plant Spent Fuel Pool

in this topic is the construction of deep geological repositories in Finland (Gil, 2020) and Sweden (Kombrink, 2022). Hopefully, this can start of progress in the deep geological repository.

2. Cost and Time of Construction

Non-technical problems, namely the costs and construction times of nuclear reactors, are also discouraging arguments used to reject nuclear technology. Nuclear power plants generally take up to ten years from construction to operation. It needs to be realized that the nuclear industry, like any other industry, is constantly adapting. It is worth noting that the construction of nuclear power plants is more effective and efficient than 20 years ago.

On average, nuclear power plants currently being built around the world can be completed and operational within 86 months from the previous 120 months (World Nuclear Association, 2021). It uses

Generation III+ technology that has been standardized and cost-effective. If a small modular type of nuclear power plant is used, a nuclear reactor can be built in as short as 2–3 years.

Regarding the cost, several types of financing schemes can also be used as examples if Indonesia wants to build nuclear power plants. Many countries have carried out these schemes, either in the form of government-to-government agreements, such as South Korea with the United Arab Emirates, and Pakistan with China, or in a government-to-business model, i.e., the British government with the Rolls Royce company. To push for innovations, policies such as incentives or acceleration programs to speed up the nuclear power plant construction process can also be a solution to boost the use of low-emissions energy around the world. Some examples of those policies can be adopted from countries like France, the UK, Ukraine, Japan, China, and the United States. Those countries have recently started the development of new nuclear power plants, as well as restarting units that were previously turned off. The United States supports developing nuclear power plants through a grant program for the development of prototypes of nuclear power plants with the latest technology (World Nuclear Association, 2020).

F. How Nuclear Energy Can Help Indonesia

After examining the ups and downs of nuclear energy around the world, this part will focus on whether Indonesia should give attention to nuclear energy and the role of nuclear energy in the future. Two major problems Indonesia faces are climate change and economic recovery post-COVID-19.

On the climate change part, the Indonesian government has targeted net-zero carbon emission in Indonesia in 2060, with the share of renewable and new energy (including nuclear energy) gradually increasing from 23% by 2025 to 100% in 2060 (Humas ESDM, 2021). This scenario would be possible if there is a good replacement for fossil energy that accounts for 60% of Indonesia's energy mix and becomes the baseload of energy in Indonesia. A just transition is necessary, including justice to consider all types of energy that have the potential to help Indonesia thrive. Until now, Indonesia's nuclear energy is still considered as the last energy option. With the continuous threat from climate change, that consideration is no longer relevant. Nuclear energy can be used to replace fossil fuels to become the baseload of energy in Indonesia. With consistently more than 80% capacity factor, nuclear energy is reliable. A reliable electricity grid is necessary for Indonesia, which still needs to industrialize and speed up development. Collaborations between nuclear energy and other renewable energy sources such as wind, solar, hydro, and geothermal are necessary for Indonesia to tackle climate change. Nuclear energy can be the baseload, and renewable energy can be the adjustable energy depending on necessity at a given time. This collaboration will result in more reliable electricity for homes and industries, which will ultimately boost Indonesia's productivity and economy.

Another way for nuclear energy to contribute to Indonesia's economy is through job creation for nuclear power plants. Post-COVID-19, Indonesia needs to economically bounce back to levels seen in previous years or even better. Nuclear energy can also create many new and sustainable jobs for the current and future generations. These jobs are not only highly skilled jobs like engineers and doctors, but also a lot of secondary jobs such as administrative jobs, affecting all levels of society. Since licenses for nuclear power plants are generally valid for forty years, these jobs will always be part of the neighborhoods.

Calls for support on nuclear energy also resonated in the COP26 in Scotland, UK. These calls came from many clean energy advocates around the world. Those energy advocates, including Indonesia, questioned nations' commitment to net-zero carbon emission. The nationally determined contribution (NDC), the official document that has been submitted by the Indonesian government explaining Indonesia's pathway to net-zero carbon emission, has mentioned the important role of nuclear energy. However, based on the pathway, nuclear will be part of the energy mix in Indonesia by 2049, which is too long considering Indonesia's pathway (Humas ESDM, 2021).

Indonesia can also look for examples in Asia. The center of excellence in nuclear energy has already been shifted to the East. Countries like China and South Korea have done or pledged to include more nuclear energy as part of their strategy to tackle climate change. The unresolved nuclear problems, especially cost overruns and delays in construction, have been solved by using design standardization.

However, a concrete strategy must exist to deploy nuclear energy in Indonesia. Based on the Integrated Nuclear Infrastructure Review (INIR) Mission from IAEA in 2009, Indonesia almost fulfills all 19 infrastructure points in Milestone 1 of the nuclear infrastructure necessary to build the first nuclear reactor. Three key areas were not fulfilled: the national position, management, and stakeholders involved. These areas can be completed by establishing the nuclear energy implementation organization (NEPIO) (Forsström et al., 2009). NEPIO is an organization tasked to prepare and organize all necessary infrastructures in a country to build its first nuclear power plants. NEPIO is also responsible for preparing the plan for future nuclear energy implementation. NEPIO will directly be responsible to the head of government of the country. NEPIO will coordinate with all the nuclear energy stakeholders to ensure that all the necessary policies and instruments are fully equipped to launch the nuclear energy program (IAEA, 2015).

NEPIO is the first step to ensuring a national position exists on nuclear energy. This step will have a crippling effect on inviting all the stakeholders to get involved in the national nuclear energy program. Local- and state-owned companies can see the opportunities to get involved in the project. Foreign investment will possibly come to Indonesia to build nuclear reactors. Three key issues that need to be considered in foreign investment are the financial scheme of the investment, the transfer of knowledge, and the national participation scheme. The financial scheme of the investment needs to consider Indonesia's economy and future prospects. The transfer of knowledge and national participation scheme is important to ensure that Indonesia's sovereignty over the technology is achieved and to limit dependency on foreign experts if things go wrong with the reactors.

NEPIO also can select technologies to be used as the first nuclear power plant in Indonesia. Many options are available around the world. Indonesia can take advantage of the development of current nuclear fleets. When the technology is chosen, Indonesia can start its nuclear energy program as soon as possible. Recent projections from the Ministry of Energy and Mineral Resources stated that the first nuclear power is targeted to be operational by 2045 (Humas ESDM, 2021). If all necessary infrastructures are met, including the establishment of NEPIO and all the milestones necessary to achieve it, the target can be pulled to earlier than 2045.

Arguably, a nuclear reactor is one of the world's most complicated types of machinery. Adding the known risk of radiation, the safety, and security level of nuclear power plants should have been one of the toughest and most over-engineered of all the technologies made by humankind. Consequently, this makes the overall cycle of nuclear power plants longer than any other technology. Those tough measures and over-engineering are being placed to ensure the robustness and the highest safety standard, especially during the first construction of a nuclear power plant known as First-of-a-Kind (FOAK). Just like any technology, construction will be the most expensive part. This is due to a lack of experience and the dependence on importing all the technologies. This was what happened to South Korea in the 1970s. At the time, South Korea constructed its first nuclear power plant with the help of the United States. Eventually, South Koreans gained experience building their nuclear power plants, and now they are exporting their nuclear power plants design (Lovering et al., 2016). Another reason that makes nuclear power plant construction slow is that there is no standardization of the design of the nuclear power plants. Every nuclear power plants are unique and designed specifically for the site where they are about to build. This makes the cost of construction rise. Some designs have accommodated the standardization of nuclear power plant design. It is expected that with this standardization, the high cost due to the site's uniqueness can be reduced significantly (Raetzke, 2010).

Nuclear energy is not the perfect technology, just like anything else. However, it is arguable that nuclear power plants can provide a significant societal impact on their existence. The secondary part of nuclear power plants is very common for any generating power station. This makes the job created by nuclear power plants not very unique to nuclear engineers. The existence of nuclear power plants—which are 40 years in minimum and can be extended up to 60 years—will create long-lasting, high-paying jobs at all levels. This will create a huge economic impact on the society surrounding nuclear power plants. Nuclear energy should be part of Indonesia's energy mix, and must be installed as soon as possible.

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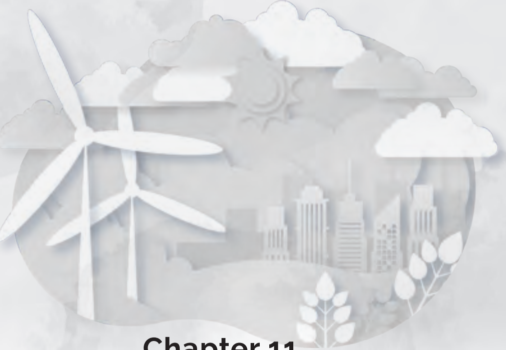

Chapter 11

Unlocking the Potential of Hydrogen in Indonesia

Denny Gunawan

A. Overview of the Importance of Hydrogen

The ever-increasing global population and economic development continue to intensify worldwide energy demand and greenhouse carbon dioxide emissions. To mitigate climate change driven by the large amounts of carbon dioxide gas released into the atmosphere, the world is now embarking on the switch from fossil fuels to alternative clean energy. Hydrogen is expected to play a crucial role as a versatile clean energy carrier and industrial feedstock with numerous applications as illustrated in Figure 11.1. More importantly, clean hydrogen generated using low or zero-emission sources can enable deep decarbonization across the energy and industrial sectors.

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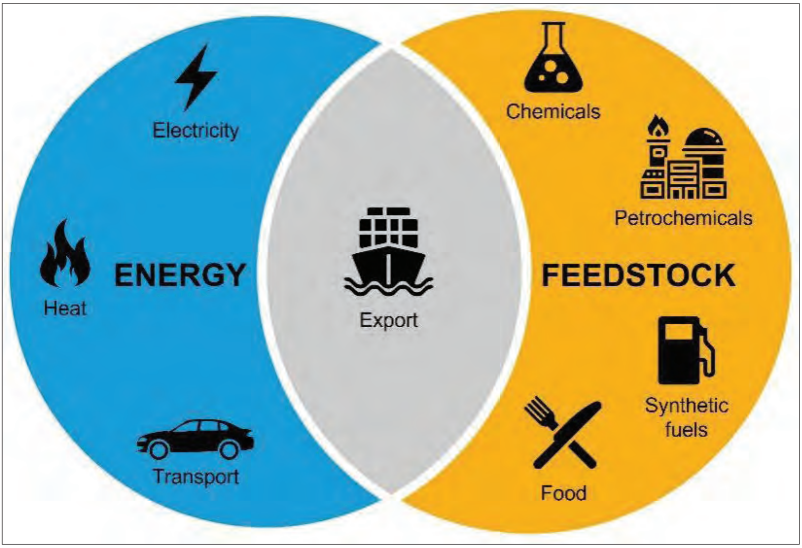
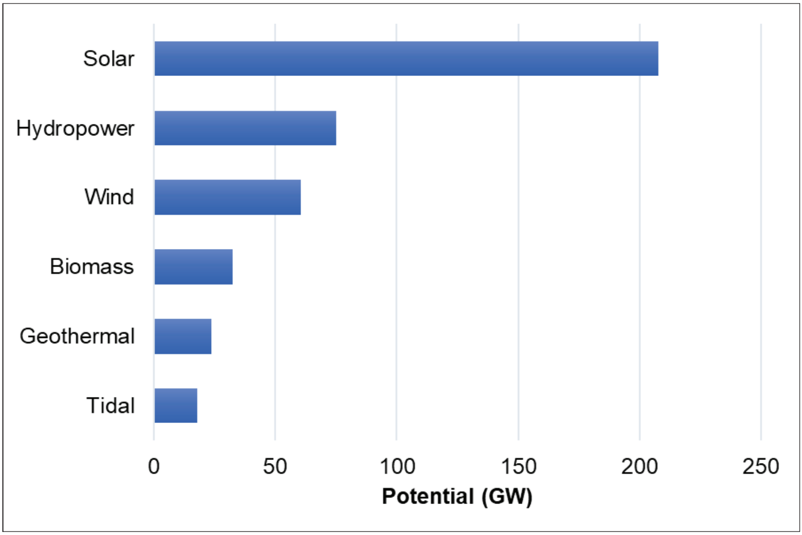
Gunawan, D. (2022). Unlocking the potential of hydrogen in Indonesia. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (209–235). BRIN Publishing.
DOI: 10.55981/brin.562.c11 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8



Source: Adapted from Bruce et al. (2018)

Figure 11.1 Applications for Hydrogen

As one of the world's largest greenhouse gas emitters, Indonesia has committed to achieving a 29–41% reduction in carbon emissions compared to the business-as-usual scenario by 2030 (Dunne, 2019). In this context, hydrogen is one in a suite of technology options to help Indonesia meet its climate targets. Moreover, the abundant renewable resources across the country, including solar, hydropower, wind, biomass, geothermal, and tidal as presented in Figure 11.2 could enable Indonesia to be a worldwide clean hydrogen powerhouse. The global market for hydrogen is projected to reach US$201 billion by 2025 (H2X Global, n.d.). Indonesia holds a huge opportunity to create new revenues by exporting renewable resources from hydrogen and its derivatives, such as ammonia and methanol.



Source: Adapted from Kementerian ESDM (2021)

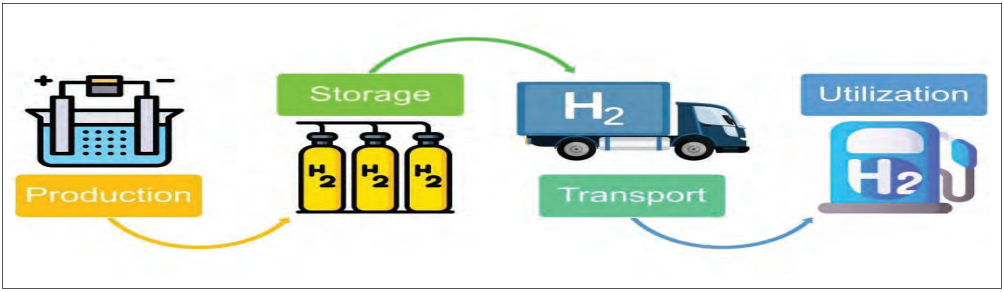
Figure 11.2 Indonesia's Renewable Energy Potential

Despite the enormous potential of clean hydrogen, Indonesia is facing a number of challenges associated with the adoption of hydrogen across its value chain. The high cost of renewable hydrogen production technologies is among the top challenges for clean hydrogen to be cost-competitive with fossil hydrogen. Extensive infrastructure requirements to ensure robust and reliable hydrogen storage and delivery is another concern revolving around the implementation of hydrogen. On top of that, the absence of any hydrogen-related policy and roadmap as well as the slow growth of renewable energy mix in Indonesia are also several potential factors that may hinder the widespread uptake of clean hydrogen in the country.

The overarching aim of this chapter is to provide a strategy recommendation for developing clean hydrogen industry in Indonesia. This chapter is expected to be a reference for various stakeholders, including government, industry, and research community to build Indonesia's hydrogen economy in a coordinated manner. The first few sections discuss the opportunities and challenges of clean hydrogen in Indonesia from both technical and economic perspectives. The following sections take the analysis further by synthesizing a national hydrogen strategy recommendation on how those opportunities can be realized within Indonesia while tackling the associated challenges.

B. Hydrogen Value Chain

The key challenge for the widespread growth of the hydrogen market is the scale-up of its value chain with affordable costs. The technologies underpinning the hydrogen value chain can be classified as production, storage, transport, and utilization as illustrated in Figure 11.3.



Source: Adapted from Bruce et al. (2018)

Figure 11.3 Hydrogen Technology Value Chain

1. Hydrogen Production

Hydrogen can be produced via several technological processes using different sources at varying greenhouse gas emissions. Currently, global hydrogen production is predominantly made from fossil fuels through steam methane reforming (SMR) and coal gasification. These two conventional pathways to produce gray hydrogen emit substantial amounts of carbon dioxide. Therefore, it is important to note that hydrogen may exhibit different cleanliness levels depending on its production. Based on the raw materials, synthesis methods, and carbon emissions, hydrogen is classified into numerous shades. Several hydrogen shades, currently or potentially utilized in Indonesia, include gray, blue, turquoise, pink, and green hydrogen as presented in Table 11.1.

Table 11.1 Selected Five Shades of Hydrogen

Color	Source	Process	Carbon footprint	Cost (US$/kg H_2) *
GRAY HYDROGEN	Natural gas or coal	SMR or gasification	High	0.50-1.70 (natural gas) 1.20-2.10 (coal)
BLUE HYDROGEN	Natural gas or coal	SMR or gasification with CCS	Low to medium (10-15% are emitted)	1.00-2.00 (natural gas) 1.50-2.80 (coal)
TURQUOISE HYDROGEN	Natural gas	Methane pyrolysis	Solid carbon (byproduct)	3.10-3.80
PINK HYDROGEN	Nuclear energy	Electrolysis or thermal splitting	Minimal	2.50-3.23
GREEN HYDROGEN	Renewable electricity	Electrolysis	Minimal	3.00-8.00

* Levelized cost of hydrogen in 2020

Source: Adapted from IRENA (2020) with additional information obtained from IEA (2021), Sánchez-Bastardo et al. (2021), and World Nuclear Association (2021a)

a. Gray Hydrogen

Gray hydrogen is produced from fossil fuels via SMR or coal gasification. This shade of hydrogen accounts for 96% of current worldwide hydrogen manufacturing (Taibi et al., 2018). In SMR, natural gas reacts with steam at elevated pressure and temperature to generate syngas (a mixture of hydrogen and carbon monoxide gases). On the other hand, coal gasification involves a reaction between coal with oxygen and steam at high temperatures and pressure to produce hydrogen and carbon monoxide gases. SMR and coal gasification are mature hydrogen production technologies that exist on a large scale across the world. The current levelized cost of hydrogen from natural gas and coal are approximately US$0.50–1.70 and US$1.20–2.10/kg hydrogen, respectively (IEA, 2021).

In the context of Indonesia where natural gas and coal resources are abundant, the existing hydrogen manufacturing plants across the country are dominated by SMR and coal gasification. Indonesia's gray hydrogen is commonly produced in the national oil and gas refinery facilities. Subsequently, hydrogen is supplied to oil processing units, ammonia plants for fertilizer industry, and methanol manufacturing plants. However, using gray hydrogen in various industries in Indonesia entails significant carbon dioxide emissions and therefore is unsuitable for achieving net-zero emissions targets.

b. Blue Hydrogen

Blue hydrogen is gray hydrogen coupled to carbon capture and storage (CCS) technology. This shade of hydrogen could assist in the reduction of carbon footprints from existing hydrogen plants during the early phase of energy transition while minimizing the pressure on renewable energy growth to produce green hydrogen. The current levelized cost of blue hydrogen is estimated to be around US$1.00–2.00 and US$1.50–2.80/kg hydrogen for CCS-coupled SMR and coal gasification, respectively (IEA, 2021). With the improved CCS technology and carbon pricing policy, future forecasts suggest that blue hydrogen could be more cost-competitive than gray hydrogen by 2030.

Indonesia is pursuing this shade of hydrogen to reduce carbon dioxide emissions from hydrogen manufacturing. For example, the Indonesian state-owned oil and gas enterprise, is now assessing the integration of CCS technology into its gray hydrogen production facilities. However, blue hydrogen has several limitations that make it inappropriate as a long-term solution. First, blue hydrogen is produced from finite resources and therefore is not sustainable. Second, the efficiency of CCS is expected to be approximately that 85–90%, implying 10–15% of the carbon dioxide is emitted (Leung et al., 2014). Although blue hydrogen significantly reduce carbon dioxide emissions, it should not be seen as the ultimate solution as it does not meet the requirements of a net-zero future.

c. Turquoise Hydrogen

Turquoise hydrogen is generated via natural gas pyrolysis with no carbon dioxide emissions. Through the pyrolysis process, the carbon in methane is solidified into carbon black, providing additional revenue. Turquoise hydrogen is still at the pilot stage in the United States. The challenges are its higher capital cost than blue hydrogen, particularly at a small scale, and the possibility of carbon coke in decreasing the catalyst lifetime and clogging up the reactor. The levelized cost of turquoise hydrogen is US$3.10–3.80/kg hydrogen (Sánchez-Bastardo et al., 2021). Resolving technical issues and scaling up the production could help reduce the cost and make it more competitive.

Indonesia could potentially pursue the production of turquoise hydrogen as a strategy to decarbonize its natural gas resource utilization. Noting that Indonesia's natural gas reserve is abundant, turquoise hydrogen production is a potential technological route to continue using natural gas with zero carbon emissions. In addition, the black carbon byproduct could generate additional revenues by selling it as a reinforcing material to local and foreign rubber product manufacturers, especially automobile tire producers.

d. Pink Hydrogen

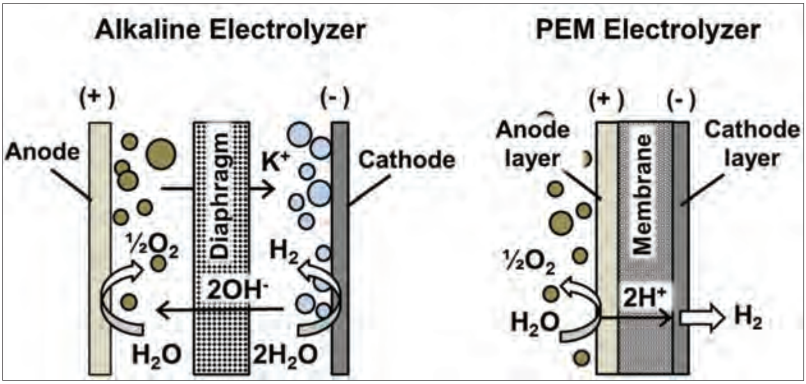
Hydrogen from nuclear-powered electrolysis is known as pink hydrogen. Although nuclear is not classified as a renewable energy source, the electricity derived from nuclear is carbon-free and hence is attractive to producing clean hydrogen. Furthermore, the heat generated from the nuclear reactor can be potentially harnessed to generate hydrogen via the thermal splitting of water or the thermal electrolysis process. The levelized cost of pink hydrogen is estimated to be US$2.50–3.23/kg (World Nuclear Association, 2021a).

With Indonesia's abundant uranium resources in Kalimantan and possibly West Papua (World Nuclear Association, 2021b), pink hydrogen is attractive zero-carbon hydrogen to be produced in the country. However, the realization of pink hydrogen largely depends on the social and political acceptance of nuclear energy which is currently considered low in the context of Indonesia. Overcoming these social and political issues revolving around nuclear energy can make pink hydrogen appealing to be incorporated into Indonesia's clean hydrogen mix.

e. Green Hydrogen

Green hydrogen means hydrogen generated from renewable energy. It is considered the most suitable form of hydrogen for energy transition toward net-zero emissions. Water electrolysis powered by renewable electricity has received tremendous attention for producing green hydrogen. The process involves two electrodes in the electrolyte solution and is connected to the renewable power supply. When a sufficient potential difference is applied between the electrodes, water is split into hydrogen on the cathode and oxygen on the anode.

To date, alkaline and proton exchange membrane (PEM) electrolyzers are the most advanced electrolyzer technologies with their advantages. Figure 11.4 depicts the setups of alkaline and PEM electrolyzers and selected characteristics of alkaline and PEM electrolyzers are presented in Table 11.2. Alkaline electrolyzers, which use a potassium hydroxide electrolyte, are the most commercially available and mature method for water electrolysis with lower capital costs. However, PEM electrolyzers, which are currently more expensive, offer a much smaller footprint, higher current density, and output pressure (Bruce et al., 2018; Schmidt et al., 2017).



Source: Esposito (2017)

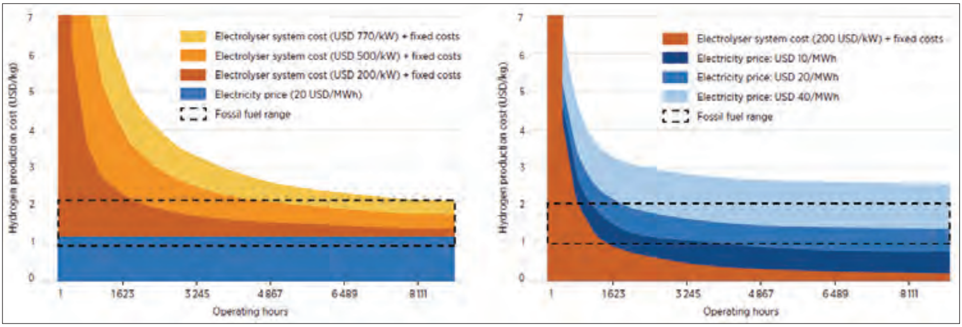
Figure 11.4 Schematic Diagrams of Alkaline and PEM Electrolyzers

Table 11.2 Selected Characteristics of Alkaline and PEM Electrolyzers

	Alkaline Electrolyzer	**PEM Electrolyzer**
Electrolyte	Aqueous KOH	Polymer membrane
Current density (A cm^{-2})	0.2–0.4	0.6–2.0
Cell pressure (bara)	<30	<70
System efficiency (kWh $kg_{H_2}^{-1}$)	4.5–6.6	4.2–6.6
Lifetime (h)	60,000	50,000–80,000
Capital cost for the entire system, >10 MW (US$ kW^{-1})	500–1000	700–1400

Source: Schmidt et al. (2017) & Taibi et al. (2020)

Major barriers to green hydrogen production are its high capital and operational costs. Green hydrogen is still much costlier (US$3.00–8.00/kg hydrogen) compared to gray and blue hydrogen (IEA, 2021). The production cost of green hydrogen is influenced by renewable electricity price, electrolyzer cost, and operational capacity as shown in Figure 11.5. The largest cost component for hydrogen production is the price of renewable electricity to power the electrolyzer system. Consequently, a low electricity cost is necessary to make green hydrogen production more competitive with other shades of hydrogen. However, declining renewable electricity cost alone is likely insufficient to reduce green hydrogen costs to the fossil hydrogen range. Lowering the cost of the electrolyzer and increasing its efficiency is also essential. Shortly, green hydrogen could be on par with blue and even gray hydrogen if continuous improvements in renewable power and electrolyzer technologies, as well as rapid process scale-up, are made.

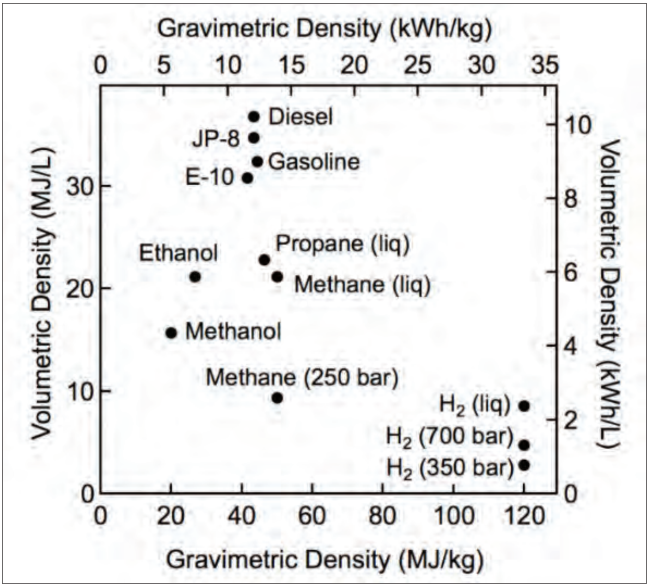


Source: IRENA (2020)

Figure 11.5 Hydrogen Production Cost as a Function of Electrolyzer Capital Cost, Electricity Price, and Operating Hours

2. Hydrogen Storage

Hydrogen storage is a crucial technology if widespread applications of hydrogen are expected. As a result, establishing robust and reliable hydrogen storage is of importance. Although hydrogen exhibits high gravimetric density, the volumetric density of hydrogen in either gaseous or liquid state is relatively low as illustrated in Figure 11.6. Consequently, efficient hydrogen storage with low space requirements and inexpensive cost is challenging. In general, hydrogen storage techniques can be classified into two main categories: physical- and material-based storage (Moradi & Groth, 2019).



Source: U.S. Department of Energy (n.d.)

Figure 11.6 Gravimetric and Volumetric Energy Density of Hydrogen Compared to Other Fuels

a. Physical-Based Storage

The physical-based hydrogen storage system comprises compressed gas, cryo-compressed, and liquid hydrogen storage (Moradi & Groth, 2019). In unpressurized gaseous form, hydrogen has a low volumetric density and requires a huge storage space. Thus, keeping large volumes of hydrogen in an unpressurized system is not economically viable due to space limitations and high capital costs. Compression of hydrogen gas is the most common and mature technique to improve its volumetric density. The compressed hydrogen can then be stored in pressure vessels at dedicated facilities.

If large volumes of hydrogen are required, hydrogen can be injected into underground geological formations (Osman et al., 2021). For example, depleted hydrocarbon reservoirs are appealing sites to store hydrogen underground due to their storage capacity.

Salt caverns are another potential underground storage medium. The key advantages of hydrogen storage in salt caverns are their high impermeability and flexibility of hydrogen discharge rate, duration, and volume (Osman et al., 2021).

Hydrogen can also be physically stored in its liquid or supercritical phase through liquefaction or cryo-compression. Compared to gas compression, these two processes exhibit higher capital and operation costs, mainly due to the extensive energy requirements for cooling to cryogenic temperature and expensive materials for cryogenic storage vessels. However, both technologies could be more viable if the hydrogen demand is very high.

b. Material-Based Storage

Although physical-based hydrogen storage offers volumetric density improvement, the space requirement is still considered large compared to other fuels. Converting hydrogen into its material derivatives with higher volumetric energy densities is attractive to improve storage efficiency. Ammonia, methanol, and metal hydrides are appealing candidates for material-based hydrogen storage.

Ammonia is a promising material-based hydrogen carrier because of its high hydrogen density and flexibility in its utilization. Conventionally, ammonia is produced via the Haber-Bosch process where nitrogen reacts with hydrogen at high temperature and pressure in the presence of a catalyst. The facilities for ammonia production exist widely in Indonesia. Therefore, storing hydrogen as ammonia does not require a high capital cost to build new infrastructures. Ammonia can be utilized by extracting its stored hydrogen or directly used as fuel. More importantly, ammonia can be easily liquefied and its storage, as well as delivery methods, are well-established. However, liquid ammonia has a higher gravimetric density than compressed and liquid hydrogen, thus leading to heavier storage (Aziz et al., 2020). In addition, releasing hydrogen from ammonia requires a relatively huge amount of energy, and a separation process is necessary to obtain high hydrogen purity.

Methanol is also a promising candidate for liquid organic hydrogen carriers that could enable carbon dioxide utilization via hydrogenation. Since methanol is liquid at ambient temperature and pressure, storage and transport are easy with the existing infrastructure. Methanol can be used directly as liquid fuel or split to release hydrogen via thermolysis, steam reforming, and partial oxidation with a low energy requirement.

Metal hydrides have recently emerged as a solid-state hydrogen storage option. The key advantage of metal hydrides is their much higher volumetric densities compared to the gaseous and liquid forms of storage. In addition, storing hydrogen as metal hydrides could minimize the hazards of pressurized hydrogen gas or liquified hydrogen. Unfortunately, the use of metal hydrides is mainly limited to stationary applications. Metal hydrides are deemed challenging to apply for mobility uptake because of the temperature requirements, the weight of storage units, and poor kinetics of hydrogen release (Bruce et al., 2018).

3. Hydrogen Transport

The delivery of hydrogen from the producers to end users is essential for a viable hydrogen infrastructure. Currently, hydrogen is typically produced near industrial facilities that use hydrogen as the feedstock. For instance, SMR and coal gasification plants in Indonesia are predominantly located within oil and gas refineries or petrochemical industries to serve as reagents for hydrotreating, hydrocracking, hydrogenation, or ammonia production. In this case, hydrogen transport is relatively simple and inexpensive due to the short distance and low or moderate quantity. Since hydrogen is emerging as an energy vector and feedstock for decarbonizing a number of major economic sectors, transporting hydrogen at a longer distance and in higher quantity is important. The key challenge is the investment cost required to build the appropriate infrastructure. In the context of Indonesia, hydrogen transport is even more challenging due to its geographical conditions.

Generally, hydrogen may be transported using land transports such as trucks and rails with inexpensive costs for short-distance delivery and low volumes of hydrogen. If delivery across islands and international export is required, hydrogen transport by ship is a transport mode that can be used. In addition to those three modes of hydrogen transport, pipeline offers simultaneous distribution with greater delivery distance (Bruce et al., 2018). Although pipeline distribution is considered a suitable delivery method to support widespread hydrogen uptake, transport of hydrogen via pipeline is complex. To reduce the pressure on new pipeline infrastructure installations, injecting hydrogen into the existing natural gas pipeline is an attractive option that can also help decarbonize the gas sector. If pure hydrogen is demanded, new pipelines or upgraded existing natural gas pipelines are necessary due to the gas property differences.

The delivery of hydrogen in its physical-stored form is difficult due to the lack of perfectly suitable infrastructure. Storing hydrogen as chemicals or material derivatives with more mature infrastructure (e.g., ammonia, methanol, and synthetic natural gas) can be a promising solution during the transition period toward hydrogen economy while further expanding pure hydrogen transport infrastructure. Indonesia is one of the largest ammonia and methanol producers in the world. Consequently, Indonesia has sufficient capability to distribute those material-based hydrogen carriers.

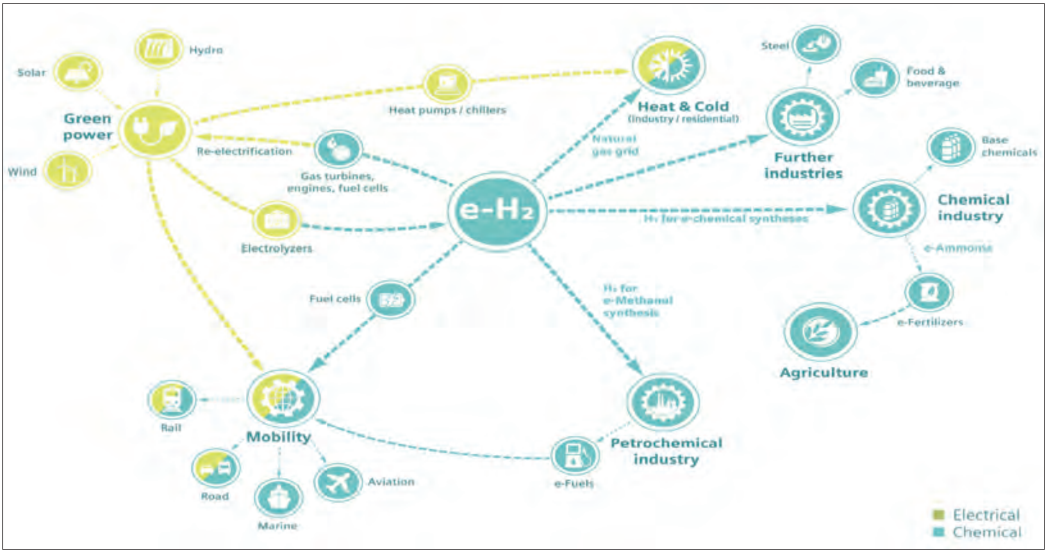
4. Hydrogen Utilization

For years, hydrogen has been extensively used as a reagent in numerous industries. Today, the top three uses of hydrogen are petroleum refining (33%), ammonia production (27%), and methanol synthesis (11%) (IEA, 2019).

In a petroleum refinery, hydrogen is predominantly required for hydrotreatment and hydrocracking processes. Hydrotreatment uses hydrogen to remove sulfur, nitrogen, and other contaminants from petroleum oil to create a cleaner fuel. Hydrocracking is a process that cracks long-chain heavy hydrocarbons to form valuable products such as gasoline, kerosene, diesel, and avtur. In addition to fossil refinery, hydrogen plays a key role in biorefinery as a reagent in the hydrodeoxygenation process to produce biofuels.

The chemical sector takes the second and third places for the largest sources of hydrogen demand including ammonia and methanol manufacturing. Ammonia is produced via a mature Haber-Bosch process by reacting nitrogen with hydrogen at high temperature and pressure in the presence of a catalyst. Currently, ammonia is mainly adopted as a feedstock for agricultural fertilizer production. More recently, ammonia is also seen as a highly potential carbon-free fuel. As the third-largest industry using hydrogen, methanol synthesis typically proceeds via carbon dioxide or carbon monoxide hydrogenation. Approximately 65% of methanol is consumed for chemicals and fuel additives production (Dalena et al., 2018).

As the world races to decarbonize, green hydrogen is expected to have broader applications. Through power-to-X (P2X) framework, hydrogen could enable deep decarbonization of hard-to-abate sectors, which is widely known as sector coupling (Figure 11.7). P2X is defined as a method of converting renewable electricity into liquid or gaseous chemical energy via electrolysis (Gunawan, 2022). Producing hydrogen through water electrolysis is at the core of P2X due to the versatility of hydrogen across different sectors.



Source: Schnettler (n.d.)

Figure 11.7 Power-To-X Framework for Decarbonizing Hard-To-Abate Sectors Using Hydrogen

The primary challenge of integrating renewable energy into the existing grid in the electricity sector is its intermittency. At times, the energy supply is higher than the demand, while the generated power is too little at other times. For instance, solar electricity production depends on the amount of sunlight reaching the solar panels and wind-generated power depends on wind velocity and air density. Therefore, adequate storage solutions are essential to resolve intermittency and ensure grid stability. Even though battery is the most common storage solution, its capacity and storage timespan are limited (Hydrogen Council, 2017). On the other hand, hydrogen offers a promising solution for long-term storage, facilitating the resilience of the grid system. Excess renewable electricity can be converted through electrolysis into hydrogen gas during oversupply. The produced hydrogen can then be transformed back to electricity using a fuel cell or a gas turbine during power deficits.

In terms of power distribution, hydrogen represents a promising energy carrier thanks to its high energy density. Hydrogen can be distributed over long distances via pipelines with nearly 100% efficiency (Hydrogen Council, 2017). In the national-level energy system, this could enable a centralized or decentralized primary or backup power source. Furthermore, in the context of global energy supply, hydrogen is a powerful enabler to exporting renewable electricity at competitive pricing, potentially ramping up national revenue.

As a versatile energy vector, hydrogen can link heat and electricity sectors (Gurieff et al., 2021). Nowadays, heating applications for domestic and industrial purposes are dominated by petroleum oil, natural gas, or coal as fuel. For example, liquefied petroleum gas (LPG) and liquefied natural gas (LNG) are typical cooking gases utilized in Indonesia. Coal or natural gas are burned to produce heat in industries requiring high thermal energy input (e.g., petrochemical and cement manufacturers). Hydrogen can help decarbonize the heat generation process through two different scenarios. The first scenario is the natural gas enrichment with hydrogen. Blended 10–15% hydrogen with natural gas can be applied using the existing infrastructures and appliances, thereby reducing the cost needed for system upgrades (Bruce et al., 2018). The second scenario, deemed more consistent with the net-zero targets, utilizes pure hydrogen to replace fossil fuels for heating applications. However, this approach will require replacing or upgrading of the existing infrastructures and appliances, rendering high capital costs.

Hydrogen can also power vehicles using a fuel cell generating electricity to run the car. Fuel cell electric vehicles (FCEVs) offer numerous key benefits such as long travel distances without refueling along with a fast-refueling rate (Hydrogen Council, 2017). Although past attempts to switch to FCEVs were baffled by the presence of battery electric vehicles (BEVs) mainly due to the lack of hydrogen refueling infrastructure, the benefits of FCEVs render them necessary in decarbonizing passenger cars, heavy-duty transport, and public transport (buses and trains). In Indonesia, for instance, the state-owned Indonesian Railways Company (PT KAI) submitted a memorandum of understanding (MoU) to Alstom on a project for hydrogen-powered trains in 2019 (Aditiya & Aziz, 2021).

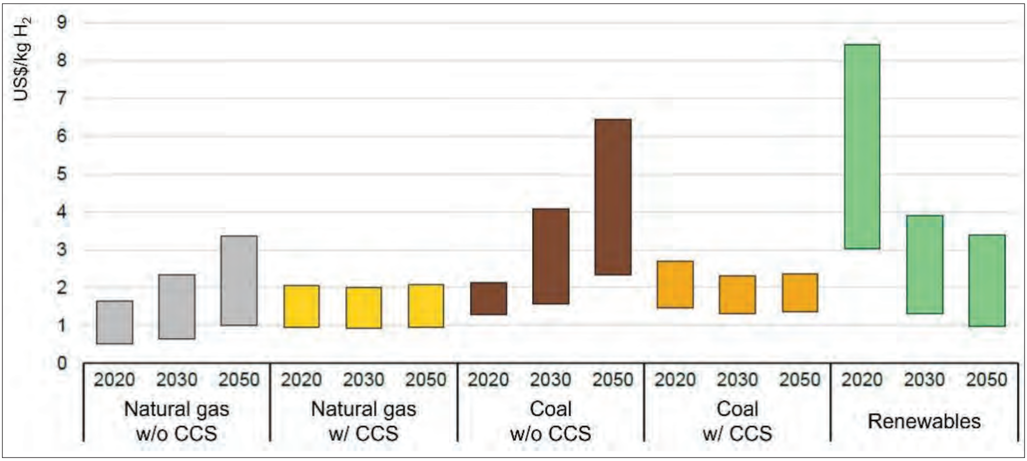
As an industrially important feedstock, hydrogen is essential in manufacturing chemicals and fuels, as described earlier. Replacing the existing gray hydrogen with green hydrogen can significantly reduce carbon footprints. In addition, carbon dioxide from emission points or the atmosphere can be processed using green hydrogen to produce valuable chemicals and fuels via methanation, hydrogenation, or Fischer-Tropsch, thereby helping close the carbon loop in heavy sectors (Daiyan et al., 2020).

C. Existing Barriers for Hydrogen Uptake in Indonesia

Hydrogen is a compelling energy carrier and industrial feedstock, and mainly green hydrogen offers a promising pathway toward a net-zero future. In Indonesia, numerous green hydrogen initiatives have appeared in recent years by state-owned and private companies. The highly abundant renewable resources, ranging from solar, hydropower, wind, biomass, geothermal to tidal, are the main driver for the green hydrogen industry in Indonesia. Nevertheless, a number of barriers that may limit the uptake of hydrogen-related technology in Indonesia exist and need to be tackled before the full benefits of hydrogen are manifested.

1. High Production Costs

At the moment, green hydrogen produced using renewable electricity is costlier than gray and blue hydrogen. In addition, utilizing green hydrogen for new downstream applications can be more expensive than its fossil counterparts. In terms of production, the major contributors to the green hydrogen price are the costs for renewable electricity generation and electrolyzers. Nevertheless, the levelized cost of green hydrogen is expected to fall by 2050 thanks to the continuous improvements in cost and performance of renewable and electrolyzer technologies. More importantly, the cost of green hydrogen could be more competitive compared with gray and blue hydrogen, as presented in Figure 11.8, if supporting policies are implemented.



Source: IEA (2021)

Figure 11.8 Levelized Cost of Hydrogen Production by Technology in 2020 and the Estimated Cost in 2030 and 2050 Under the Net-Zero Emissions Scenario

2. Lack of Hydrogen Infrastructure

Up to now, most of the hydrogen in Indonesia is produced near utilization sites, such as petroleum refinery, biorefinery, and petrochemical manufacturing plant. Consequently, dedicated hydrogen transport infrastructures are limited, especially for long-distance delivery. For fuel cell electric vehicle applications, hydrogen uptake is also currently hindered due to the absence of refueling stations. Therefore, investments in hydrogen infrastructure with a long horizon are needed.

3. Absence of National Hydrogen Strategy

Developing a hydrogen economy requires a coordinated effort by the government, industry, and research community. A national hydrogen strategy, which comprises a roadmap and a set of policies, is essential to synergize all stakeholders. The lack of a clear national strategy indicates the poor commitment made by the government on hydrogen and eventually discourages potential investors.

4. Insufficient Recognition of Hydrogen Value

Today, the hydrogen capability to reduce carbon footprints in various sectors is recognized as a concept but does not receive enough valuation. In Indonesia's energy statistics, hydrogen is not listed in the total final energy consumption (Kementerian ESDM, 2020). While the government continues to increase cash subsidy for fossil fuels which accounts for 8% of Indonesia's total budget in 2020 (Sumarno & Sanchez, 2021), the incentives to promote the use of green hydrogen are lacking, thereby restricting potential markets for green hydrogen.

D. Indonesia's Pathway to a Hydrogen Economy

The hydrogen economy decarbonize hard-to-abate sectors such as cement, steel, chemicals, and heavy-duty transportation. These sectors are difficult to electrify directly using renewable electricity due to the nature of the processes, high-temperature heat requirements, and/or high-density energy source requirements. As nearly a third of global carbon dioxide emissions are attributed to these sectors, a viable alternative solution to decarbonize hard-to-abate industries is vital. Hydrogen, particularly green hydrogen, appears to be the most promising decarbonization pathway for these sectors.

Implementing green hydrogen as a widespread energy carrier in Indonesia will require meticulous national strategies and a set of comprehensive national policies to overcome existing barriers. Unfortunately, Indonesia has not formulated any hydrogen roadmap and policies yet. To stimulate the development of the hydrogen industry in Indonesia, herein, a national hydrogen strategy, which comprises a detailed national hydrogen roadmap and enabling policies, is proposed according to Indonesia's current position and existing barriers in hydrogen uptake across the country.

1. Establishing Indonesia's National Hydrogen Roadmap

Developing a sustainable hydrogen economy in Indonesia to achieve net-zero emissions targets can be daunting without comprehensive early planning. While many countries have published their hydrogen strategies, Indonesia has not drafted any step-by-step roadmap to incorporate hydrogen in its energy policies. To accelerate the uptake of hydrogen across different applications on the path to net-zero emissions, the following national roadmap is proposed to the Indonesian government. Indonesia's national hydrogen roadmap should aim for an integrated system across the hydrogen value chain. To meet net-zero emissions by 2060, the roadmap has to focus on green hydrogen as the ultimate target due to its suitability to combat climate change. This proposed national hydrogen roadmap adopts a step-by-step approach including five transition phases. Electrolyzer capacity milestones in each phase are set by considering the best policy scenario proposed by Tampubolon et al. (2021).

Phase 1 (2022–2025)

Indonesia shifts from gray/black hydrogen to blue hydrogen by deploying CCS technology in the existing gray/black hydrogen production facilities. The initial focus is to reduce carbon footprints in industrial applications that already use hydrogen as the feedstock. Hence, the existing hydrogen storage and transport infrastructure can still be used. At the same time, the government has to facilitate the uptake of hydrogen in new downstream applications (e.g., fuel cell power plants, fuel cell electric vehicles, and heating appliances) through project collaborations with stakeholders.

Phase 2 (2026–2030)

Indonesia continues to generate and utilize blue hydrogen while starting the green hydrogen initiative by developing demonstration plants with at least 10 MW capacity each. For instance, the government could build a water electrolyzer for hydrogen production in the North Kalimantan Green Industrial Park (Gunawan, 2022). This steppingstone is expected to encourage state-owned and private heavy industries to build green hydrogen production facilities and gradually phase out fossil hydrogen. At this stage, hydrogen is also likely to expand its applications to public transport (e.g., fuel cell electric buses and trains) in major cities. If possible, the existing facilities provide infrastructure and a number of refueling stations are built to supply the hydrogen demand from fuel cell electric public transport.

Phase 3 (2031–2040)

Indonesia develops five green hydrogen hubs in its major islands including Sumatra, Java, Kalimantan, Sulawesi, and Papua with a total capacity of at least 100 GW (Tampubolon et al. (2021) proposed 138.7 GW capacity as the best policy scenario in 2040). Prospective locations for the green hydrogen hubs are presented in Figure 11.9 based on each renewable energy potential. All industries are expected to use green hydrogen as the feedstock and energy source by building hydrogen power plants. Blue hydrogen can still be used in limited quantities to ensure sufficient supply to meet the demand while ramping up national green hydrogen capacity. The hydrogen applications are further extended to private vehicles (e.g., fuel cell electric cars) and gas networks using natural gas enrichment scenario. In addition, at this crucial phase, Indonesia has to focus on developing the hydrogen infrastructure, including large-scale storage systems (e.g., pressurized vessels and underground storage) and hydrogen pipelines across the country for long-distance delivery.

Source: Adapted from IESR (2018)

Figure 11.9 Prospective Locations for the Green Hydrogen Hubs according to Renewable Potential and Installed Capacity Including Variable Renewables (Solar, Wind, and Tidal) and Controllable Renewables (Hydropower, Biomass, and Geothermal)

Phase 4 (2041–2050)

Indonesia scales up its electrolyzers to a total capacity of at least 200 GW (Tampubolon et al. (2021) proposed 229.1 GW capacity as the best policy scenario in 2050) by upgrading the facilities in selected sites with huge potential for renewables and land availability such as Kalimantan and Papua hubs. The production of blue hydrogen is phased out, but natural gas may still serve as raw material for turquoise hydrogen production if viable. At this phase, Indonesia is expected to continue the construction of hydrogen infrastructures to ensure a just energy transition while developing a capability to export hydrogen and its derivatives.

Phase 5 (2051–onward)

Indonesia becomes a global hydrogen powerhouse in which green hydrogen reaches maturity and is deployed across various sectors. Green hydrogen, ammonia, and methanol are exported to resource-constrained countries in Asia-Pacific such as Singapore, Japan, and South Korea, thereby generating additional revenues.

2. Establishing Supporting Policies to Overcome Barriers

In addition to a national roadmap, the government should support the development of a green hydrogen economy through enabling policies to overcome existing barriers. The policies reflect the government's commitments to integrating hydrogen into the national energy system toward a net-zero future across all sectors.

Regarding hydrogen production, green hydrogen currently suffers from higher costs due to expensive renewable energy technologies and electrolyzers. Numerous policies can help reduce the cost of green hydrogen. First, the government should set optimistic yet realistic targets for national renewable energy share and electrolyzer capacity. The proposed national hydrogen roadmap targets could attract domestic and foreign investors. Second, cutting taxes and providing incentives for the installations of renewable energy infrastructures and electrolyzers will increase capacity growth rate, thus reducing the price as well as ramping up revenues and the rate of return. Support for research to improve electrolyzer efficiency via funding and international collaborations are also essential to lower the capital costs.

Another significant challenge of hydrogen is the lack of infrastructure for storage and transport. To overcome financial issues for infrastructure developments, the government has to collaborate with developed countries through global trading agreements. In addition, green policies need to be formulated to encourage private sectors to develop hydrogen infrastructure. For instance, a carbon taxing policy where carbon dioxide emissions are priced as the environmental cost could stimulate industry to phase out fossil fuels and build the capacity to produce, store, and transport green hydrogen. More importantly, a national timeline to phase out high-emission technologies will push industries to develop end-use technologies that align well with hydrogen, thereby creating a new market for green hydrogen.

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Section 3
Indonesia's New Strategy to Achieve Net-Zero Emission in 2060

Chapter 12

Socio-Economic Impacts of Renewable and Carbon-Neutral Energy Development

Nevi Cahya Winofa

A. Overview of Socio-Economic Impact of Renewable and Carbon-Neutral Energy Development

Energy is the input of nearly all economic activities. Having the fourth largest population in the world and Southeast Asia's largest economy, Indonesia has the largest energy consumption in the Southeast Asia Region, accounting for 40% of the total energy consumption. Hence, Indonesia's energy supply structure is critical for determining economic development. In COP26, Indonesia has pledged to achieve a 29% reduction in greenhouse gas emissions by 2030 and net-zero emission by 2060. One of the mitigation measures in the energy sector is increasing renewable energy shares by 23% in 2025 and 31% in 2050.

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Winofa, N. C. (2022). Socio-economic impacts of renewable and carbon-neutral energy development. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (239–266). BRIN Publishing. DOI: 10.55981/brin.562.c12 ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

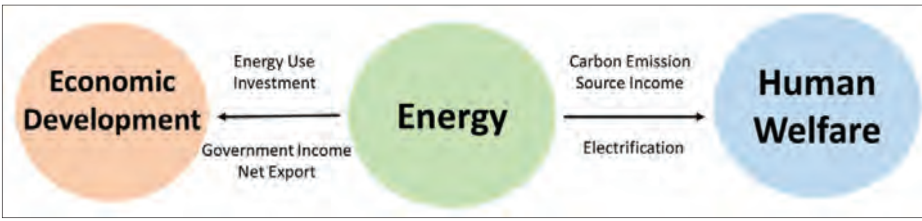
Table 12.1 The Scope of the Chapter

	Socio-Economic Benefit	Key Challenges	Policy and Recommendation
Renewable and Carbon free Energy Economic Development Human Welfare	**1. Energy Security** a. Diversified Energy Sources b. Reducing Reliance on Import	**1. Competitiveness of Renewable and Clean Energy Cost to Conventional Energy** a. Unfair competition with subsidized fuel b. Unseen positive externalities	**1. Competitive Renewable and Clean Energy Cost** a. Removing Fossil Fuel Subsidy b. Carbon Pricing
	2. Boost Economic Growth a. Increase Investment b. Activate Domestic Industries	**2. Increase Investment in Renewable and Clean Energy Cost** a. Lack of Transparancy and low predictability in procurement b. Risk Allocation c. Unsupportive Tariff System	**2. Accelerate Investment in Renewable and Clean Energy** a. Reforming Tariff Cap b. Restructure Risk Allocation c. Renewable and Carbon Free Energy Auction Program
	3. Job Creation A high Demand of workers from Equipment and Infrastructre **4. Human Welfare** Increase household consumption, income, and improve air-quality	**3. Positive net employment: balancing between growth in renewable and clean energy and losses in fossil fuel employment.** a. Dislocated workers b. A high demand of high skill workforce	**3. Achieving Positive Net Employment** a. Reskilling and Upgrade Skill Fossil Fuel Workers b. Building the skill of new entrance
	4. Gender Equality Broad range of Multi dicipline Role	**4. Low women participation in renewable and clean energy job** a. Cultural, Social Norm, and Stigma b. Low participation in STEM field	**4. Balancing gender participation in deployment of renewable and clean energy** a. Integrating gender in each value chain of renewable and clean energy b. Improving access to STEM education and training

While meeting the environmental objective, energy transition also impacts the social and economic aspects. This chapter reveals a full range of macroeconomic benefits of renewable and carbon-neutral energy deployment: increasing energy security, fueling GDP development, creating job opportunities, enhancing human welfare, and achieving gender equality. Several challenges need to be tackled to maximize the benefit of the energy transition, such as uncompetitive renewable and carbon-neutral energy cost to conventional energy, lack of renewable and carbon-neutral energy investment, gap in achieving positive net employment, and low participation of women in renewable and carbon-neutral energy jobs. Some policies and recommendations are also proposed to address the challenges of renewable and carbon-neutral energy development in Indonesia. Figure 12.1 summarizes the scope of discussion in this chapter.

B. An Overview: Energy Structure, Economic Development, and Human Welfare

The energy structure has a high impact on economic and human welfare. Figure 12.1 shows the relationship between how changes in the energy sector will influence economic and human welfare. Energy contributes to each component of GDP: consumption, investment, government income, and net export. Although the impact of energy structure on human welfare is already reflected in GDP, energy has additional impacts such as carbon emission, source of income, and electrification, which also has a derive impact on the quality of health and education.

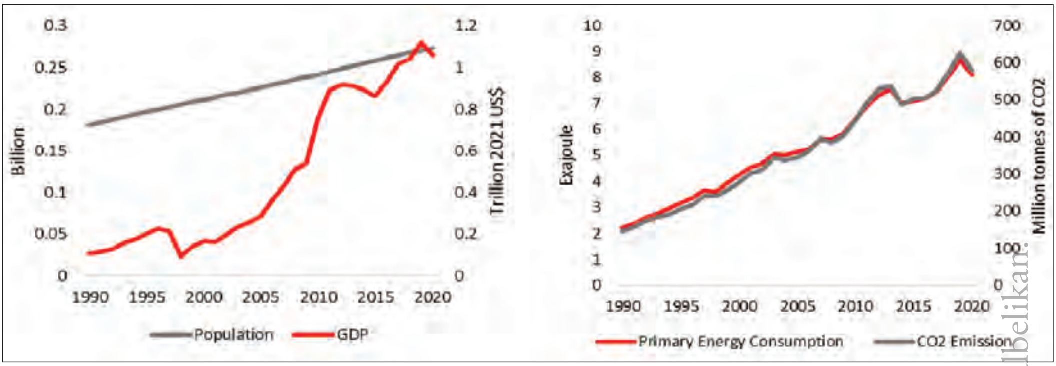


Source: modified from IRENA (2016)

Figure 12.1 The Relationship between Energy, Economic Development, and Human Welfare

1. Current Indonesia's Energy Structure, Economic Development, and Human Welfare

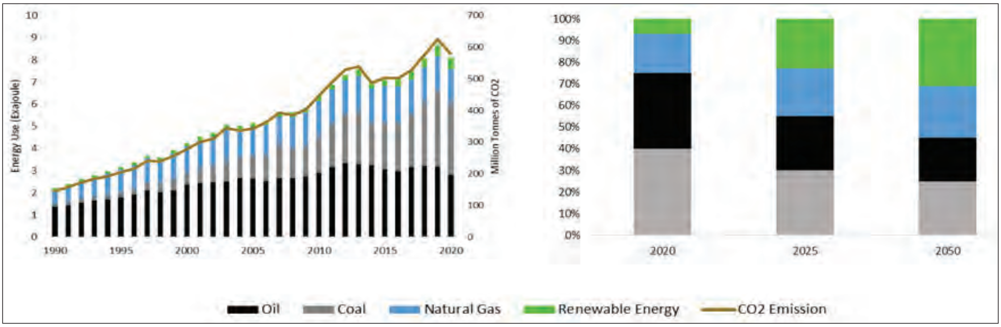
With a population of 277 million which is constantly growing by 1–2% per year between 1990 and 2020, Indonesia has become the fourth most populous country in the world (Worldometers, 2022). Regarding economic development, Indonesia has had a remarkable economic growth of 5% on average GDP growth per year for more than thirty years (BP Statistical Review, 2021). Therefore, the country becomes the largest economy in Southeast Asia and the tenth-largest global economy in terms of purchasing power (World Bank, 2021). This impressive development is also reflected in Indonesia's energy consumption. Figure 12.2 shows that the primary energy consumption has a similar trend with the GDP. Energy demand grows as the economy develops. However, it also can be seen that CO_2 emission also increases as energy consumption increases.



Source: World Bank (2022) & BP Statistical Review (2021)

Figure 12.2 Population and Economic Development (Left) and Total Energy Use and CO_2 Emissions Trend (Right)

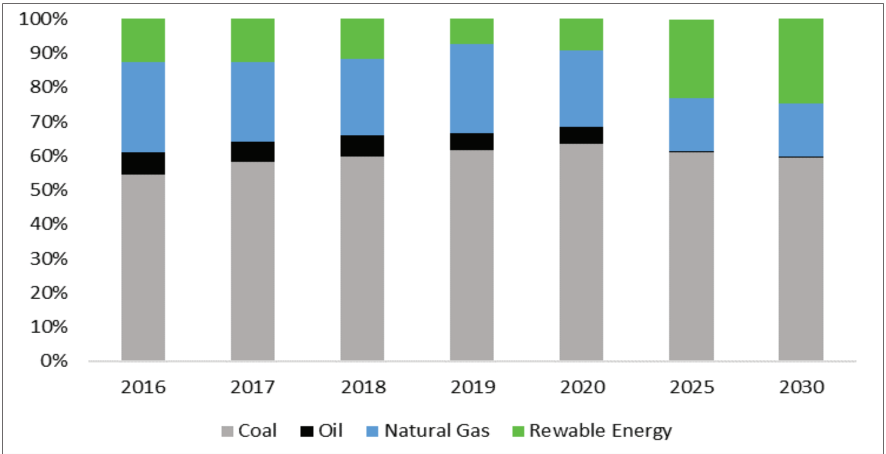
Looking into more details, the energy supply in Indonesia is still dominated by fossil fuels which are coal, oil, and natural gas. Figure 12.3 (left) shows the development of Indonesia's energy mix. Although the share of oil consumption has declined, the share of coal has soared especially in the last ten years. Undoubtedly, CO_2 emission has increased as energy use increases because it was mainly supported by fossil fuels. This condition was the opposite of the country's commitment to reduce greenhouse gas emission by 2030 and to achieve net-zero emissions in 2060. Figure 12.3 (right) shows that fossil fuel contributed 93% to total energy consumption in 2020 (coal: 40%), (oil: 35%), and (natural gas: 18%) while renewables only contributed 7%. It is still far from the country's energy mix transformation target to increase the renewable shares from 23% in 2025 to 31% in 2050 as stated in the Government Regulation No. 79/2014 on National Energy Policy.



Source: BP Statistical Review (2022)

Figure 12.3 The Development of Indonesia's Energy Mix (Left) and Comparison Between Current Energy Mix and Target in 2020 and 2050 (Right)

The demand for coal mostly came from electricity consumption. The electricity generation still heavily relied on coal. Coal utilization in electricity generation has consistently increased by 2% over the last five years. Accounting for 64%, coal is the main resource of electricity generation in 2020, followed by natural gas at 23%, renewables at 9%, and oil at 5%. According to the National Power Generation Plan in RUPTL 2021–2030, the power generation will continue to be dominated by coal for the next ten years (Figure 12.4). The increase in the share of renewables is from replacing the diesel power generation only from 3T (front, outermost, and disadvantaged) regions. Knowing that fossil fuel is less expensive, the state electricity company (PLN) faces conflicting challenges between increasing the share of renewables and keeping the rate of BPP (electricity generation cost). Although the PLN applied co-firing to reduce the environmental damage of coal, it will continue to be a major supplier of electricity.



Source: PT PLN (2020)

Figure 12.4 Indonesia Electricity Energy Mix and Its Target in 2025 and 2030

2. How COVID-19 Changes Energy Demand and Economic Structure

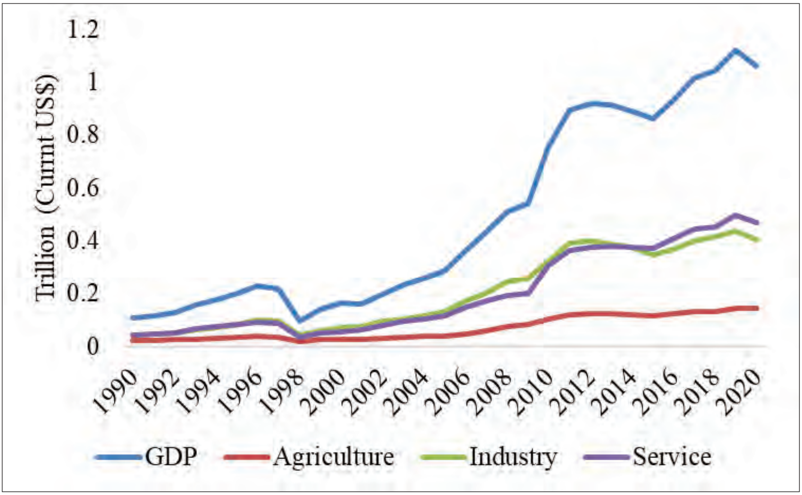
Despite impressive economic progress, the sudden shock due to the COVID-19 pandemic has shrunk Indonesia's economic growth by 6% in 2020 (World Bank, 2022). This condition was the biggest falling since the financial crisis in 1998. The rapid spread of the virus has significantly reduced productivity, increased unemployment, loss of life, and closed businesses. This made the government of Indonesia concentrate its effort on the health and economic recovery.

The pandemic has also impacted the energy sector with a decline by 7% in total energy demand. To mitigate the massive spread of the virus, travel restrictions were imposed, leading to a cut-off on gasoline and diesel fuel consumption by 15–20% and jet fuel consumption by 30–0% (McKinsey & Company, 2020). The large-scale restrictions in major cities resulted in a delay in several energy projects, affecting energy companies' profit and reducing the new investment. PT Pertamina (state oil company) and PT PLN reported experiencing US$768 million loss and almost no profit in the first half of 2020, respectively (McKinsey & Company, 2020). Several under-construction projects need to be delayed in renewable and carbon-neutral energy development. Some funding distribution also got delayed because of the concern of project sustainability during the pandemic. As a result, this condition has pushed back the target from the original plan.

Although the country suffers from the shock, its economy will gradually come back as large-scale tracing, tracking, and vaccination of COVID-19 has been widely applied. The World Bank (2021) estimates that Indonesia's economy will continue to recover in 2021 and accelerate in 2022. It is known that economic development will drive an increase in energy demand. The significant growth of energy demand post-COVID-19 is an opportunity to promote renewable and carbon-neutral energy to supply additional energy demand.

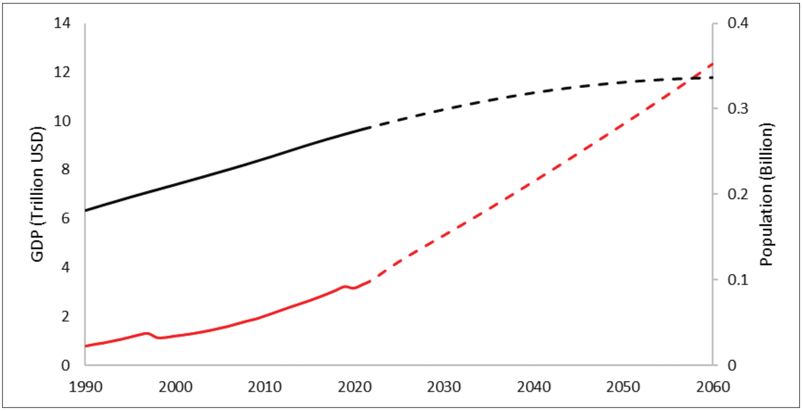
3. Projection of Economy and Energy Demand in 2030 and 2060

As energy efficiency improved, the economy moved from the industrial sector (highly energy-intensive sector) to the service sector (less energy-intensive sector). Figure 12.5 shows the changes in structural economic activity over three decades. It is projected that the service sector will be continuing to grow in the future. Even though Figure 12.6 shows that this is projected to increase until 2030 and even until 2060, energy demand will increase at a slower rate in line with slow growth in population compared to GDP. This is a momentum for renewable and carbon-neutral energy to take over the energy market. While the preparation is underway, consistent energy policies and regulations must be introduced to ensure that Indonesia does not miss the momentum to strengthen the green economy.



Source: World Bank (2022)

Figure 12.5 The Development of Indonesia Structural Economy



Source: World Bank (2020) & OECD (2018)

Figure 12.6 Current and Projection of Indonesia's Population and Economic Growth

C. Socio-Economic Benefit of Renewable and carbon-neutral Energy

While achieving greenhouse gasses reduction targets, the deployment of renewable and carbon-neutral energy has multiple benefits to economic and social development. This subchapter discusses how increasing renewable and carbon-neutral energy share in the energy mix can improve economic and human welfare.

1. Energy Security

Maintaining an adequate and stable supply of energy at a reasonable price has become a serious problem when facing the possibility of economic upheaval. This concept refers to energy security. It is known that energy is the input to economic activity. An inadequate and unstable energy supply potentially disrupts economic activity, leading to macroeconomic dislocation. The probability of disruption is higher when the country relies on other countries to meet its national demand. Any political action restricting the energy supply can be a major national threat. Indeed, by engaging in international trade, the country must face the uncertainty of the world price of energy. In addressing energy security, the idea of diversification of energy sources and reducing imported energy has been echoed. It is known that energy transition plays an important role in those areas while also achieving environmental objectives.

a. Diversifying energy sources

Renewable and carbon-neutral energy can contribute to ensuring a stable energy supply through energy resource diversification. Increasing the share of renewable and carbon-neutral energy in the energy mix gives an ability to substitute among other energy sources, which help to reduce the risk of disruption in the energy supply. It is known that oil and gas prices, sometimes, can be extremely volatile. Thus, the availability of renewable and carbon-neutral energy as a substitute can help avoid price uncertainty. It was seen in Japan when they were facing the oil shock in the 1970s. They tried to diversify their energy source for electricity generation by increasing nuclear energy, gas and coal and promoting energy efficiency and conservation. Therefore, energy policy needs to be made to reduce the cost of renewable and carbon-neutral energy to benefit energy security.

b. Reducing reliance on imported energy

Increasing renewable and carbon-neutral energy shares can make the country more independent in supplying energy. It is known that Indonesia currently imports 50% of its energy use. The country is net importer of crude oil with more than 236,000 bpd of imported crude oil in 2020 (EIA, 2021). Already net imported crude oil, Indonesia is also predicted to be net imported natural gas for the next five years (McKinsey & Company, 2020). This condition makes local energy production critical to reducing the reliance on energy supply from foreign countries. Deploying renewable and carbon-neutral energy can increase domestic energy production, reducing energy import. While increasing local production, it also pushes the risk of disruption in energy supply from external factors. In this case, an energy policy to increase renewable and carbon-neutral energy investment is valuable to increase its contribution.

2. Boosting Economic Growth

Energy drives economic growth. The changing structure of the energy supply will directly impact the economic development shown in national GDP growth. A reliable, secure, and most importantly environmentally friendly energy resource is equally important in stimulating economic growth. Bappenas (2021) predicted that the economy will grow 6.1–6.5% on average per year between 2021 and 2050 through a low-carbon growth path. The robust increase in GDP is mainly caused by an increase in renewable and carbon-neutral energy investment and a reduction in energy import.

a. Increasing investment

An increase in renewable energy investment will trigger economic growth. It is known that the characteristic of renewable energy development is capital-intensive. In other words, it has a high upfront investment (physical asset) while having a low operational cost (fuel cost). An increase in the share of renewable energy in the energy mix will increase the demand for investment in infrastructure. Therefore, renewable and carbon-neutral energy investment needs to be scaled up to meet the growing demand.

b. Accelerating domestic industries growth

Another important renewable and carbon-neutral energy role in raising economic development is growing domestic industry. Renewable and carbon-neutral energy development will activate the construction and manufacturing sectors. This can be a source of national income, directly giving additional value to GDP. While stimulating activity in the construction and manufacturing sector, it also contributes to ensuring energy supply and increasing job opportunities. It still does not count the positive impact of the increase in the electrification rate, which also encourages economic productivity. Thus, it is reasonable that renewable and carbon-neutral energy significantly contributes to enhancing economic growth.

3. Job Creation

Job creation is always a national concern because it benefits from skill acquisition, gender equality, and reducing social conflict. Increasing the employment rate is also indirectly related to increasing GDP and improving human welfare. With a well-designed policy, deploying renewable and carbon-neutral energy can result in positive net employment. By pursuing net zero-emission, Indonesia potentially creates 1.8–2.2 million jobs in 2030 in renewable energy, electric vehicle technologies, energy efficiency, land use interventions, and improved waste management (Bappenas, 2021). The increase in employment rate results from the growing renewable and carbon-neutral energy technology industry and its related infrastructure.

Renewable and carbon-neutral energy development will activate a broad range of industries starting from equipment manufacturers industries, the construction and installation, operation and maintenance, and fuel supply until its infrastructure. All these sectors are labor-intensive. It not only needs more workers, but also results in new roles in energy industries that are more specialized. Although there are job losses from conventional energy abandonment, a supported energy transition policy can achieve positive net employment. Therefore, education and skill matching are required to maximize the benefit of renewable and carbon-neutral energy employment.

4. Human Welfare

While decarbonizing the economy, the impacts of renewable and carbon-neutral energy on welfare are equally important. Even though GDP measures country's standard of living, it does not show the full impact on the human welfare of the country. IRENA (2016) reveals that the benefit of an energy transition to human welfare can surpass the GDP growth. Human welfare also needs to consider the effect of the natural resource depletion and health and environmental cost associated with energy resource extraction. Therefore, to understand the impact of renewable and carbon-neutral energy on human welfare, it can be seen from economics (increase in real income and household consumption), social (increasing life expectancy by improving air quality), and environment (reducing greenhouse gas emission).

a. Increased household consumption, income, and improved air quality

Renewable and carbon-neutral energy growth will positively impact the economy. An increase in renewable and carbon-neutral energy investment will encourage the domestic industries to grow, which correlates positively with real income due to the increased employment. Increasing renewable and carbon-neutral energy access also contributes to rising household income. Moreover, increasing the electrification rate helps provide a better health service and improve teaching and learning process. Indeed, deploying renewable and carbon-neutral energy in the region can give additional revenue to develop a better health and education infrastructure. Most importantly, renewable and carbon-neutral energy contributes to reducing greenhouse gas emission and improving air quality. Bappenas (2021) projects that a net-zero emission path will reduce 87–96 billion tons of CO_2 over 2021–2060, potentially save 40,000 lives in 2045 alone from air pollution reduction.

b. Gender equality

Renewable and carbon-neutral energy development offers a broad range of employment opportunities. It is important to ensure these opportunities are equally accessible to get equal benefits. As an active economic agent, women's contribution can give a more diverse perspective in the workplace, increasing overall energy industry performance. However, perception of gender in terms of social and cultural norms, inadequate skill and education, and lack of gender equality policy are major barriers for women to step up in the energy industry.

Having a multidisciplinary field, renewable and carbon-neutral energy will increase women's contribution to energy sectors. It is reported that renewable and carbon-neutral energy has women representation accounting for 32%, which is 10% higher than conventional energy at 22% (IRENA, 2019). Therefore, renewable and carbon-neutral energy is important in making the energy sector more gender-balanced. Gender perspective in energy policy and preparation for women to be qualified talents for energy transition becomes even more crucial.

D. Key Challenges of Renewable and carbon-neutral Energy Development

While the transition is underway, some challenges need to address to achieve the benefit of renewable and carbon-neutral energy development. This sub-chapter shows the key challenge that needs to be tackled.

1. Uncompetitive Renewable Energy Cost to Conventional Energy

To penetrate the energy market, renewable and carbon-neutral energy must be cost-competitive to conventional energy. Low-cost renewable and carbon-neutral energy can also be the backbone of a decarbonizing economy. Regarding the technology, renewable and carbon-neutral energy have shown a remarkable decline globally over the past decade. For instance, IRENA (2020) reported that the cost of electricity generated from utility-scale solar photovoltaics (PV) has sharply decreased by 85% between 2010 and 2020. Albeit its low cost of technology, renewable and carbon-neutral energy still cannot take over the electricity market in Indonesia. It is seen from the National Power Generation Plan in RUPTL 2021–2030 that power generation will continue to be dominated by coal. Apart from improving technology, the barriers come from an unsupported regulation framework and unrepresented externalities in market price.

a. Unfair competition with subsidized fossil fuel

To be the main player in the electricity market, renewable and carbon-neutral energy needs to be compared head-to-head with conventional energy. As a net coal exporter, Indonesia has a much cheaper electricity generation cost than other energy sources. It is reported that it only costs US$3 cent/kWh from existing coal plants and US$7 cent/kWh from new coal plants (Umah, 2021). Accounting for US$5.8 cent/kWh, the largest solar PV in Indonesia and Southeast Asia, Floating Solar PV Cirata, West Java, still cannot reach the below range of coal cost (Rahman, 2020). The low-cost coal results from government policy that subsidizes coal as input for power generation. Since 2018, the government of Indonesia has required the coal miners to supply 25% of their annual production to the PT PLN at a maximum price of US$70 per metric ton. The purchasing price is so much lower than the market price. It is less than half the market price in January 2022 at US$158.50 per metric ton and a third of market price in November

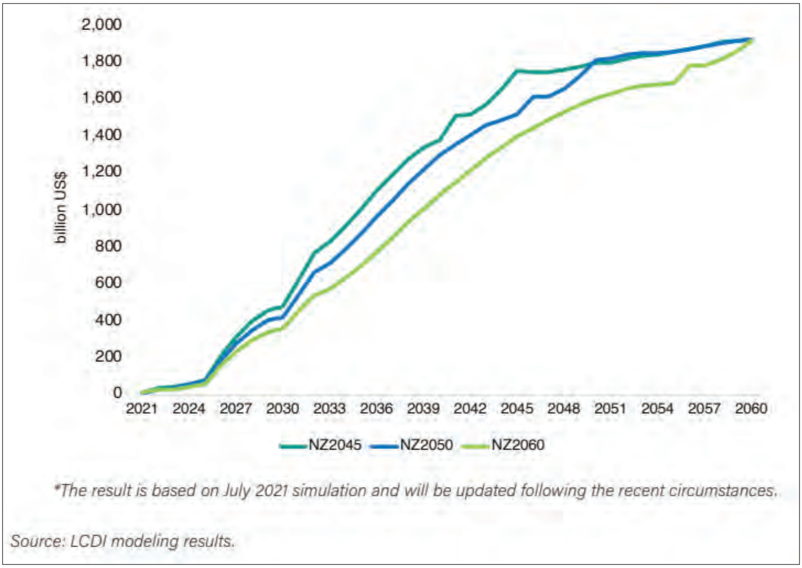
2022 at US$215.01 per metric ton (ESDM, 2022). This condition has made renewable and carbon-neutral energy less attractive compared to coal.

b. Unseen positive externalities

Another challenge is that the positive externalities of renewable energy are still not reflected in its market price. It is known that renewable and carbon-neutral energy is a reliable energy source that saves people's health and the environment. As stated before, Bappenas (2021) projects that a net-zero emission path will reduce 87–96 billion tons of CO_2 over 2021–2060, potentially saving 40,000 lives in 2045 alone from air pollution reduction. Therefore, the value of positive externalities can reduce the cost of renewable and carbon-neutral energy. Likewise, the negative externalities from burning and producing fossil fuels also need to be shown in its market price. IRENA (2015) shows that if externalities associated with CO_2 emission are valued in terms of price (assuming US$20 to US$80/ton of CO_2), the price of electricity generation from fossil fuel increases by US$1 cent to US$13 cent /kWh (depending on country and technology). Giving a value for externalities will dramatically change renewable and carbon-neutral energy competitiveness.

c. Lack of renewable and carbon-neutral energy investment

Renewable and carbon-neutral energy is a high-cost investment since it requires high upfront capital. However, once tapping into the field, the marginal cost of renewable and carbon-neutral energy is almost zero. A sharp decline in the cost of renewable and carbon-neutral energy is supposed to be an opportunity to drive its investment. Bappenas (2021) forecasts required investment to achieve net-zero emission starting from around US$20 billion per year in 2021–2022 (about Rp291 trillion) and an average of US$150–200 billion (Rp2.2–2.9 quadrillion) per year as shown in Figure 12.7.



Source: Bappenas (2021)

Figure 12.7 Investment Needed to Achieve Net-Zero Emission in 2021–2060

However, Indonesia's renewable and carbon-neutral energy investments are still mainly below the country's target. Accounting for US$1.17 billion in September 2019, the investment was 65% of the target of US$1.8 billion (IESR, 2019). Half of the total investment comes from geothermal energy, while a meager contribution is from other renewable energy sources. It is shown that renewable and carbon-neutral energy is still lacking its investment. Regulation uncertainty is a major issue in reducing investor confidence in Indonesia's renewable and carbon-neutral energy investment.

While dealing with resources and technology risks, renewable and carbon-neutral energy investors also need to deal with risk from inconsistent regulation and the effect of market structure. Survey taken by PwC in 2018 indicates that 94% of investors in the Indonesian power sector agree that uncertainty in regulation is a major barrier to new large-scale power generation investment. The regulation uncertainty includes a lack of transparency and low predictability in procurement, risk allocation, and unattractive tariff systems.

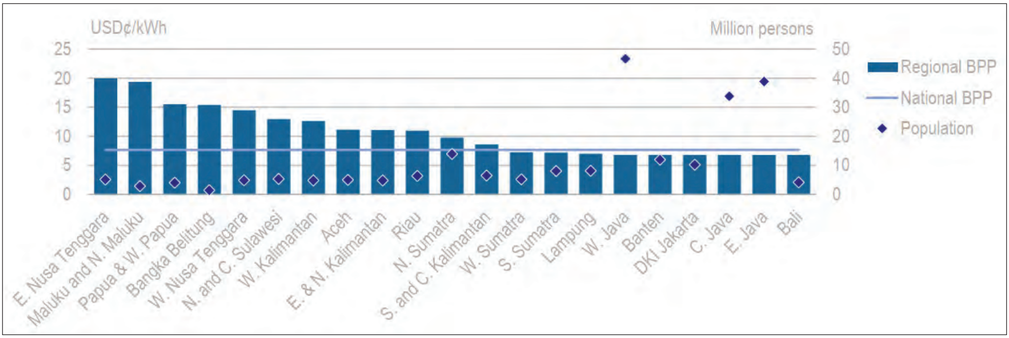
d. Lack of transparency and low predictability in procurement

In terms of the electricity market, Indonesia adopts a vertically integrated market structure where PT PLN is the only market player in electricity generation, transmission and distribution, and electricity retailing. This structure gives PT PLN a powerful market power to determine the price in the electricity market. The procurement process by PT PLN can be conducted in three different ways: (1) Direct Appointment, PT PLN directly appoints an IPP to conduct the project. (2) Direct Selection, PT PLN selects a project proposal from more than one submitted IPPs proposal. (3) Competitive Tender, if only the IPPs project is not eligible for direct appointment or selection. The main concern is that the direct selection by PT PLN does not always reach financial closure and is time-consuming (OECD, 2021). In addition, PT PLN agreed to purchase the electricity tariff if the price is less or equal to National BPP. When it is higher, the price will be discussed business to business between PT PLN and IPP. The closed-door negotiation between IPPs and PT PLN gives an impression of a lack of transparency and predictability in procurement. The company takes this as a risk, which also increases the required rate of return of the project. As a result, the price of electricity generation will be higher.

e. Unattractive tariff system

The current tariff system adopted by Indonesia does not give a strong incentive to invest in renewable and carbon-neutral energy development. Under MEMR Regulation No. 31/2009 on Purchased Electricity Tariff by PLN (Persero) from small- and medium-scale renewable energy power generation or excess electricity, the renewable and carbon-neutral energy tariff cap is set based on the average cost of electricity production in each region. The tariff cap is well designed to make it a competitive alternative to renewable and carbon-neutral energy in regions dominated by diesel generation. However, it is too low for other regions dominated by coal plant generation. Figure 12.7

reveals that the price cap is too low, especially for regions with high populations. This potentially discourages investors from investing in renewable and carbon-neutral energy with a high population, while the energy demand is high.



Source: OECD (2021)

Figure 12.8 The Comparison between National BPP and Regional BPP with Its Population

f. Gap in achieving positive net employment

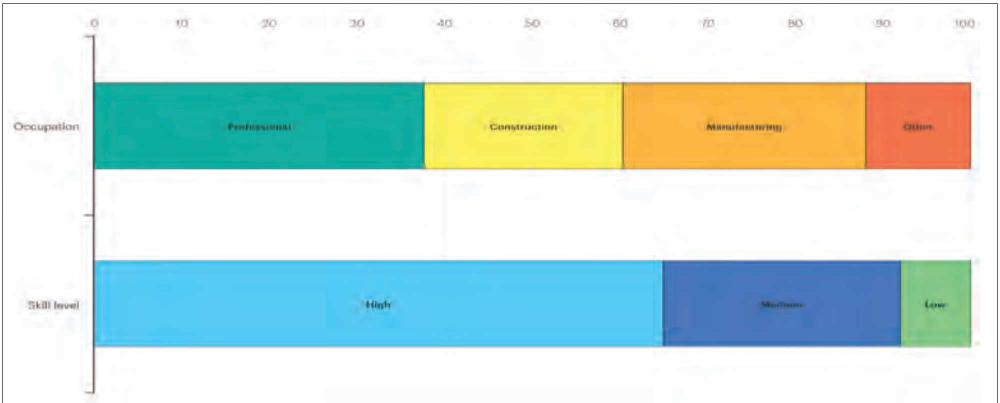
While accelerating the transition to renewable and carbon-neutral energy will create more jobs, it also results in job losses in the conventional energy industry and its supply chain. PT PLN has pledged to cut coal-fired generation and stop building new coal plants after 2023 and start to abandon coal after 2055 to achieve the net-zero emission target of 2060. As one of the largest producers and net exporters of coal, Indonesia had more than 121,000 employees in the coal sector in 2019 (Laird, 2021). It still did not include the number of workers in its supply chain, local economy, retail, food services, and other dependent sectors. If the coal generation is stopped, there will be a reduction in the employment rate, which also impacts the GDP and human welfare. To achieve the benefit of the energy transition, it is important to ensure that the gain from renewable and carbon-neutral energy development exceeds the loss from the reduction in fossil fuel use, which results in positive net employment. It is known that fostering energy transition potentially creates 1.8–2.2 million jobs in 2030 (Bappenas, 2021). Therefore, to maximize the potential, several challenges need to be tackled such as worker dislocation and education and skill gap.

Dislocated Workers

The total new jobs created from renewable and carbon-neutral energy might surpass the job losses from conventional energy. However, where new jobs growth is not always the same as a place with job loss. Most jobs associated with fossil fuels are geographically concentrated and integrated with the local economy. Compared to 1.8–2.2 million jobs created by renewable and carbon-neutral energy, the loss of 121,000 employees seems insignificant. However, it will deteriorate the local economy and community. Currently, it happens in the United States and China. Although the coal industry only represents 0.06% of the United States workforce and 0.4% of the Chinese workforce, the disruption of coal mine closure to the regional and local economy is inevitable (World Bank, 2018). Therefore, a strategic energy policy is required to ensure that energy will not severely impact not only the workers but also the local economy and community associated with the industry to achieve a "transition for all."

Shortage of high-skills workforce

While deploying renewable and carbon-neutral energy creates job opportunities, it still faces a challenge in finding qualified talents. Undeniably, the renewable and carbon-neutral energy industry requires high-skilled level laborers. Figure 12.8 shows that highly skilled workers dominate each value chain stage of renewable and carbon-neutral energy development. For example, the development of solar PV under the RUKN scenario for Indonesia needs high-skill workers such as engineers and management professionals at 52% while the demand for medium to low-skill workers such as technical and non-professional workers at 48% (GGGI, 2020). It can be an opportunity for workers who lost their jobs in the fossil fuel industry because education and skills from conventional energy can also be transferred to renewable and clean resources. However, the rapid development of renewable and carbon-neutral energy results in a higher future demand for new talents. Therefore, preparing the new talents is necessary to benefit from energy transition.



Source: OECD (2021)

Figure 12.9 The Value Chain of Renewable and Carbon-Neutral Energy and Its Level of Skill Required

g. Low women participation in renewable and carbon-neutral energy job

Mostly in charge of fulfilling their family's energy needs, women have a major role in the decision-making of household energy consumption. However, they are still underrepresented in energy policy-making and the energy industry. Women face challenges from internal and external factors. While most women internally lack training opportunities in science, technology, engineering, and mathematics (STEM) programs, they also must face cultural and social challenges.

Cultural, social norms, and stigma

A cultural and social norm is the most common challenge for women when contributing to energy sectors. The perception of gender roles that women have full responsibility in household work and childcare (and even elderly care) has limited women's participation in overall economic activity. Allocating their time to household work, women have limited time to fully engage in formal education and work. Another perception is that the energy sector is dirty, too technical, and unsafe. It is far from what society expects from a women's job, which is mostly related to secretary and administration. The dynamics of conventional energy politics give the impression that energy is a "dirty" business. Then, having low participation in STEM programs deteriorates women's confidence to pursue careers in energy sectors that seem too technical. Lastly, the safety and remoteness of field location issues also contribute to low energy sector jobs.

Low participation in STEM field

It is undeniable that renewable and carbon-neutral energy sectors are STEM-intensive fields. The low participation in the STEM field makes women underrepresented in renewable and carbon-neutral energy sectors. International Labor Organization (2017) reported that only 24.4% of Indonesian women studied a program related to STEM compared to men at 50%. Having time constraints linked to household responsibility, women also have limited access to education and training in the STEM field. Women are likely presented in minor income-generating activities such as administrative sectors and underrepresented in more technical sectors. This condition makes households less likely to invest in women's education, narrowing women's education access. The confidence gap between men and women in math due to the myth of the math brain makes STEM programs less attractive to women.

E. Policy and Recommendation to Maximize Socio-Economic Benefits of renewable and carbon-neutral energy

Although it has a broad range of benefits for social and economic, some barriers still need to be addressed. Some policies and recommendations are proposed to tackle the barrier and foster the transition.

1. Competitive renewable and carbon-neutral energy Costs

In line with cost reduction in renewable and carbon-neutral energy, supporting policies are required to ensure it can fairly compete head-to-head with fossil fuel.

a. Removing fossil fuel subsidy

While cutting greenhouse gas emissions, removing fossil fuel subsidies in electricity generation can increase the competitiveness of renewable and carbon-neutral energy in the electricity market. By cutting off the subsidy, the fences of market barriers for renewable and carbon-neutral energy will disappear. Hence, renewable and carbon-neutral energy can enter the market and actively compete with fossil fuels. As the subsidy is eliminated, it is faster to reach the backstop price and provide an opportunity for renewable and carbon-neutral energy as an energy substitute. Indeed, subsidies to fossil fuels give a wrong price signal to the user to consume more of the commodity. It is contrary to the country's decarbonization objectives.

b. Carbon pricing

Carbon pricing is the key solution to increase the competitiveness of renewable and carbon-neutral energy by revealing the actual cost of renewable and carbon-neutral energy and fossil fuel. The practice of carbon pricing has been widely adapted to achieve mitigation targets. The implementation of carbon pricing can vary from one country to another. Carbon pricing can be a tariff on per tons emission produced. It is reported that The High-Level Commission on Carbon Prices projects that carbon prices will be at least in the range of US$40–80/$tCO_2$ by 2020 and US$50–100/$tCO_2$ by 2030 to achieve the temperature limit in the Paris Agreement (World Bank, 2020). Besides helping renewable and carbon-neutral energy competes with fossil fuels, carbon pricing also can increase government revenue. Indonesia also has decided to implement carbon pricing as a mitigation measure in the NDC commitment. It can be a big step for Indonesia to achieve net zero-emission 2060.

2. Accelerate Investment in renewable and carbon-neutral energy

The deployment of renewable and carbon-neutral energy requires a huge amount of investment. A strong policy is needed to attract potential investors to invest in Indonesia's renewable and carbon-neutral energy projects.

a. Reforming tariff cap

The BPP is set as a price cap for renewable and carbon-neutral energy. Understandably, that the government wants to ensure the affordability of electricity generation. However, the BPP reference in some regions does not reflect the actual price of electricity generation. For example, in the regions of Java and Bali, electricity generation is dominated by coal. It is known that PT PLN still received subsidies to purchase electricity from coal plants. Using cheap coal as a price cap for renewable and carbon-neutral energy in this region is unfair. It would be better if the tariff cap is set based on the marginal cost of each technology. By combining this approach with the auction program, renewable and carbon-neutral energy prices can be lower, which is an incentive to invest in renewable and carbon-neutral energy projects.

b. Renewable and carbon-neutral energy auction program

While reducing the cost of renewable and carbon-neutral energy, an auction is the best instrument to facilitate transparent and predictable electricity procurement processes. One of the auction's objectives is to alter market barriers for the new market entrants. The auction mechanism can be different from one country to another. Mostly, the project development participates in the auction by submitting the electricity price per unit. Then, the government will evaluate the offer document with the price and sign an agreement with the auction winner. In terms of the evaluation project, it is almost the same as the procurement process adopted by PT PLN. However, it is more open to the public.

3. Achieving Positive Net Employment

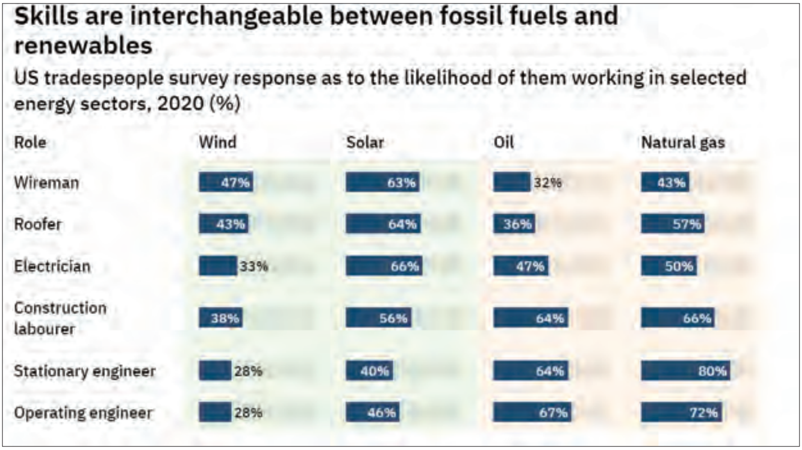
As the transition toward renewable and carbon-neutral energy continues to create new jobs, job losses from fossil fuels are not inevitable. Dislocated workers and a shortage of high-skilled level workers are challenges to achieving positive net employment from renewable and carbon-neutral energy. Some recommendations are reskilling, upgrading fossil fuel workers and building skills for new entrances.

a. Reskilling and upgrading skill for fossil fuel workers

A closely related skill between fossil fuels and renewables technology and its supply chain makes the skill interchangeable, which will benefit the workers. Recognizing the transferable skills from the fossil fuels industry to the renewable and carbon-neutral energy industry is important to assist the workers dealing with job losses. Figure 12.9 shows interchangeable skills between fossil fuels and renewables. Supplementary education and training will give provision for the workers to encounter job losses. However, the employment losses impact not only the workers, but also the local economy and community, which strongly rely on fossil fuel production. Long-term engagement and social dialogue between stakeholders, workers, businesses, and local communities are needed to understand how the change in energy structure will impact their income and how to deal with it soon.

b. Building the skill of new entrants

Planning and preparation for new talent are required of a high demand for high skill levels. Early exposure to climate change and how renewable and carbon-neutral energy contribute are important to increase awareness and drive problem-solving skills to prepare youth to be future energy professionals. Integrating renewable and carbon-neutral energy knowledge in STEM programs, social studies, etc. will attract youth interest in pursuing renewable and carbon-neutral energy career. A well-designed curriculum structure addresses the demand for cross-disciplinary skills, emerging skills (technology, storage, resource), and innovation and entrepreneurship will elevate the new talent skill.



Source: Ferris (2021)

Figure 12.10 The Value Chain of Renewable and Carbon-Neutral Energy and Its Level of Skill Required

4. Balancing Gender Participation in Deployment of renewable and carbon-neutral energy

The equitable participation of women and men will improve the overall sector's performance. However, the barriers such as cultural, social norms, stigma, and inequality in education access can result in a slow rate of sector development. Therefore, a strong policy is required to ensure women's participation so that the benefit of a diversified workforce can foster the development of renewable and carbon-neutral energy. Some recommendations include integrating gender in each renewable and carbon-neutral energy sectors value chains and improving access to STEM education and training.

a. Integrating gender perspective in each value chain of renewable and carbon-neutral energy

To ensure gender equality in renewable and carbon-neutral energy sectors, all genders should be included in each value chain. It is important to recognize the roles and potential contribution of gender in those areas to maximize the overall sector performance. According to the role and potential contribution, human resources policies for equal opportunity and quotas for gender parity are needed to be implemented. Equally important, a supporting working environment is necessary to increase gender equality. Imposing a human resource policy tackling gender discrimination and sexual harassment, and guaranteeing the safety of the employees is critical to gender participation.

b. Improving access to STEM education and training

Having low participation in STEM programs, women are underrepresented in energy sectors. Improving STEM education and training access can potentially increase women's participation in energy sectors. Highlighting women role models who pursue careers in STEM programs can give self-esteem to other women to choose the same pathway. This also can increase people's awareness that women have potential in STEM programs and start to invest in women's education. Investing more in women's education will give more access to women to be engaged in STEM programs. A supportive environment is also needed to increase women's participation in the education system. It can be done by designing curricula that maintain gender interest in STEM programs.

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Chapter 13

Pathways and Recommendations on Energy Transition Strategy to Achieve Net-Zero Emissions by 2060

Harun Ardiansyah & Putty Ekadewi

A. Indonesia's Path towards a Net-Zero Future: Identification of Necessary Actions

Indonesia is the biggest economy in Southeast Asia. The power behind Indonesia's massive economy is the size of the country and its population, which is advantageous in the country's case with a population of more than 270 million. Economic growth always goes together with energy consumption. As an effect, Indonesia's final energy demand is expected to shoot up in the near future to 388 MTOE (million tons of oil equivalent) with 1.2 TOE (tons of oil equivalent) per capita in 2050 (APEC, 2019). The growth in demand is double the country's energy demand in 2020, which means in a span of 30 years Indonesia must be ready to double its energy supply. Talking about energy sup-

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Ardiansyah, H., & Ekadewi, P. (2022). Pathways and recommendations on energy transition strategy to achieve net-zero emissions by 2060. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (267–281). BRIN Publishing. DOI: 10.55981/brin.562.c13 ISBN: 978-623-7425-83-0
E-ISBN: 978-623-7425-87-8

ply, the country is currently relying on fossil fuels, especially coal to generate electricity from coal power plants. Coal power plants are widespread in the country, one of the reasons being the abundance of coal, making Indonesia one of the world's most important coal exporters. In fact, coal export in 2018 was more than three-fourths of the total production (IESR, 2019a).

Contrary to the current situation, in the future fossil fuels are expected to be abandoned in favor of cleaner energy sources. The drive behind this transition is mainly environmental. The Earth is facing its biggest climate crisis if it stays on its current track of dependence on fossil resources. The environmental effect is so detrimental that it may topple down our current living systems: introducing famine, infectious diseases, biodiversity collapse, and deaths from major natural disasters.

Aside from the environmental factors, overall drastic growth in population is also threatening the Earth's ability to supply energy equal to the human population if world governments continue to rely on fossils. Fossil fuels are considered non-renewable since they took a long time to renew themselves, so these resources are finite in nature. If we continue to rely on fossils, it is just a matter of time before we deplete the earth's natural deposit of fossils. The consequences will be grave in the society as governments fight over fossil fuels, leading to wars.

Collectively, we are aware of these threats. World governments have crafted plans, goals, associations, and planned actions together to start the transition to non-fossil-based renewable energies. In Indonesia, the guideline to base energy transition was set on the National Energy Plan (RUEN-Rencana Umum Energi Nasional) in 2017. The aim is to gradually increase renewables proportion in the national energy mix to 31.2% by 2050 while reducing fossil proportions (Rencana Umum Energi Nasional, 2017). The target is set quite loose for renewables, as all forms of renewables are grouped into the same category. Globally, renewables already make up 29% of the global share of electricity generation in 2021 (IEA, 2021). However, the latest data in Indonesia show that renewables make up only 11.2% of the national energy mix in 2020 (Ditjen EBTKE, 2021). In the Southeast Asian region, Indonesia is trailing behind Vietnam, which generates more than twice the amount of Indonesia's renewable energy production (IRENA, 2020).

Indonesia's path towards a net-zero future can only be achieved if we successfully transition to renewables, focusing on carbon-free renewables. Aside from pushing for energetic transition, the country also needs to take care of other aspects as outlined in this chapter.

1. Investing in Carbon Capture and Offset Technologies

The Indonesian government holds power to develop carbon capture and carbon offset technologies through state-owned companies like PT Pertamina or PT PLN. Using state-owned enterprises to achieve national directives makes coordination easier to jumpstart the process, which will help the country speed up its efforts to reduce carbon release into the atmosphere. Technologies to take up carbon exist and are ready to be deployed. Carbon capture and storage (CCS) work by taking up CO_2 released from a power plant before it is emitted. The amount of removed CO_2 can reach 85–95% for a thermoelectric plant (Eldardiry & Habib, 2018). However, the use of CCS technology to complement existing power plants must not serve as a justification to continue burning coals to generate electricity.

Since state-owned companies already hold the biggest share of electricity generation in the country, nationwide government-backed installations of CCS units will substantially impact the country's emissions rate, pushing ahead the country in reducing CO_2 emissions.

Another important technology, especially for the Indonesian energy sector, is bioenergy with carbon capture and storage (BECSS). The advantage of BECSS over CSS is the ability to reach negative net carbon emissions. In BECSS, bioenergy crops are grown to naturally take up environmental CO_2, CSS technology is applied at the end to take up released CO_2 from the use of the bioenergy crops, i.e., in combustion processes. By itself, bioenergy is already considered carbon neutral. As the country is already putting its vision on bioenergy, adding CSS technology would complete the cycle, in line with the country's net-zero emissions target.

2. Reforestation and Restoration of Green Areas in Urban Settings

Forests are known to be the natural carbon sink. Indonesia has lost 18% of its natural forest areas (a reduction from 74% to 56% forest coverage) in the 3–4 decades leading up to 1990 due to urban developments (Indrajaya et al., 2022). The loss of natural carbon sink has affected the natural balance of carbon (CO_2). Reforestation and green area restoration will help offset the carbon released from human activities thanks to their ability to carry out photosynthesis. Moreover, the presence of green areas in urban settings increases the livelihood of the surroundings by providing benefits like shading, aesthetic improvements, restoring mini-ecosystem, and function as recreation sites among others.

3. Strengthening and Equalizing Access to Public Transport Friendly Infrastructure

Indonesia's public transport sector is developing little by little. Reforms have been carried out in several parts of the country, notably the Jakarta Metropolitan Area (Jabodetabek), in various modes of transport. Jakarta has been equipped with a bus rapid transit system (BRT) called TransJakarta since 2004. The system can now reach satellite areas to help daily urban mobility, reducing both congestion and individual carbon footprints of its users. The regional train system has also been updated to increase user comfort, enticing middle-upper class citizens to use the system. In 2019, the city installed a line of mass rapid transit (MRT) and light rail transit (LRT) lines, further increasing urban mobility. This level of accessibility is still limited to the capital city and its suburbs. In most parts of the country, public transport is still weak. To reduce carbon emissions from the transportation sector, accessibility of public transport needs to be improved to equal that of Jakarta.

4. Biodiversity and Environmental Protection

Indonesia is a known biodiversity hotspot, which existence is threatened by the rapid rise of global surface temperature and the looming climate crisis. Biodiversity collapse can have widespread effects affecting agricultural supply chains. For example, the dwindling bee population is already identified as a potential threat to food industries (UNEP, 2010). Therefore, Indonesia's efforts to achieve a net-zero future must not disregard biodiversity and the ecological cost of the energy transition as discussed in a previous chapter.

5. Developing Policies to Incentivize Low-Carbon Industries and Enforcing Carbon Tax in Manufacturing Sectors

Incentives help attract new actors into the scene; developing a low-carbon industry from scratch requires large capital and technologies, often resulting from the result of intense research and development (R&D) activities. The presence of incentives helps build up investors' confidence in the project by lowering risks and opening economic opportunities. On the other hand, the enforcement of carbon tax work to disincentivize large carbon emitters due to a real economic consequence of CO_2. Carbon taxes have been successfully implemented in Sweden, Canada, and France since this policy decouples the economic growth (GDP) trend from carbon emissions (Criqui et al., 2019).

6. Simplifying Investments and Bureaucracy on Renewable Energy Projects

Similar to putting incentives on low-carbon industries, the simplification of bureaucracy and investments in renewable energy projects aims to bring private actors to the scene, which will drive innovations and increase market competitiveness. Complicated bureaucracy has been identified as one of the causes behind the stalling of Indonesia's growth in the renewable energy sector, making this problem urgent to solve (IESR, 2019b).

7. Regulating Costs Between Conventional and Renewable Energy in the Market to Maintain Competitiveness

Still related to the economics of transition, the price is one common factor preventing the Indonesian public from preferring low-carbon energy. Indonesia's demographic is highly price-sensitive, especially on fuel costs. Government-subsidized petrol, albeit at lower octane numbers (88 and 90) than the others offered (92 and 95), is highly popular in the field. To ease the transition, not only does the government need to monitor pricing, but programs intending to reduce capital costs need to be considered, for example, solar PV subsidy or a reduction in tax on electric vehicles.

8. Public Education on the Importance of Energy Transition and Carbon Offset Activities

Finally, the most important point is to build awareness of the public on the importance of renewable energy with an emphasis on transitioning to a net-zero future. Public awareness helps bridge the inevitable economic gap to push forward renewable, carbon-free energy while pulling back economic support for fossil energy. Failure to communicate the country's vision and policies are detrimental to the success of reaching Indonesia's net-zero target by 2060. After all, it is part of the government's job to communicate well with the public it represents.

We must realize that energy transition alone cannot entirely reduce human activities' carbon emissions. However, energy drives human activities; as such, we need to start a carbon-free future by transitioning to renewable and carbon-free energy. The transition itself is affected by social, economic, and political factors. It also needs to take care of the environmental and sustainability aspects. All actions identified previously are all interlinked to achieve a net-zero future. The following section in this chapter summarizes and presents recommendations for Indonesia to implement each energy source and technology.

B. Recommendation for Carbon-Free and Renewable Energy Implementation

From the previous sections, options for carbon-free and renewable technologies have been explored. Each technology has its uniqueness and challenges. However, they have one similarity, the potential for deployment in Indonesia is extremely likely. To deploy these technologies, some recommendations can be implemented.

1. Investment and Market Climate

In an industry, investment and market climate is important to ensure that the industry can grow and survive, including in the energy sector. The government should invest more to ensure that the energy market creates a conducive sector and can grow. This can be done by policies that will benefit the energy market. However, the government should also concern about the citizen. It is not ideal if the government is only concerned with the market and investment, and not with the well-being of the citizen. In this case, NIMBY (not-in-my-backyard)-ism could grow rapidly, and hold up Indonesia's growth.

2. Solar Energy

Indonesia has a large potential for solar energy deployment. Even among ASEAN members, Indonesia has the largest solar energy potential. Located in the equatorial region, solar irradiation in Indonesia is relatively evenly distributed along the countries. Indonesia's global horizontal irradiation is also better than some countries that invest heavily in renewable energy. The question is then shifted to the sites and locations to put these solar panels to achieve their maximum potential. Currently deployed technology is mainly the land-based solar panels, which took much of Indonesia's land area. According to data from the Geospatial Information Agency (BIG), Indonesia has a land area of 1.9 million km^2 and a maritime area of 6.4 million km^2. On top of the land area, 5800 lakes and reservoirs can be found with a total area of 5,868 km^2. Indonesia needs to explore other solar panel technology that can be optimized in Indonesia. One of the technologies is floating solar PV.

As the name suggests, floating solar PV or floating solar panel requires no land space to generate electricity. This works best with some water bodies such as lakes and reservoirs. Current technology of floating solar PV technology has also been optimized to reach higher performance than rooftop solar PV. The performance ratio is 10% to 15% higher than typical rooftop PV systems. Floating solar panels are also able to reduce water evaporation. This is useful for areas that are susceptible to drought.

Like other technology, some aspects of solar energy need to be optimized to generate electricity effectively. Some challenges remain become questions that researchers need to solve. Some of them include the capital cost of solar panels which is still higher than conventional energy producers. Intermittency of solar energy has also been a limiting factor in optimizing solar panels. Other challenges also involve the land use of solar panels and the waste generated by the retired solar panels.

3. Hydropower

Indonesia has a great potential in hydropower. However, those potentials are limited to Indonesia's geography and socio-economic issues. Indonesia's rivers are typically not ideal site for constructing a large-scale hydropower plant. Also, the ecological issues due to the possible destruction of the river ecosystem and NIMBY syndrome can affect large-scale hydropower plant projects. Although hydropower plants are necessary to be the renewable energy baseload, the use of hydropower can be expanded in different ways. One way is to reduce the capacity of the hydropower plant and create micro-hydropower plants. Micro-hydropower plants will be an essential addition to residential and farming areas. The other way is to use pumped storage hydroelectric plants. PSH offers flexibility and reliability to fulfill the supply and demand of electricity. PSH can also be built far from rivers and residential areas. In these ways, hydropower can be a renewable energy backbone for Indonesia.

4. Wind Energy

As mentioned in strategic planning in Directorate General of New, Renewable and Conservation Energy, MEMR, 2020–2024, the technical potential of wind power notes in the MEMR is about 60.6 GW, with the utilization being about 0.15 GW until 2020. This utility is still far from the target in RUEN that in 2020, at least 0.6 GW of wind power is already installed in Indonesia.

Several locations have been developed into PLTB, such as in Jeneponto and Bantul. The Jeneponto PLTB, located in Jombe Village, Turatea District, Jeneponto, will contribute around 70 MW to the Sulselrabar PLN System. Meanwhile, the PLTB Bantul is the largest PLTB in Indonesia and is part of the Electricity Infrastructure Program (PIK), better known as the 35,000 MW Electricity Program. With 30 wind turbines installed, 50 MW of electricity can be harvested later. Other PLTB locations are in Bangka Belitung, Bali, and Nusa Penida, each with one unit, Selayar Island with three units, and North Sulawesi with two units (2007 status). In addition, the government also plans to build PLTB in various areas, such as Sukabumi, West Java.

Some solutions can be implemented to advance the development of wind energy sources in Indonesia. First, it can be built in the middle of the sea so there is no need for land acquisition. It is well known that land acquisition has become a complicated issue in several areas. Second, it can be built in remote areas to meet the needs of people in remote areas of the country, including in the outermost, underdeveloped, and remote areas. This can increase the national electrification ratio and provide equal distribution of electricity.

5. Biomass

As an archipelago located on the equator, Indonesia is uniquely blessed with bountiful sunlight all year. This leads to a plentiful growth of vegetation and crops, translating to a high biomass yield over all corners of the country. This presents a prospect and a challenge in itself. With such high biomass yield, Indonesia has enormous potential for its biomass to be used as an energy source. On the other hand, being an archipelagic nation means many scattered islands must be connected to the grid to allow electrical access to all parts of the society.

Currently, two types of major waste biomass are found to have the highest potential for conversion to bioenergy: rice husks and palm oil wastes. They are produced as by-products of rice cultivation and palm oil production. Both are high in volume and represent a significant untapped portion of biomass energy that can be utilized for energy production and converted to the proper form of biofuel based on needs. Rice husks can be fermented into bioethanol and solid biofuels for combustion. Palm oil mill effluents (POME) can be utilized to produce biogas as an alternative to natural gas resources.

However, there are two issues hampering progress in biomass utilization. The first issue is the relatively high price of electricity from New Renewable Energy (NRE) sources. Currently, energy subsidy is concentrated in minimizing fuel oil, LPG, and electricity price. Electricity price reduction comprises 42% of total subsidy, and as of 2021, 47% of total electricity production comes from coal-based steam power plants. Therefore, it is interesting that this subsidy portion can be potentially redirected towards reducing the price of electricity from NRE sources, making them more competitive in general and incentivizing investments in NRE-based power plants. The second issue is the relatively high-interest rate for NRE projects from the financial sectors, which is unfortunately true. To realize the transition to NRE from fossil-based energy quicker, cooperation from all sectors is required to convince the financial sector that investments in NRE projects are the way forward.

6. Geothermal

The development of the geothermal industry is still facing many challenges, especially related to the participation of international or domestic companies in investing their money and taking a risk in Indonesia's geothermal industry. The characteristic of the geothermal industry is high risk, high capital, and high technology, which means there are no possibilities to reach the target that Indonesia's government has made without support from international companies. There are many recommendations for encouraging the development of the geothermal industry in Indonesia:

1. Applying and implementing a new fiscal term to support the project's economic viability. It is called cost recovery; these fiscal terms also have been used in Indonesia's oil and gas industry and have proven their success in accelerating the development of the industry. There are many reasons for these issues because there are many similarities between those two industries geothermal and oil and gas.
2. Indonesia needs to adopt or use Australia's standard reporting code to accommodate investor's interests because many international companies have used those codes and gained international recognition.
3. Doing more investigations and studies to get proven and mature data, especially through exploration drilling. Indonesia needs to conduct a Government Drilling Program, based on advice given by investors, the lack of quality and quantity data is one of the concerns and needs to improve. So, the climate of investment in Indonesia's geothermal industry will be more attractive because the government has successfully decreased the uncertainties by providing proven and mature drilling data, which is one of the most important things.

4. Decreasing the total project investment or capital expenditure, by selecting and applying new technologies suitable to geothermal layers or lithology formations and characteristics of the geothermal reservoir.
5. It is necessary to improve the laws and regulations related to geothermal utilization and management so that it is more comprehensive and does not overlap with other regulations. The government must also play a more active role from just policy discourse into a more concrete and implementable policy that can attract investors and clarify authority in applying rules and governance to geothermal.

7. Nuclear

Nuclear energy has been developed for more than 70 years. However, there are still a lot of controversies surrounding the technology. This is because the first introduction of nuclear energy to the world was through atomic bombs in Hiroshima and Nagasaki in 1945. Since then, nuclear energy has experienced its ups and downs. Just like any other technology, nuclear energy is not perfect. Few things need to be resolved by the nuclear energy industry and the government, mainly nuclear waste and financial problems with investing in nuclear energy. Some steps have been taken to solve this problem, from an engineering and public policy standpoint.

Right now, nuclear energy is gaining back its momentum. There has been a massive support for nuclear energy, especially from the young generations. Nuclear energy has everything necessary to tackle climate change: low carbon emissions, safest energy source, and creates high-paying jobs. For Indonesia, nuclear energy is the key to tackling climate change and economic recovery post-COVID-19. Nuclear energy can be the baseload of energy in Indonesia to provide carbon-free and reliable energy all the time. Nuclear energy can also accelerate the economy by creating new and sustaining jobs for families within the localities of the nuclear reactor.

To achieve this, Indonesia first needs a national strategy for deploying nuclear energy. If the strategy is settled and all the infrastructures are prepared, Indonesia's first nuclear power plant can be operational earlier than 2045. This strategy will reflect Indonesia's national position on nuclear energy. Indonesia has all the infrastructure needed for nuclear energy but the national position. Nuclear energy program implementing organization (NEPIO) is one step necessary to ensure the national position. NEPIO will ensure that all the infrastructures and organizations necessary to build Indonesia's first nuclear power plant are fulfilled and run well.

8. Hydrogen

Hydrogen plays a crucial role as a versatile clean energy carrier and industrial feedstock in decarbonizing hard-to-abate sectors. As one of the world's largest greenhouse gas emitters, Indonesia could harness the benefits of hydrogen to meet its climate targets. The main driver for developing an economically sustainable hydrogen industry in Indonesia is its abundant renewables across the country, including solar, hydropower, wind, biomass, geothermal, and tidal. As the global hydrogen market is estimated to reach US$201 billion by 2025, Indonesia has a huge opportunity to export renewable resources in the form of hydrogen and its derivatives, such as ammonia and methanol, thus ramping up national revenues.

Despite the enormous potential to be a global clean hydrogen powerhouse, Indonesia is facing a number of challenges associated with the adoption of hydrogen across its value chain. At the moment, green hydrogen produced using renewable electricity is costlier than gray and blue hydrogen. In addition, utilizing hydrogen for new downstream applications can be more expensive than its fossil counterparts. Another critical challenge is the lack of dedicated hydrogen infrastructure for large-scale storage and long-distance transport. The absence of a national hydrogen strategy exacerbates the hydrogen uptake as it reflects the low commitment made by the government on hydrogen and ultimately discourages potential investors. The government gives insufficient recognition of hydrogen value to reduce carbon footprints in hard-to-abate sectors.

To stimulate the development of the hydrogen industry in Indonesia, a national hydrogen strategy, which comprises a national hydrogen roadmap and enabling policies, is proposed based on Indonesia's current position and existing barriers in hydrogen uptake across the country. Indonesia's national hydrogen roadmap should aim for an integrated system across the hydrogen value chain. The roadmap must focus on green hydrogen as the ultimate target due to its suitability to meet net-zero targets. A step-by-step approach for the transition from gray to green hydrogen is adopted. In the early stage, gray hydrogen has to be phased out and replaced with blue hydrogen which is equipped with carbon capture and storage technology while facilitating green hydrogen uptake at the same time. In the middle stage, the crucial decision has to be made where Indonesia needs to start the development of green hydrogen hubs across the country and build the required infrastructure. As a result, Indonesia could become a global hydrogen powerhouse beyond 2050 with deployment across various sectors and export capability to resource-constrained countries such as Singapore, Japan, and South Korea.

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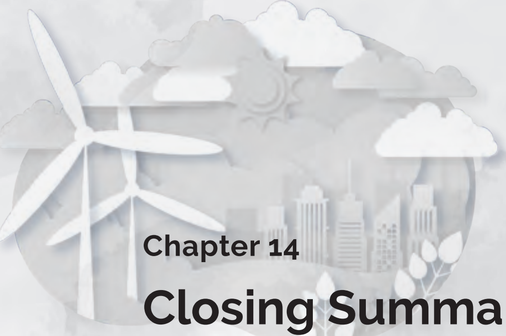

Chapter 14

Closing Summary: Deploying Indonesia's Energy Resources for a National Carbon-Neutral Energy Ecosystem

Harun Ardiansyah & Putty Ekadewi

This book is the melting pot of the minds of Indonesian students who are currently pursuing higher education abroad. The authors are spread into different backgrounds, all with the same intent and focus: as students, what can we do and how can we help Indonesia achieve its energy targets?

When we think of energy and electricity in Indonesia, the first things to come to mind are coal mines, oil and gas economies, and electricity outages. The public has fewer ideas about Indonesia's progress in renewable energy or even the country's strategies to integrate renewables into the mix. Failure of the public to comprehend the country's energy vision, in some way, has affected the way the public view strategic energy projects and policies. For example, our high reliance on fossil resources is driven by various cost subsidies from the

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Ardiansyah, H., & Ekadewi, P. (2022). Closing summary: Deploying Indonesia's energy resources for a national carbon-neutral energy ecosystem. In H. Ardiansyah, & P. Ekadewi (Eds.), *Indonesia post-pandemic outlook: Strategy towards net-zero emissions by 2060 from the renewables and carbon-neutral energy perspectives* (283–287). BRIN Publishing. DOI: 10.55981/brin.562.c14
ISBN: 978-623-7425-83-0 E-ISBN: 978-623-7425-87-8

government that makes renewable options seem costly, thus unable to compete economically. This book tries to close this knowledge gap by summarizing the ecosystem of Indonesia's energy sector and outlining the general ideas behind several alternative energies: solar, wind, hydro, geothermal, and biomass. This book tries to go beyond the 'classics' by introducing new technology like hydrogen as energy storage and nuclear energy, bringing the debate closer to the Indonesian public.

Energy is at the core of human existence alongside primary necessities like water and nutrition. It is one element that could make or break a country's global status in the modern post-industrialization world. Indonesia is one of the world's highly populated countries. As a result, the energy needs of the country is expected to grow significantly along with the rise in population and globalization. The COVID-19 pandemic has seen workplaces and classes moved to a 'from home' setting. A direct impact of this phenomenon is the highlight of inequality in the country. Students living in rural areas find it difficult to have stable access to electricity and internet connections necessary to support their at-home studies. The effect of the pandemic on energy industries is phenomenal. Almost equally across all sectors, activities are lower or even suspended, putting existing projections and scenarios off track. It is important to evaluate, assess, and re-strategize Indonesia's plans for a net-zero future by 2060 to stay on target despite the pandemic's disturbances and new opportunities.

We have discussed several points concerning renewable, carbon-free energy, and energy transition strategies for Indonesia based on selected alternative energy sources in the book.

A. Status and Challenges of Indonesia to Achieve Net-Zero Emission by 2060

From policy developments to the global shift in perspectives, it is clear that Indonesia is moving towards a net-zero future albeit slowly, one of its strategies being energy transition from fossil-based resources to renewable energy. We are still far from targets loosely written on paper on various policy instrumentations in the field. There is an urgent need to speed up energy transition if Indonesia is still aiming to reach its targets by 2025 and 2050 as written in the RUEN or by 2060 as stated with regards to the recent COP26 meeting in Glasgow, UK.

B. Redefining Nationally Defined "New and Renewable Energy" to International Standards of Carbon-Neutral and Renewable Energy

The term renewable energy has always been loosely defined, relying on the characteristics of the energy source, which leaves room for the identification of new non-fossil-based energy into the group. However, sustainability does not only rely on the ability of the source material to renew itself as sustainability revolves around the complex interaction between living and non-living systems on Earth (ecology). We have seen in this chapter the need to further clarify our future energy source by adding another characteristic: carbon-free. Moreover, the ecological cost of energy transition must also be considered when choosing alternative energy. These costs are often associated with land clearing, construction, and system startup, but will be offset later by the installations as it runs.

C. Potentials and Challenges of All Possible Carbon-Free and Renewable Energies

Classic renewables like solar, wind, hydro, biomass, and geothermal energies are already installed worldwide, including Indonesia, in varying proportions. Thanks to the characteristics of the energy source itself, geographical factor plays a big role in determining the type of alternative energy adopted by each country. In Indonesia, wind power installation is less popular because the country has an overall low wind speed. Instead, the country chose to adopt biomass to be used as biofuel, which drastically increases biomass energy utilization in the national energy mix compared to solar, although the latter is equipped with energy potential several magnitudes over the former. In the future, solar energy is expected to grow exponentially.

Moving on from 'the classics', nuclear and hydrogen emerge as new technologies for the Indonesian energy market. Nuclear energy in the world has developed over time, each time with better safety protocols and lower risks of disaster. However, not all countries in the world can use this energy source, debates revolving around nuclear are still rolling since the energy source is regarded as a hot ball today. Indonesia's commercial nuclear power plant number is still at zero, meaning nuclear energy has not contributed to the national energy mix. The government needs to launch the debate on nuclear power potentials versus concerns in order to position itself on the topic, keeping in mind of both future energy and environmental security. On the other hand, hydrogen emerged recently as the solution for energy storage, which can be coupled with various types of renewables to maintain energy stability.

D. Multi-Sectoral Approach to Deploy Renewable and Carbon-Neutral Energy in Indonesia

Indonesia is a country with a large and socioeconomically diverse population. Energy is the drive behind the daily economic activity of the citizens. To successfully deploy renewables in Indonesia, the challenges rely on consumer demand and its sensitivity on energy pricing. Therefore, to launch a transition campaign successfully, the government needs to either drive up consumer demand for renewables over fossil-based energy or take on energy transition's economic load to minimize the consumers' economic burden. The first option requires mass education of the people, which is problematic given our current timeline. The second option is better suited for the first phase. Government incentives could increase renewables uptake in the first phase of transition. Along the way, better education and an economically rising population could push for better government actions and industrial sector accountability to commit to their climate protection pledges.

E. Impact of Carbon-Free and Renewable Energy Deployment on Society

The energy transition is reflected in other aspects, besides fossil-based consumption and alternative energy generation. We can see the impacts of energy transition in: reduced CO_2 emissions, less environmental pollution, decreased rate of global surface temperature increasement, increased health and well-being of the society, better equality between genders, increased proportion of skilled workers in the energy sector, and increased economic growth in the renewable sector among others. The first and most direct impact of energy transition can be felt by eliminating of coal power plants in favor of non-polluting wind or solar generators. Coal power plants are widely known to bring detrimental health effects to surrounding populations, which is dismal because now coal still plays a big role in the energy sector. After a while, the global increase in surface temperature can be halted because of lower CO_2 emissions, known to contribute to the greenhouse effect, the power behind a rapid rise in Earth's surface temperature. Finally, by developing the renewable energy sector, jobs will open. This will lead to an overall increase in skilled workers and a better opportunity to close the gender gap, affecting the economy positively. The effect of the energy transition is significant, which is why Indonesia needs to catch up in developing this sector, not only to target the national energy mix, but also to improve the livelihood of its citizens.

Finally, we hope that by aiming to close the knowledge gap on renewables and alternative energies as well as suggesting several points to re-strategize Indonesia's energy targets, we can help the country stay on track to its vision for a net-zero future by 2060.

List of Abbreviations

Abbreviation	Description
AEP	Annual Energy Production
AGR	Advanced Gas-Cooled Reactors
APV	Agrophotovoltaic
BaU	Business as Usual
BEVs	Battery Electric Vehicles
BOE	Billion Oil Equivalents
BPP	*Biaya Pokok Penyediaan Tenaga Listrik* (Electricity Generation Cost)
BPS	Central Bureau of Statistics
BWR	Boiling Water Reactor
B30	Biodiesel 30 (%)
CANDU	Canadian Deuterium Uranium Reactor
CCS	Carbon Capture & Storage
CFPP	Coal-fired Power Plant
CH_4	Methane
COD	Commercial Operation Date

CoE	Cost of Energy
COP	Conference of the Parties
CO_2	Carbon Dioxide
CPO	Crude Palm Oil
CSP	Concentrated Solar Power
DME	Dimethyl Ether
EBR	Experimental Breeder Reactor
EFB	Empty Fruit Bunches
EU	European Union
FPV	Floating Solar Photovoltaic
FB	Financial Balanced
FCEVs	Fuel Cell Electric Vehicles
FFB	Fresh Fruit Bunches
GEA	Geothermal Energy Association
GDP	Gross Domestic Product
GHI	Global Horizontal Irradiation
GW	Gigawatt
GWh	Giga Watt-hour
HAWT	Horizontal Axis Wind Turbine
HPHT	High Pressure High Temperature
HTGR	High Temperature Gas-cooled Reactors
H_2	Dihydrogen
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INIR	Integrated Nuclear Infrastructure Review
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
JOGMEC	Japan Oil, Gas, and Metals National Corporation
JORE	Joint Ore Reserves Committee
KEN	*Kebijakan Energi Nasional* (National Energy Policy)
KESDM	Kementerian Energi dan Sumber Daya Mineral
KOH	Potassium Hydroxide
KUBE	*Kebijakan Umum Bidang Energi* (General Policy on Energy)

kW	kilowatt
kWh	kilowatt-hour
LCoE	Levelized Cost of Energy
LNG	Liquefied Natural Gas
LPC	Levelized Production Costs
LPG	Liquefied Petroleum Gas
MEMR	Ministry of Energy and Mineral Resources
MeV	Mega-electron-Volt
MF	Mesocarp Fiber
MoU	Memorandum of Understanding
MSR	Molten Salt Reactors
Mt	Mega ton
MW	Megawatt
NDC	Nationally Determined Contribution
NEPIO	Nuclear Energy Program Implementation Organization
NIMBY	Not-In-My-Backyard
NPV	Net Present Value
NPP	Nuclear Power Plant
NRE	New & Renewable Energy
OECD	Organisation for Economic Co-operation and Development
PB	*Pembangunan Berkelanjutan* (Sustainable Development)
PCD	Polycrystalline Diamond
PEM	Proton Exchange Membrane
PEN	*Pemulihan Ekonomi Nasional* (National Economic Recovery)
PSH	Pumped Storage Hydroelectricity
PKM	Palm Kernel Meal
PKS	Palm Kernel Shell
PLN	Perusahaan Listrik Negara
PLT Bio	Bioenergy Power Plant
PLTBg	Biogas Power Plant

PLTBm	Biomass Power Plant
PLTBn	Biofuel Power Plant
PLTSa	Waste-to-Energy Power Plant
PLTU	Coal-Fired Power Plant
POME	Palm Oil Mill Effluent
PT KAI	Indonesian Railways Company
PV	Photovoltaic
PWR	Pressurized Water Reactor
P2X	Power-to-X
RBMK	Reaktor Bolshoy Moshchnosty Kanalny
RK	Low Carbon (Rendah Karbon)
RMA	Resource Management Act
RPJMN	*Rencana Pembangunan Jangka Menengah Nasional* (National Medium-Term Development Plan)
RUEN	*Rencana Umum Energi Nasional* (National Energy General Plan)
RUKN	*Rencana Umum Ketenagalistrikan Nasional* (National Electricity Master Plan)
RUPTL	*Rencana Usaha Penyediaan Tenaga Listrik* (National Power Generation Plan)
RUU EBT	*Rancangan Undang-Undang Energy Baru dan Terbarukan* (Draft of New and Renewable Energy Bill)
SBO	Station Black-out
SMR	Small and Modular Reactor
SMR	Steam Methane Reforming
STEM	Science, Technology, Engineering, and Math
TJ	Terra Joule
TRIGA	Training, Research, Isotopes, General Atomics
TWh	Terawatt-hour
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNSC	United Nations Security Council
US$	United States Dollar
US DOE	United States Department of Energy

VAWT	Vertical Axis Wind Turbine
VVER	Vodo-Vodyanoi Energetichesky Reaktor
W	Watt
WFLO	Wind Farm Layout Optimization
WHO	World Health Organization
WKP	*Wilayah Kerja Panas Bumi* (Geothermal Work Area)
WT	Wind Turbine
W&PB	Work and Program Budget
3Gs	Geology, Geophysics, and Geochemistry

Index

Editors' Biography

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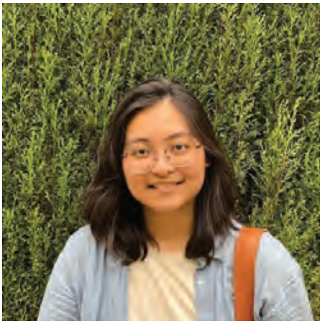

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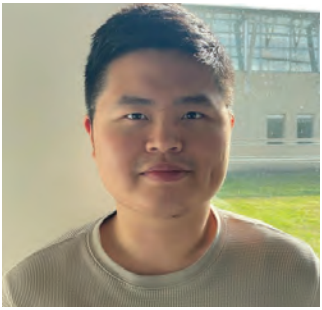

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Indonesia Post-Pandemic Outlook

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INDONESIA

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COVID-19 has disrupted all aspects of human life. To mitigate the impact of the pandemic, several efforts have been taken, including by Indonesian scholars abroad. This book entitled *Indonesia Post-Pandemic Recovery Outlook: Strategy towards Net-Zero Emissions by 2060 from the Renewables and Carbon-Neutral Energy Perspectives* explores energy sustainability and climate change issues and how it can progress further. There are also discussion on the delays caused by the COVID-19 pandemic to a few major renewable energy projects that should have been done in 2020-2021.

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Published by:
BRIN Publishing
Directorate of Repositories, Multimedia, and Scientific Publishing
Gedung B.J. Habibie, Jln. M.H. Thamrin No. 8, Kb. Sirih, Kec. Menteng, Kota Jakarta Pusat, Daerah Khusus Ibukota Jakarta 10340
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DOI: 10.55981/brin.562

ISBN 978-623-7425-83-0