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Indonesia's Energy Transition Preparedness Framework Towards 2045

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Publisher's note

Facing 2045 is a hope and a challenge at the same time. There is hope for a greener life in 2045; green economy, green energy, and all other elements of green development. All are connected to the Net Zero Emission target in 2045. The challenge to achieve these conditions is to develop a mature plan. Many aspects need to be prepared in the current stages. Thus, support from all stakeholders in this country is essential.

The aim of this book is to strengthen nationwide literacy and fulfill the role of BRIN Publishers in encouraging the participation of various parties. By gathering thoughts from researchers, practitioners, and observers, it is hoped that we can find out the status of Indonesia's energy transition readiness to face 2045, and what are the steps needed to strengthen the efforts. With the editors' and the authors' deep research, practice expertise, and insights to global ecosystem, this book has uniquely positioned itself to bring together the understanding, technologies, innovation, and partnerships needed to help navigate and accelerate the journey to net-zero.

This book is intended for the general public. We hope this book can give a framework to pursue the energy transition and to strengthen energy supplies, so that it will eventually accelerate clean-energy momentum.

BRIN Publishing would like to thank the editors and the authors who have given their commitment and dedication to prepare this book. Hopefully, Indonesia's vision towards a green environment can be achieved in 2045.

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Foreword

In the pursuit of sustainable development, the journey towards renewable energy is both an imperative and an opportunity. As the world confronts the challenges of climate change, environmental degradation, and the need for energy security, nations find themselves at a critical crossroads. Among those nations, Indonesia stands as a beacon of promise, navigating the path towards a more sustainable and resilient energy future.

This book represents a significant milestone in Indonesia's commitment to fostering a transition towards renewable energy. It unveils a comprehensive framework that encapsulates the nation's preparedness for this transformative journey. From the lush landscapes of Sumatra to the vibrant cities of Java, Indonesia's rich diversity is mirrored in its approach to energy transition—a journey that encompasses not only technological advancements, but also socioeconomic considerations, policy dynamics, and the empowerment of its people.

As we embark on this exploration of *Indonesia's Energy Transition Preparedness Framework Towards 2045*, we delve into the intricacies of a nation's commitment to balancing economic growth with environmental stewardship. Through the pages that follow, we will witness the collaborative efforts of government bodies, industry leaders, environmentalists, and communities, all working in harmony towards a common goal—a sustainable and renewable energy future for Indonesia.

The complexities of such a transition are vast and multifaceted. This book provides a roadmap, a guide for policymakers, stakeholders, and citizens alike, offering insights into the challenges and opportunities inherent in the shift towards renewable energy. It is a testament to the spirit of innovation and collaboration that defines Indonesia's approach to sustainable development.

In the chapters ahead, you will encounter the stories of communities empowered by decentralized energy solutions, the breakthroughs in technology that redefine the energy landscape, and the policy frameworks that provide the necessary scaffolding for this profound transformation. This is not just a book about energy; it is a narrative of resilience, adaptability, and the collective will of a nation to shape its destiny in the face of global challenges.

I extend my heartfelt appreciation to the authors, researchers, policymakers, and all those who have contributed to the creation of this framework. Your dedication is a testament to the shared vision of a sustainable and vibrant future for Indonesia.

May this book serve as a source of inspiration, knowledge, and motivation for all those engaged in the noble endeavor of steering Indonesia towards a future powered by renewable energy.

With optimism and commitment,

Surabaya, October 2023

Irjen Pol (purn) Drs. Anton Setiadji, S.H., M.H.
Rector of Bhayangkara University Surabaya

Chapter 1

Indonesia's Energy Transition: A Challenge

Agus Kiswantono

A. A Turning Point to Net Zero Emissions

The world is standing at a pivotal juncture in its quest for a sustainable future. The global consensus on the need to address climate change and reduce greenhouse gas emissions has set in motion an energy transition of unprecedented scale and significance. At the heart of this transformation lies the realization that our reliance on fossil fuels must diminish, and we must embrace cleaner, more sustainable energy sources (Anderson, 2020; Kamran & Fazal, 2021). In the context of Indonesia, a sprawling archipelagic nation endowed with abundant natural resources and a rapidly growing population, the energy transition presents both a formidable challenge and an immense opportunity. The urgency to curb emissions, coupled with

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the imperative to meet the energy demands of a burgeoning populace, calls for a meticulous and multifaceted approach (Brown et al., 2019; Wolgamot et al., 2012).

This book presents the approaches encapsulated in the *Energy Transition Preparedness Framework Towards 2045*, a comprehensive roadmap for navigating the complex terrain of Indonesia's energy future. Our journey through the roadmap has taken us on a captivating exploration of diverse themes, each shedding light on crucial aspects of the nation's transition towards a sustainable energy landscape. From examining the role of sub-national green leadership to dissecting the intricacies of environmental assessments for energy transition technologies, we have delved deep into the heart of Indonesia's energy transformation.

This chapter, a prologue to the whole book, serves as a comprehensive culmination of our odyssey through these themes. Within the pages, we will visit the critical discussions and analyses that have punctuated our exploration. Furthermore, we will extrapolate from these discussions, seeking to chart a course forward, examining the readiness and potential pitfalls on Indonesia's path toward a cleaner, greener energy future. As we embark on this intellectual journey, we invite you to join us in this examination of Indonesia's energy transition preparedness.

Before the journey starts, there are several important questions that must be answered. What potential and opportunities does Indonesia have to face this energy transition period? Are we truly ready for the challenges and opportunities that lie ahead? Can we harness the collective power of collaboration, innovation, and sustainable leadership to drive this transformation? The answers to these questions are vital, not only for Indonesia but for the global community as we collectively strive to mitigate the effects of climate change and secure a prosperous future for generations to come.

Thus, let us turn the page and dive into a comprehensive exploration of the *Energy Transition Preparedness Framework Towards 2045*, its implications, and the promise it holds for Indonesia and the world.

B. POTENTIAL ENERGY IN THE FUTURE

Due to its geographical position, Indonesia has various energy potentials. As an equatorial country, Indonesia receives abundant amounts of sun radiation throughout the year, making it the perfect place for harnessing solar power. As an archipelagic state, Indonesia boasts a plentiful of wind energy from the difference of characteristics between its land and sea. Ultimately, as a maritime nation, Indonesia has vast oceans teeming with natural resources. Most notably in terms of energy, the oceans store fossil fuels in the forms of oil and gas. However, these resources will not last forever, unlike solar and wind power. Therefore, there is a need to explore alternative way of utilizing Indonesia's open and enormous oceans as a potential renewable energy.

Ocean Thermal Energy Conversion (OTEC) has emerged as a promising frontier in the pursuit of sustainable and renewable energy that take advantage the ocean's temperature to produce energy. We need to explore the noteworthy progress witnessed in OTEC technology, with a specific focus on its technological readiness and ongoing efforts in system optimization.

Recent advancements in OTEC technology have propelled it closer to mainstream viability. Required technological readiness include these following points:

1) **Efficiency Enhancements**. Substantial efforts have been directed toward enhancing the efficiency of OTEC systems. What innovations exist in heat exchanger design? How have the exploration of high-performance working fluids played a crucial role in improving the overall conversion of thermal energy into electricity?
2) **Materials Innovation**. The challenging marine environment necessitates materials that can withstand corrosion. In this regard, we need innovations in materials science that led to the development of robust and corrosion-resistant materials, contributing to the longevity and economic viability of OTEC systems.

3) **Pilot Projects.** There is a need for small-scale OTEC facilities and pilot projects that serve as invaluable testing grounds. These initiatives are expected to provide real-world data, operational insights, and essential validation of OTEC's feasibility, and the process of moving the technology from theoretical concepts to practical applications.
4) **System Optimization.** System optimization is a critical avenue for maximizing the efficiency and impact of OTEC. Ongoing efforts required in this domain encompass the following points:
    a) **Heat Exchanger Refinement.** System optimization involves continuous refinement of heat exchangers to enhance heat transfer efficiency. Improving this key component contributes directly to the overall efficiency of OTEC systems.
    b) **Environmental Considerations.** As OTEC projects progress, there has to be an improvement emphasizing on mitigating potential environmental impacts. Addressing concerns such as the discharge of nutrient-rich deep ocean water must be an integral part of the ecological sustainability of OTEC systems.
    c) **Integration with Other Energy Sources.** To bolster the reliability of OTEC systems, integration with other renewable energy sources needs to be explored. This includes examining synergies with solar and wind energy to create hybrid systems that can provide consistent power regardless of variations in weather conditions.
    d) **Scale-Up Strategies.** System optimization also needs to involve strategies for scaling up OTEC systems to utility-scale applications. This includes considerations for offshore installations, grid integration, and economic viability at larger scales.
    e) **Economic Viability.** The economic feasibility of OTEC is a crucial aspect of system optimization. Innovative financing models, cost-reduction strategies, and exploration of market

incentives are being actively pursued to make OTEC more competitive within the broader energy landscape.

As OTEC technology advances and system optimization efforts progress, it stands on the brink of transforming from a theoretical concept to a commercially viable and impactful source of renewable energy. The inexhaustible potential of ocean thermal energy positions OTEC as a significant player in the global pursuit of sustainable and clean energy solutions.

In addition to technical requirements, OTEC faces challenges, including high upfront costs and limited geographic applicability. Overcoming these challenges requires ongoing collaborative efforts between researchers, industry stakeholders, and policymakers. Looking ahead, continued refinements in OTEC technology, coupled with supportive policies and investments, could position it as a pivotal contributor to the global energy mix. Technological readiness and system optimization underscore OTEC's potential as a transformative force in the transition towards a sustainable and diversified energy future.

C. INDONESIA'S ENERGY TRANSITION READINESS: AN IN-DEPTH ANALYSIS

As Indonesia stands at the crossroads of a monumental energy transition, a critical question reverberates through policy chambers and public discourse alike: are we genuinely prepared for the challenges and opportunities this transition presents? This question arises considering the complexity of the existing problems. As stated by President Joko Widodo at the S20 High Level Policy Webinar on Just Energy Transition, energy transition is not just about switching the utilization and use of fossil fuels to renewable energy. More than that, the energy transition also involves a number of very complex aspects from science and technology to socioeconomics and the environment (Primadhyta, 2022). To answer that question, an incisive analysis of readiness is needed across several major aspects provides a nuanced understanding of Indonesia's position on the precipice of this transformative journey. The readiness analysis includes:

1) Infrastructure Readiness

The backbone of any energy transition is infrastructure. In Indonesia's case, there are both commendable strides and lingering gaps. Urban areas often showcase a more robust energy infrastructure, especially in the context of renewable energy projects. However, rural and remote areas face challenges in accessing reliable energy sources. A comprehensive analysis should delve into the existing infrastructure, identifying bottlenecks and outlining strategies for equitable development.

2) Policy Landscape

The policy environment sets the tone for the success of an energy transition. Indonesia has made significant strides in formulating policies that promote renewable energy adoption and sustainability. However, the efficacy of these policies hinges on implementation. An in-depth analysis should scrutinize policy frameworks, exploring their coherence, enforcement mechanisms, and adaptability to evolving technological landscapes.

3) Public Awareness and Engagement

The success of an energy transition is intricately linked to public awareness and engagement. While awareness of environmental issues is increasing, there remains a gap in understanding the nuances of energy transition technologies. A comprehensive analysis should assess the effectiveness of public awareness campaigns, educational programs, and the overall level of public engagement.

4) Technological Innovation and Research Development

Indonesia's energy transition necessitates cutting-edge technological solutions. A critical analysis of the readiness in technological innovation and research development should explore ongoing initiatives, collaborations between research institutions and industry, and the nation's capacity to harness emerging technologies. This includes advancements in renewable energy, energy storage, and smart grid technologies.

5) Investment and Financial Preparedness

The scale of the energy transition demands substantial financial investment. A comprehensive analysis should evaluate Indonesia's financial preparedness, exploring the availability of funding mechanisms, incentives for private investment, and the nation's ability to attract international capital. A clear understanding of financial readiness is pivotal for the sustained momentum of the energy transition.

6) Environmental and Social Impact Mitigation

As energy transition projects unfold, mitigating environmental and social impacts becomes paramount. An analysis should scrutinize the frameworks in place for impact assessment, community engagement, and the mechanisms for addressing adverse effects. This includes evaluating the effectiveness of regulatory bodies in ensuring that projects adhere to environmental and social standards.

In the case of Indonesia, the analysis reveals a nation on the brink of transformation. While strides may have been made, challenges persist. The intricate interplay of infrastructure, policies, public awareness, technology, finance, and impact mitigation necessitates a holistic approach. We recognize that these challenges provides an opportunity for strategic interventions to fortify areas of weakness and amplify strengths. The readiness for an energy transition is not a static state; it is a dynamic equilibrium that requires continuous refinement and adaptation. Indonesia's case serves as a microcosm of the global challenge. Through a meticulous analysis of these major aspects, the nation can chart a course that aligns economic development with environmental sustainability, ensuring that the energy transition becomes a catalyst for a prosperous and resilient future.

D. COLLABORATION: CORNERSTONE OF SUCCESS

In the pursuit of a sustainable energy transition, collaboration stands as one of the cornerstones needed to achieve success. The complex nature of energy systems requires the collective effort of diverse stakeholders, ranging from government bodies and private enterprises to local communities. An equitable and sustainable energy transition demands a comprehensive action plan built on collaboration, ensuring that the benefits of this transition are shared by all. Central to this collaborative action plan is the need for a multi-stakeholder approach. Government bodies, at both national and sub-national levels, must work in tandem with private sector entities, non-governmental organizations, and local communities. A robust regulatory framework that encourages collaboration and establishes clear roles and responsibilities is essential. This framework should incentivize innovation, investment, and adherence to sustainable practices.

Equity in the energy transition is not solely about equal distribution of benefits, but also about inclusivity in decision-making processes. Communities impacted by energy projects should have a seat at the table, contributing to the design and implementation of initiatives. This participatory approach is needed to ensure that the transition is sensitive to local needs and concerns, fostering a sense of ownership and responsibility. Furthermore, a collaborative action plan should prioritize knowledge exchange and capacity building. This is particularly pertinent in the context of Indonesia, where the diversity of regions requires tailored solutions. Initiatives that facilitate the sharing of technological know-how, best practices, and lessons learned can bridge the gap between regions at different stages of the transition journey (Lu, et al., 2020; Chen, in press).

Case studies from collaborative initiatives in Indonesia, such as public-private partnerships in renewable energy projects, illustrate the potential impact of a united front. By pooling resources, expertise, and finances, these collaborations have accelerated the deployment of renewable energy infrastructure. This not only contributes to environmental sustainability but also stimulates economic growth and job creation. However, challenges persist, including the need for transparent communication and conflict resolution mechanisms.

A collaborative action plan must anticipate and address potential conflicts of interest, ensuring that the transition process remains inclusive and avoids exacerbating existing disparities. Basically, a collaborative action plan for an equitable and sustainable energy transition is not a mere aspiration but a pragmatic necessity. It requires a holistic approach that engages all stakeholders, fosters inclusivity, and prioritizes knowledge-sharing. As we navigate the complexities of Indonesia's energy landscape, the success of collaborative initiatives underscores the transformative power of collective action. In the coming years, the strength of these collaborations will determine the pace and inclusivity of Indonesia's journey towards a more sustainable energy future.

E. CLEAN COMPANY FOR BETTER COLABORATION

One of the elements needed in a collaborative grid toward net-zero emission is clean power companies. This is not an easy step. Becoming a clean power company is a transformative journey that hinges on a holistic commitment to sustainability and environmental responsibility. The path to achieving this goal involves a series of strategic steps and considerations, all aimed at reducing environmental impact and promoting clean energy practices. Several aspects needed to create a clean power company include:

1) **Commitment to Sustainability.** At the heart of every clean power company is an unwavering commitment to sustainability. This commitment should be reflected in the company's core values, mission, and business strategies. It serves as the guiding principle that underpins all efforts toward a cleaner energy future.
2) **Transition to Renewable Energy Sources.** A pivotal step in becoming a clean power company is the adoption of renewable energy sources. This includes investing in solar, wind, hydro, and other clean technologies for energy generation. Companies

should set ambitious targets for transitioning to renewable energy and work diligently to achieve them.

3) **Energy Efficiency and Conservation.** Prioritizing energy efficiency and conservation is essential. Companies must take steps to minimize energy waste, employ energy-efficient technologies in their operations, and promote energy-saving practices both internally and among customers.
4) **Grid Modernization and Smart Technologies.** Grid modernization and the integration of smart technologies are key elements of a clean power strategy. These initiatives enhance grid reliability, facilitate the integration of renewable energy sources, and enable real-time monitoring and demand response.
5) **Carbon Emissions Reduction.** Addressing carbon emissions is a central goal. This includes reducing emissions associated with energy generation as well as those stemming from the entire value chain, including manufacturing, transportation, and supply chain operations.
6) **Collaborations and Partnerships.** Collaboration with other clean energy stakeholders is crucial. Partnerships with government agencies, research institutions, and industry peers can foster innovation, knowledge sharing, and the identification of financing opportunities for clean energy projects.
7) **Regulatory Compliance and Policy Advocacy.** Clean power companies must adhere to environmental regulations and advocate for supportive policies that accelerate the clean energy transition. Engaging with policymakers and industry associations is a strategic approach to shaping favorable regulatory environments.
8) **Customer Engagement and Education.** Engaging and educating customers about clean energy options is essential. Companies should communicate the benefits of renewable energy, offer green energy products, and provide tools and resources to help customers reduce their energy consumption.

9) **Transparency and Reporting.** Maintaining transparency is critical for building trust and accountability. Clean power companies should regularly report on their environmental performance, including emissions reductions, renewable energy capacity, and sustainability initiatives.

10) **Continuous Improvement and Innovation.** The journey to becoming a clean power company is an ongoing process. Companies should foster a culture of continuous improvement and innovation to stay at the forefront of clean energy technologies and practices.

Thus, the transformation into a clean power company requires a holistic commitment to sustainability, clean energy adoption, and environmental responsibility. By embracing these principles, companies can reduce their environmental impact, lead by example, and contribute to a cleaner and more sustainable energy future.

F. BATTERYLESS ROOFTOP SOLAR HOME SYSTEM FOR URBAN AREA

In the hustle and bustle of Indonesia's urban landscapes, a quiet revolution is taking place atop countless rooftops—the advent of the batteryless rooftop solar home system (RSHS). This gives hope for the strengthening of energy transition in Indonesia. In a departure from traditional solar setups, this innovation sidesteps the need for energy storage, redefining how urban households harness and utilize solar energy. One of its remarkable features is cost efficiency. By forgoing the expense of batteries, the overall cost of the system takes a dip, bringing the benefits of solar power within financial reach for urban dwellers. This affordability is instrumental in encouraging community participation and collaboration between parties in the widely adopting of renewable energy in urban settings.

The expected advantages of this system include:

1) **Efficient Solar Energy Utilization.** This groundbreaking system directly taps into the power of the sun. Solar panels, neatly

installed on rooftops, capture sunlight and seamlessly convert it into electricity. This electricity is immediately employed to meet the energy needs of households, doing away with the necessity for energy storage solutions like batteries.

2) **Reliability and Grid Independence.** The batteryless RSHS operates in tandem with the grid when the sun graces the sky. This means that households can seamlessly transition between solar power and the grid, ensuring a constant and reliable energy supply. It is a step towards reducing dependence on the grid, especially in areas prone to frequent power outages.
3) **Reduced Environmental Footprint.** By eschewing the need for energy storage batteries, this system makes a subtle yet impactful contribution to reducing the environmental footprint of solar energy adoption. The lifecycle impacts of battery manufacturing and disposal are bypassed, aligning with Indonesia's commitment to a more sustainable and eco-friendly energy landscape.
4) **Scalability and Integration.** Flexibility is a hallmark of the batteryless RSHS. It is a scalable solution, allowing households to expand their solar capacity based on evolving energy needs. Moreover, its adaptability allows for seamless integration with other renewable energy sources and energy-efficient technologies.

However, challenges persist. The intermittent nature of sunlight and nighttime energy requirements necessitate thoughtful considerations. Solutions lie in the integration of smart grid technologies and energy management systems. Additionally, urban policies and regulations need fine-tuning to accommodate and incentivize the widespread adoption of this innovative energy paradigm.

The silent revolution happening on urban rooftops is expected to rewrite the narrative of solar energy adoption. The batteryless rooftop solar home system represents a leap towards a more sustainable and grid-independent urban energy landscape. As this technology matures and regulatory frameworks catch up, it has the potential to be a cornerstone in Indonesia's journey toward a cleaner, greener, and more energy-efficient urban future.

G. ENVIRONMENTAL ASSESSMENT FOR ENERGY TRANSITION TECHNOLOGY

As Indonesia embarks on its journey towards a sustainable energy transition, cleaner, greener, and more energy-efficient, environmental assessment (EA) emerges as a critical tool to guide decision-making and ensure that the transition aligns with ecological sustainability. Five pivotal aspects related to EA for energy transition technologies in Indonesia warrant in-depth consideration are as follows.

1) **Environmental Impact Assessment (EIA).** A cornerstone of EA, EIA examines the potential environmental consequences of energy transition technologies. In the Indonesian context, this involves evaluating the impact on ecosystems, air quality, and water resources. Robust EIAs are essential to identify and mitigate adverse effects while preserving valuable natural assets. Indonesia's rich biodiversity and diverse landscapes necessitate comprehensive EIAs. Specific attention must be given to ecosystems vulnerable to disruption, such as rainforests and coastal regions. It is crucial that EIAs adhere to international best practices and are conducted by independent experts to ensure objectivity (Burke & Stephens, 2018).
2) **Social and Cultural Impact Assessment.** Energy transition technologies often intersect with local communities and cultural heritage. Assessing the social and cultural impacts is essential to mitigate potential conflicts and ensure equitable development. For Indonesia, this includes evaluating how projects may affect indigenous communities and traditional practices. An inclusive approach to social and cultural impact assessment involves meaningful engagement with affected communities, respecting their rights and traditions (Mulia, et al., 2023; Escobar et al., 2021). Transparent and participatory processes can foster mutual understanding and collaborative solutions.
3) **Health Impact Assessment.** The health of the population must not be overlooked. The deployment of energy transition technologies should prioritize public health by assessing potential

health risks associated with emissions, pollutants, or disruptions caused by these technologies. In Indonesia's urban areas, where air quality can be a concern, health impact assessments should address issues like respiratory health and quality of life. Robust health impact assessments can guide mitigation measures and prioritize the well-being of communities.

4) **Regulatory Compliance and Permitting.** Navigating Indonesia's regulatory landscape is complex, and energy transition projects must adhere to stringent environmental regulations. Ensuring compliance with these regulations and obtaining the necessary permits is a fundamental aspect of EA. Streamlining permitting processes, enhancing regulatory clarity, and providing clear guidance for compliance can facilitate the efficient deployment of energy transition technologies. Timely approval is essential to minimize delays and costs.
5) **Long-term Sustainability and Monitoring.** The effectiveness of EA does not end with project approval. Continuous monitoring and evaluation are vital to assess the ongoing impact of energy transition technologies and ensure that they remain aligned with sustainability goals. Developing a robust framework for post-project monitoring and environmental management is imperative (Resosudarmo et al., 2023). This includes mechanisms for adaptive management, addressing unforeseen issues, and ensuring that projects evolve to meet changing environmental standards and expectations.

Environmental assessment is an indispensable component of Indonesia's energy transition journey. Key aspects discussed here underscore the need for a holistic, multidisciplinary approach that considers ecological, social, cultural, and health-related impacts. By prioritizing rigorous assessments, Indonesia can steer its energy transition towards a sustainable future, where clean energy technologies coexist harmoniously with the environment and society.

H. GREEN LEADERSHIP: ANOTHER PILLAR OF THE ENERGY TRANSITION

The global imperative for sustainable development has placed sub-national entities at the forefront of transformative change. Within the context of Indonesia's energy transition, the role of sub-national leadership becomes pivotal. Green leadership, characterized by a commitment to sustainable practices and innovation, emerges as a driving force at the regional level. Sub-national entities, including provinces and municipalities, wield significant influence over energy policies and local development initiatives. Green leadership at this level is not merely a theoretical concept but a tangible force capable of shaping the trajectory of the nation's energy landscape. Several regions within Indonesia have exemplified this transformative potential, leveraging local resources and governance structures to champion sustainable practices.

Central to the concept of green leadership is the integration of environmental considerations into policy formulation. Sub-national leaders play a crucial role in crafting policies that balance economic growth with ecological sustainability (PwC, 2021). By prioritizing renewable energy sources and incorporating eco-friendly practices into urban planning, these leaders set the stage for a resilient and sustainable energy future. Furthermore, the role of sub-national entities in promoting renewable energy projects should not be understated. Green leaders leverage their local knowledge to identify and exploit renewable energy potential unique to their regions. Whether it be harnessing solar energy in sun-drenched provinces or tapping into geothermal reservoirs near volcanic regions, these initiatives are tailored to the specific characteristics of each locale. Case studies from regions like East Java and Bali offer compelling narratives of successful green leadership. In East Java, local authorities have championed geothermal energy projects, tapping into the vast potential beneath the earth's surface. Bali, on the other hand, has become a beacon of sustainable tourism, showcasing the symbiotic relationship between environmental conservation and economic growth.

Yet, challenges persist. While some regions have embraced green leadership, others grapple with infrastructural limitations and resource constraints. The need for capacity building and knowledge transfer becomes apparent. Initiatives that facilitate the exchange of best practices and provide technical support can catalyze green leadership in regions facing hurdles. In conclusion, the transition at the sub-national level through green leadership emerges as a linchpin in Indonesia's journey towards a sustainable energy future. It is not merely a theoretical construct but a dynamic force shaping policies, driving innovation, and inspiring communities. As we reflect on the strides made by provinces and municipalities, it becomes evident that fostering green leadership is not only imperative but achievable. The success stories and lessons learned at the sub-national level serve as a beacon, guiding Indonesia toward a future where sustainability and progress coalesce.

I. EMBARK ON AN ENERGY TRANSITION JOURNEY

Indonesia's Energy Transition Preparedness Framework Towards 2045 represents a comprehensive blueprint for navigating the complex and transformative journey towards a more sustainable and clean energy future. This framework encompasses a multitude of critical aspects, each contributing to Indonesia's readiness and success in its energy transition efforts.

To strengthen Indonesia's preparations for this energy transition, a collaborative action plan is needed, supported by clean and environmentally friendly companies, and a better urban energy system. In addition, an environmental assessment system is needed that is supported by green leadership. Collaboration among stakeholders, from government bodies to local communities, is pivotal in achieving equitable and sustainable energy transition outcomes. The framework underscores the importance of multi-stakeholder engagement, transparency, and knowledge exchange.

We start by identifying the status of progress in energy technology. Progress on technological readiness and system optimization: **OTEC**

technology is making significant strides in technological readiness and system optimization. It represents a promising avenue for sustainable energy generation, with ongoing advancements positioning it as a transformative force in Indonesia's energy landscape. However, technological innovation will not provide any progress if there are no other pillars needed to build energy transition readiness. Indonesia's readiness for the energy transition was analyzed, showcasing progress in key areas while acknowledging the need for ongoing efforts to address challenges and enhance preparedness.

That is why, **clean power companies** are at the forefront of the energy transition. They prioritize sustainability, renewable energy adoption, and continuous improvement. This theme underscores the importance of commitment to clean energy, innovation, and transparency in becoming a leader in the clean power sector. Furthermore, as Indonesia's urban areas face energy challenges, the innovative **batteryless rooftop solar home system** offers an affordable, reliable, and environmentally friendly solution. Its adoption can revolutionize urban energy landscapes and contribute to a cleaner future. However, robust **environmental assessment** processes are essential to mitigate the environmental and social impacts of energy transition technologies effectively. The framework highlights five crucial aspects related to EA, ensuring that sustainability remains at the forefront of Indonesia's energy transition. Ultimately, the transition to sustainable energy at the sub-national level requires visionary **green leadership.** This theme recognizes the importance of local leadership and community engagement in Indonesia's diverse landscape.

Therefore, our journey within the *Indonesia's Energy Transition Preparedness Framework Towards 2045* offers a comprehensive roadmap for Indonesia's journey towards a cleaner and more sustainable energy future. Each theme underscores critical aspects that, when combined, create a holistic approach to navigate the complex terrain of the energy transition. By embracing these principles, Indonesia can lead by example, setting the stage for a brighter and more sustainable energy landscape for generations to come.

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Part 1
Indonesia‘s Ocean Energy Overlook

Chapter 2

Ocean Thermal Energy Conversion: Technological Readiness and Indonesia Progress

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A. Ocean for Clean Energy Development

Global energy consumption has increased over the last three decades (IEA, 2020) followed by an increase in non-renewable energy production from fossil fuels (IEA, 2021). Continuation of these conditions triggers climate change and global warming, directly affecting human health (Naing et al., 2019), human prosperousness (Calleja-Agius et al., 2021) and environmental sustainability (Shukla et al., 2017). Therefore, the need and the urgency for clean energy is undeniable.

Global renewable energy potential is estimated to reach 5,016.3 TWh (Moriarty & Wang, 2015) where ocean energy sources have a promising potential of about 10 TW (Esteban & Leary, 2012). One of the ocean energy resources with a promising, underutilized energy

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source is Ocean Thermal Energy Conversion (OTEC). It uses the temperature difference between warm surface and cold deep seawater to generate energy (Nihous & Vega, 1993). OTEC is advantageous because it produces no greenhouse gas emissions during operation, can run without fuel, and provides many ancillary benefits besides energy. The energy produced by OTEC has the potential to replace fossil fuels (Wang et al., 2011). Despite its many advantages, OTEC has yet to be widely deployed, remains largely unexplored and untapped at its potential sites.

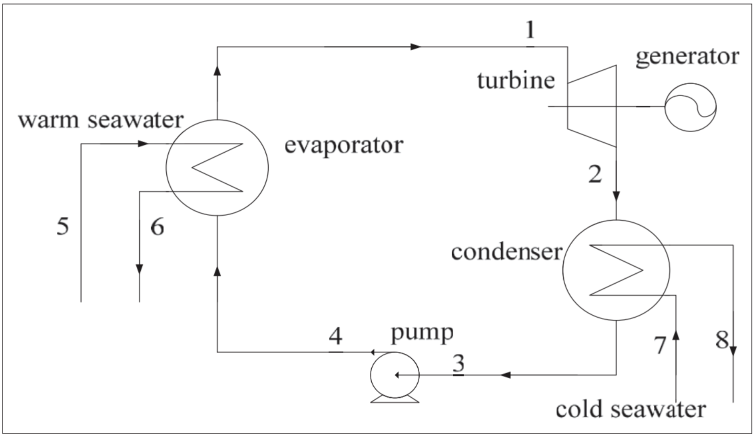
Analysis of OTEC technology and development problems is compiled comprehensively by reviewing the global current state of OTEC technology and system optimization. The review covers various aspects, starting with a detailed examination of the technical aspects of OTEC, including the advances made in supporting components, support structures, working systems within the OTEC domain, OTEC side benefits, and OTEC environmental impacts. In addition, the assessment of the economic implications associated with using and developing OTEC would be discussed. The economic analysis includes critical factors such as levelized cost of energy (LCOE) and initial capital calculations. By examining these economic aspects, this chapter aims to shed light on OTEC projects' financial viability and potential return on investment in Indonesia.

B. Ocean Thermal Energy Conversion System

OTEC power plants generate electrical energy by taking advantage of the temperature difference between warm seawater at the surface and cold seawater at depth. Roughly speaking, the amount of energy produced by OTEC power plants is equal to the amount of thermal energy extracted from the seawater. The OTEC system was first proposed by D'Arsonval in 1881, who introduced the use of marine thermal energy by using cyclic heat engines to generate electricity (Kobayashi et al., 2001). The basic principle of the OTEC system is to use the surface heat of seawater to evaporate the working fluid. The vapor produced is then directed to drive the turbine and then converted into electrical energy by the generator. The vapor coming out of the turbine is then returned to liquid by utilizing the cold temperature of deep ocean water. Based on the type of cycle, OTEC systems can be divided into three main categories, namely closed-cycle, open-cycle, and hybrid cycle.

1. Closed-cycle OTEC

Closed-cycle OTEC uses cyclic heat engines with working fluid that are placed in a closed cycle where there is no direct contact between the seawater and the working fluid. The Rankine cycle is one example of simple closed cycles, but is widely used in closed thermodynamic cycles. The Rankine cycle system consists of an evaporator, condenser, water pump, turbine and generator, and working fluid pump (see Figure 2.1). The Rankine cycle has four thermal processes, namely isentropic compression, isentropic heating, isentropic expansion, and isobaric condensation (Yang & Yeh, 2014). In the Rankine cycle, fluids with low boiling points require smaller turbines for higher efficiency (Ganic & Moeller, 1980).



Source: Chen et al. (2019)

Figure 2.1 Closed-cycle OTEC System Flow Diagram

In the closed-cycle OTEC, heat transfer occurs in the evaporator. The heat transfer from the warm seawater brings the working fluid to saturated vapor state. The vapor then passes through the turbine to the lower pressure zone and moves it. The movement of the turbine is then converted into electrical energy by the generator. The saturated vapor is then returned to liquid form in the condenser using the low temperature of cold seawater. The success of the Rankine cycle depends on how much energy is recovered from the cycle. As the vapor expands through the turbine, it gets energy, then used some of the energy to return to its liquid state. Due to isothermal evaporation and condensation of the working fluid, irreversible losses in the heat exchange process are inevitable for the Rankine cycle. As a result, it limits the improvement of the system performance. When the temperature difference between warm seawater and cold seawater is about 15–25°C, the maximum thermal efficiency of the Rankine cycle is about 3% (Nakaoka & Uehara, 1988).

Closed-cycle OTEC calculation is similar to the Rankine cycle, in which the calculation is based on a T-S diagram as shown in Figure 2.2. The thermal efficiency of closed-cycle OTEC is significantly affected by the power generated in the turbine (W_T W_T) and the power required to drive the working fluid pump (W_p W_p). The calculation of the thermal efficiency of the cycle has been formulated as Equation (2.1) (Chen et al., 2019).

$$\eta = \frac{W_{net}}{Q_E} = \frac{W_T - W_P}{Q_E} = \frac{(h_1 - h_2) - (h_4 - h_3)}{h_1 - h_4} \qquad (2.1)$$

Where:

W_{net} : Net output power of system

Q_E : Total heat of warm surface seawater

: $M_f(h_1 - h_2)$

W_p : Power of the working fluid pump

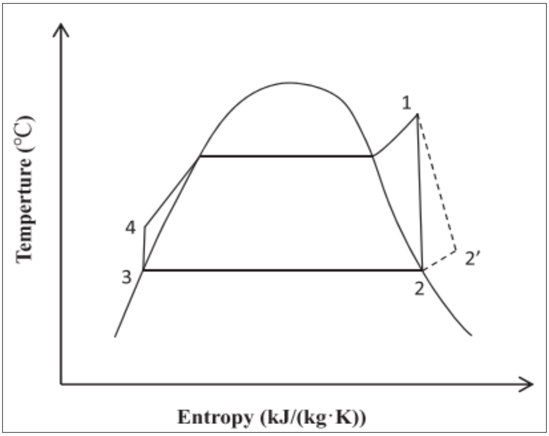
: $M_f(h_4 - h_3)$

W_T : Work in the turbine

: $M_f(h_2 - h_3)$

M_f : Mass flow rate of the working fluid

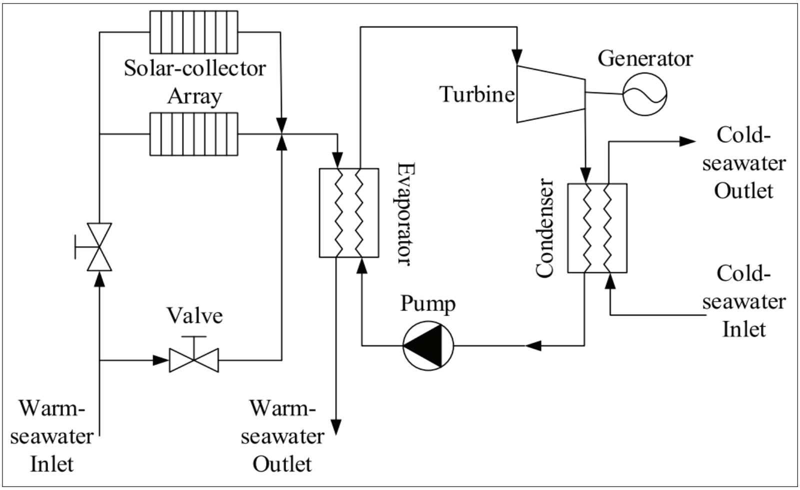
h : Specific enthalpy.



Source: Chen et al. (2019)

Figure 2.2 T-S Diagram of the Rankine Cycle

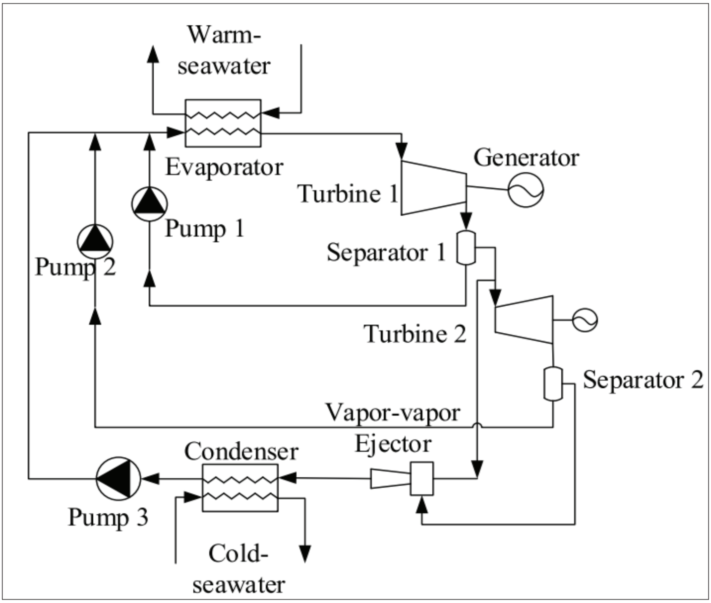
Several studies have been carried out to improve the efficiency of closed-cycle OTEC systems as reviewed in Liu et al. (2020). Aydin et al. (2014) investigated the use of solar energy to improve cycle efficiency. The study was conducted by comparing two closed cycle systems. In the first system, solar energy was used to raise the temperature of the warm seawater before it entered the evaporator (Figure 2.3). Meanwhile, in the second system, solar energy is used to heat the working fluid to a superheated state before it passes through the turbine. Aydin et al. (2014) concluded that under the same conditions, the thermal efficiency of the first and second cycle was 1.9% and 3%, respectively.



Source: Liu et al. (2020)

Figure 2.3 Solar-boosted OTEC Diagram

On the other hand, Lee et al. (2015) use ejectors to optimize turbine work output and improve cycle thermal efficiency in closed-cycle OTEC as shown in Figure 2.4. Vapor ejectors are used to ensure the pressure difference between the turbine outlet and the condensing pressure of the working fluid. This results in an increase in turbine 2 work output for a given volume of circulating working fluid. The conclusion is that the change in nozzle diameter of the ejector has the greatest effect on the thermal efficiency of the cycle. Even so, a larger diameter does not necessarily result in a higher level of efficiency, but rather needs to be in an optimal setting. At the most optimal setting, the thermal efficiency of the system reaches 2.47%, while the efficiency of the Rankine cycle under the same conditions is only 2.2%.

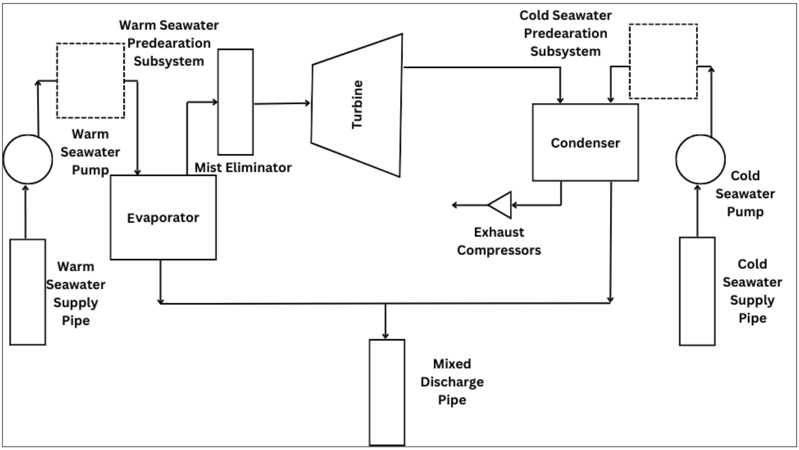


Source: Liu et al. (2020)

Figure 2.4 Vapor Ejector OTEC Diagram

2. Open-Cycle OTEC

Open-cycle OTEC was first proposed by G. Claude in the late 1920s to address the high cost and biofouling potential of closed-cycle OTEC. The diagram of the open-cycle OTEC can be seen in Figure 2.5. The main difference between open-cycle and closed-cycle OTEC is the use of warm seawater as the working fluid. The warm seawater is evaporated by lowering its boiling point by adjusting the vacuum pressure on the evaporator. As in the closed cycle, the vapor is then used to drive turbines (Masutani & Takahashi, 2001). In general, open-cycle OTECs have lower efficiencies than closed-cycle OTECs and require anti-corrosive materials for the production facility due to the salinity of the working fluid. However, open-cycle OTECs can produce desalinated water as a byproduct, which is 0.5–0.6% of the warm seawater input used by the cycle (Mutair & Ikegami, 2014).

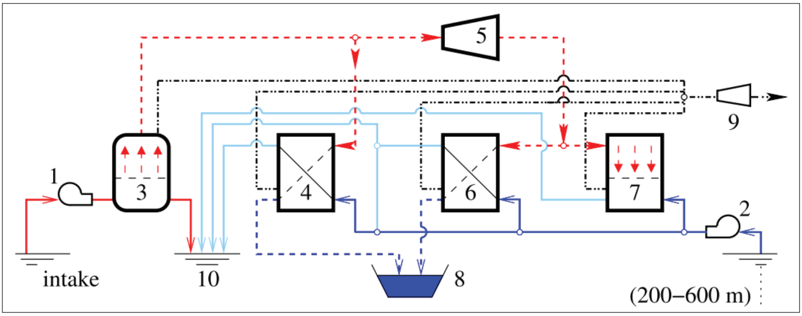


Source: Elaborated based on Link & Parsons (1986)

Figure 2.5 Open-cycle OTEC System Flow Diagram

Unlike closed-cycle OTEC, the entire open-cycle OTEC system operates under partial vacuum conditions (Bharathan et al., 1990). Open-cycle OTEC uses seawater as the working fluid, in which seawater is evaporated by lowering the boiling point of seawater by reducing the pressure below saturation pressure in the evaporator. The vapor produced in the evaporator is a relatively pure vapor. The transfer of heat energy occurs from most of the warm seawater to a small portion of the mass of warm seawater that becomes vapor (Masutani & Takahashi, 2001). Less than about 0.5–0.6% of the liquid warm seawater entering the flash evaporator is converted to vapor. As in other cycles, the vapor then passes through the turbine at low pressure, which then converts its motion into electrical energy by the generator (Bharathan et al., 1990).

As shown in Figure 2.6, the open cycle production of net electricity and desalinated water can be flexible with the use of multiple condensers as designed by Kim et al. (2016). The warm seawater vapor produced by the evaporator is divided into turbines for power generation and E-condensers for primary desalination. The vapor from the turbine then flows to the T- and D-condensers for secondary desalination and disposal. Uncondensed vapor is removed from the system by a vacuum compressor. Based on testing in four modes (power generation only, desalination only, half desalination and half power without recycling, and half desalination and half power with recycling), Kim et al. (2016) concluded that the half desalination and half power mode produces 50% less electrical energy than the power generation mode alone. For the seawater desalination results in a 206 kW generator, both the half-desalination and half-power modes and the desalination mode produce 3.5 kg/s of fresh water per 113.05 kg/s of seawater.



Note: Numbers indicate as follows: (1) pump for warm surface water, (2) pump for cold deep-sea water, (3) flash evaporator, (4) E-condenser, (5) a turbine, (6) T-condenser, (7) D-condenser, (8) fresh water reservoir, (9) vacuum compressor, and (10) open sea

Source: Kim et al. (2016)

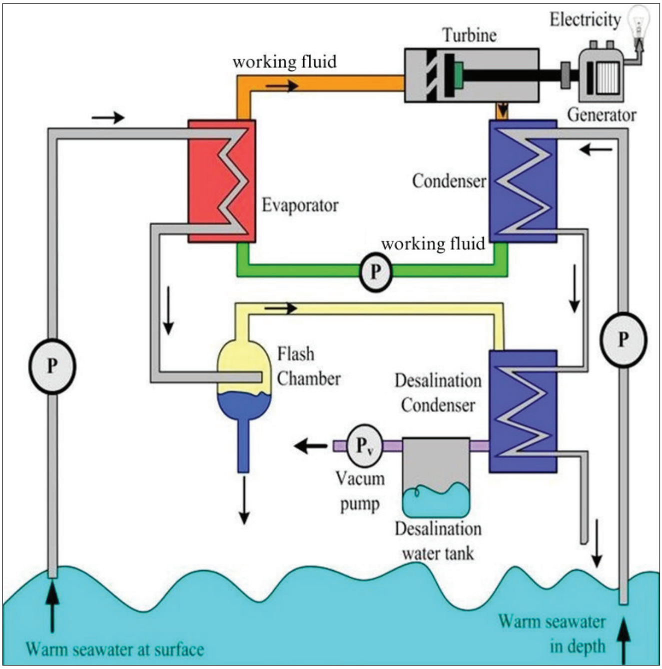
Figure 2.6 Multiple Condenser Open-cycle OTEC

Hernández-Romero et al. (2022) optimized the performance of the open-cycle OTEC system by combining ocean thermal energy with solar thermal energy. The optimization is focused on cycle performance in generating electricity and desalinated water. Solar thermal energy is collected through solar collectors to then be used to increase the temperature of warm seawater before it reaches the evaporator. Optimization is carried out in two operational modes, namely by prioritizing electricity production and desalination water production. In the mode with priority of electricity production, at optimal conditions, it can generate 82,848 kW/year of electrical energy and 1366 m^3/year of desalinated water. On the other hand, in the mode with the priority of desalinated water, at ideal conditions, it can produce 3,575 m^3/year of desalinated water and 31,738 kW/year of electrical energy.

3. Hybrid Cycle OTEC

Open-cycle OTEC requires a large turbine, which also has a large inertia, to produce desalinated water (Vega, 2013). The large inertia decreases the difference of pressure between inlet and outlet part of turbine and reduced the efficiency of the turbine. Closed-cycle OTEC, on the other hand, requires a smaller turbine because the boiling point of the working fluid is much lower than seawater, making the system more efficient. Hybrid-cycle OTEC is designed to combine the previous two types of cycles to produce working fluid vapor, which is then used as desalinated water (Herrera et al., 2021).

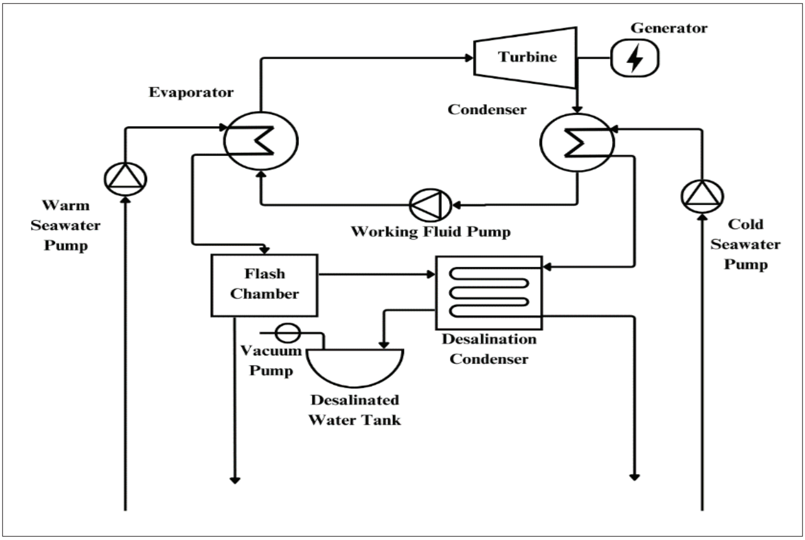
In the OTEC hybrid cycle shown in Figure 2.7, warm seawater is evaporated in a partial vacuum. Warm seawater vapor then enters the heat exchanger to evaporate the working fluid (Panchal & Bell, 1987). Some of the warm seawater vapor condenses into desalinated water, while the working fluid vapor circulates through turbines and condenses in condensers. The working fluid vapor is then condensed on the condenser by transferring heat to the cold seawater. The non-condensable vapor is then compressed by a vacuum pump and vented to the atmosphere. The main weakness of the hybrid cycle is that there is a critical relationship between desalinated water production and power generation, so if one system experiences a problem, both systems cannot function (Masutani & Takahashi, 2001).



Source: Suparta (2020)

Figure 2.7 Hybrid-cycle OTEC System Flow Diagram

Uehara et al., (1996) compared the performance of power production as well as water production in a hybrid cycle with a closed-cyle combined with flash desalination process, which called integrated-hybrid cycle (Figure 2.8). Based on the optimization of existing design results, the net power output and desalinated water production of the integrated hybrid cycle is higher than that of the regular hybrid cycle (Panchal & Bell, 1987), while the overall cost performance may be required including maintenance and operation.



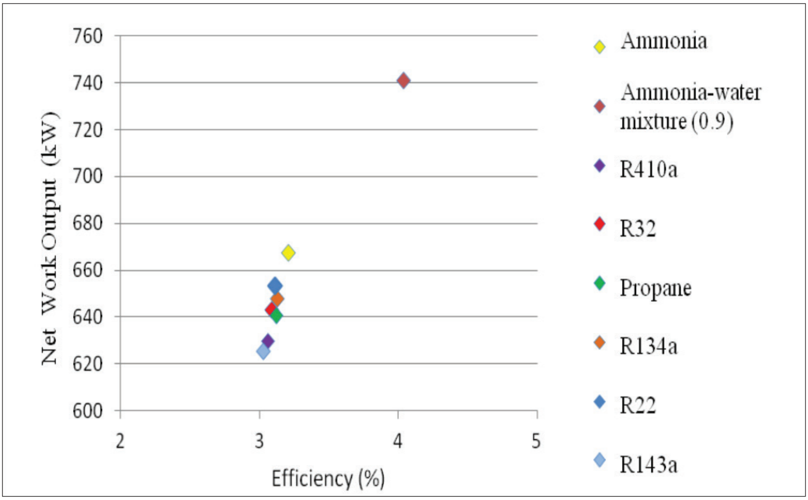
Source: Uehara et al. (1996)

Figure 2.8 Integrated-hybrid OTEC system combining a closed-cyle with flash desalination process

4. Working Fluid

In addition to the characteristics of the system, the working fluid has a significant impact on the efficiency of the OTEC cycle. Working fluids used in the OTEC cycle must have appropriate thermophysical properties and be stable over a specified temperature range. Working fluid selection must be based on thermal efficiency and cycle exergy, considering the economic value of the system (Liu et al., 2020). The working fluid commonly used in OTEC power plants is ammonia because its physical properties are ideal for the OTEC cycle (Wang et al., 2011). In his research on the Rankine cycle, Sun et al. (2012) concluded that ammonia is more ideal than refrigerant R134a which is made of ethane-based molecule as a working fluid in terms of net power output produced.

Samsuri et al. (2016) compared the efficiency of two types of working fluids for the Rankine OTEC cycle system. The two types of working fluids are pure chemicals and pseudo-pure fluids. The working fluids used in the category of pure chemicals are ammonia, R134a, R143a, propane, and R22. As for the category of pseudo-pure fluids, they consist of ammonia-water mixtures, R410a, R470c, R404a, and R507a. The results, as shown in Figure 2.9, ammonia and ammonia-water mixtures have higher net power and efficiency than the other working fluids. However, a separator is required to ensure that water vapor from the liquid does not damage the turbine blade, especially in the case of ammonia-water mixtures. It has been demonstrated that an ammonia-water combination produces more net power and has a lower cost of the main product than pure ammonia. Although it requires additional separators and reduces cost efficiency, ammonia or an ammonia-water mixture is still the best working fluid to increase net power.

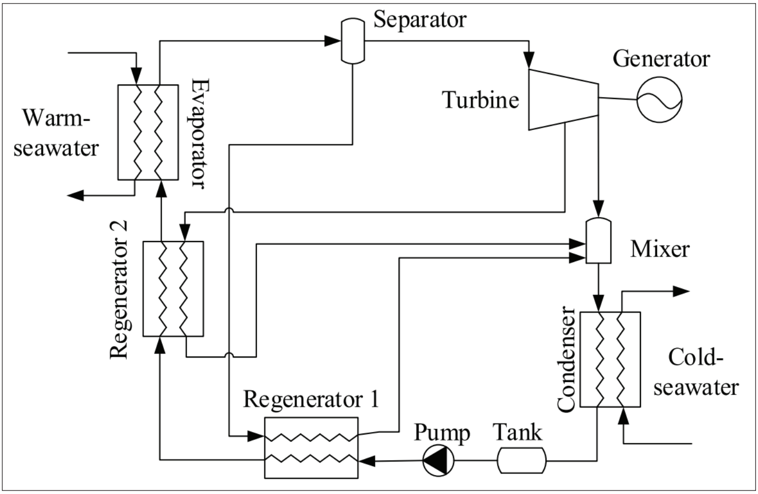


Source: Samsuri et al. (2016)

Figure 2.9 The Relationship between the Net Power Output and Efficiency

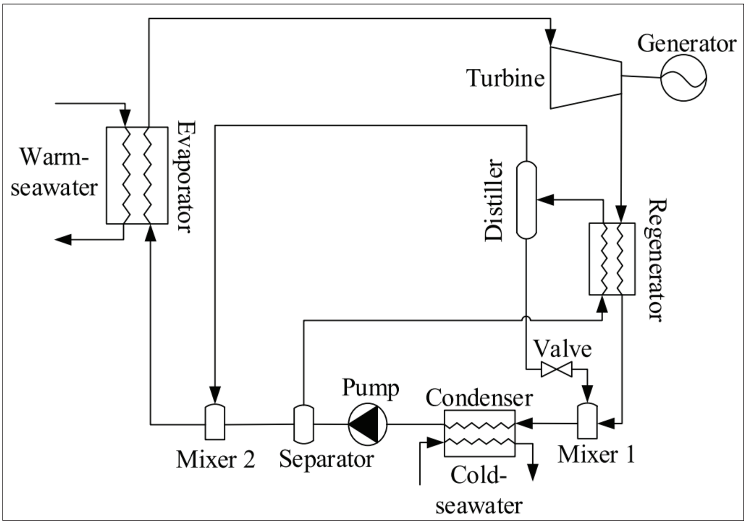
Figure 2.10 shows the Guo Hai cycle proposed by Liu et al. (2011). The Guo Hai cycle uses a mixture of ammonia and water as the working fluid. As in the Rankine cycle, the ammonia-water mixture is heated in an evaporator, but the ammonia vapor is then separated in a separator. A portion of the vapor is used to drive the turbine and then used to heat the working fluid in regenerator 2 until the working fluid reaches a saturated vapor state. The other portion of the ammonia vapor is then used to heat the working fluid in regenerator 1. The separation of the ammonia vapor allows the turbine to produce more net power. The heating of the working fluid in the Guo Hai cycle is more efficient than the regular Rankine cycle by combining the ammonia solution regenerative cycle and the extraction regenerative cycle in the system. The Guo Hai cycle can achieve a thermal efficiency of up to 5.16%.

The Kalina cycle, shown in Figure 2.11, uses a mixture of ammonia and water as the working fluid to vary the evaporation temperature (Kalina, 1984; Liu et al., 2020). The concentration of ammonia in the mixture decreases during the evaporation, raising the boiling point of the solution. This makes the process in accordance with the heat transfer process. The irreversible losses during the heat transfer process are significantly reduced, thus increasing the thermal efficiency (Kalina, 1983; Liu et al., 2020).



Source: Liu et al. (2011)

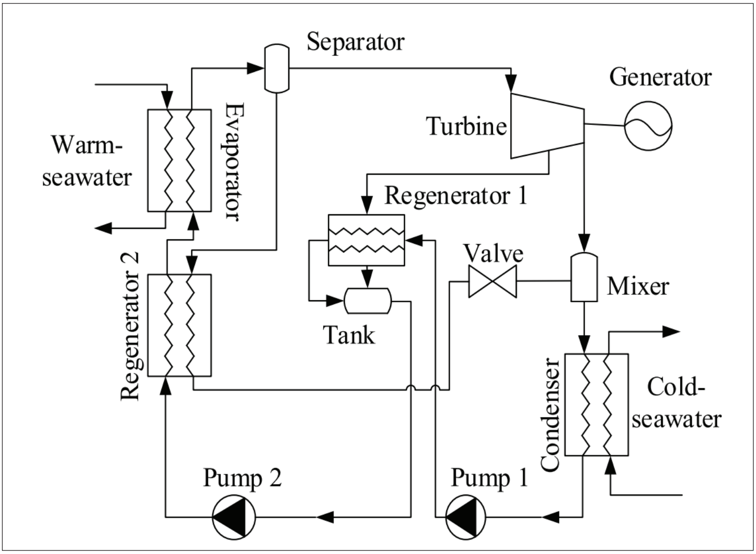
Figure 2.10 Guo Hai Cycle System Flow Diagram



Source: Liu et al. (2020)

Figure 2.11 Kalina Cycle System Flow Diagram

The Uehara cycle, shown in Figure 2.12, uses an ammonia-water mixture as the working fluid and a two-stage turbine system (Uehara et al., 1998). In the Uehara cycle, the exhaust heat recovery stage is eliminated and replaced by ammonia heat recovery and a regenerative extraction cycle. The process is designed to minimize the irreversible loss of working fluid during the heat transfer process (Liu et al. 2011). Thus, the thermal efficiency of the Uehara cycle can reach 5.4%.

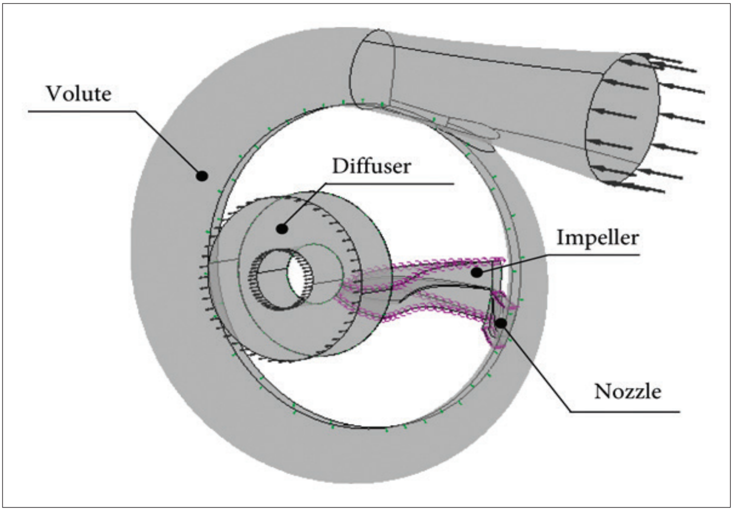


Source: Liu et al. (2020)

Figure 2.12 Uehara Cycle System Flow Diagram

5. Turbine

In the OTEC cycle, turbines are one of the main components in the process of producing electrical energy. Turbines are an important component in linking system displacement cycles and electrical energy output (Chen et al., 2022). Turbine outlet pressure is a key element in determining cycle efficiency (Wang et al., 2008). Closed-cycle OTEC typically uses a radial flow turbine as shown in Figure 2.13. The radial flow turbine has a high efficiency even though the power output and working fluid mass flow rate are minimal.



Source: Ma et al. (2022)

Figure 2.13 Radial Flow Turbine Model

Turbine efficiency is an important key to increasing net power output, especially due to the low overall cycle efficiency. Therefore, the aerodynamic design of the turbine must be carefully considered to maximize turbine efficiency. Some aerodynamic characteristics that have a major influence on turbine efficiency are impeller diameter ratio ($\overline{D}_2\overline{D}_2$), the degree of reaction ($\Omega\Omega$), and the velocity ratio ($\overline{u}_1$ $\overline{u}_1$) (Liu et al., 2020). The impeller diameter ratio is the ratio of the outlet diameter of the impeller to the inlet diameter of the impeller. The high and low impeller diameter ratio affects the operating capacity of the turbine. The degree of reaction is the ratio of the isentropic enthalpy droplets on the impeller to the decrease in total isentropic enthalpy. The degree of reaction represents the distribution of energy as the vapor expands in the nozzle and impeller. The velocity ratio is the ratio of the velocity of the vapor entering the impeller to the ideal velocity of the vapor under isentropic conditions. In addition to these three variables, there are four other variables that affect turbine efficiency. Turbine efficiency is calculated using the formula shown in Equation (2.2) (Liu et al., 2020).

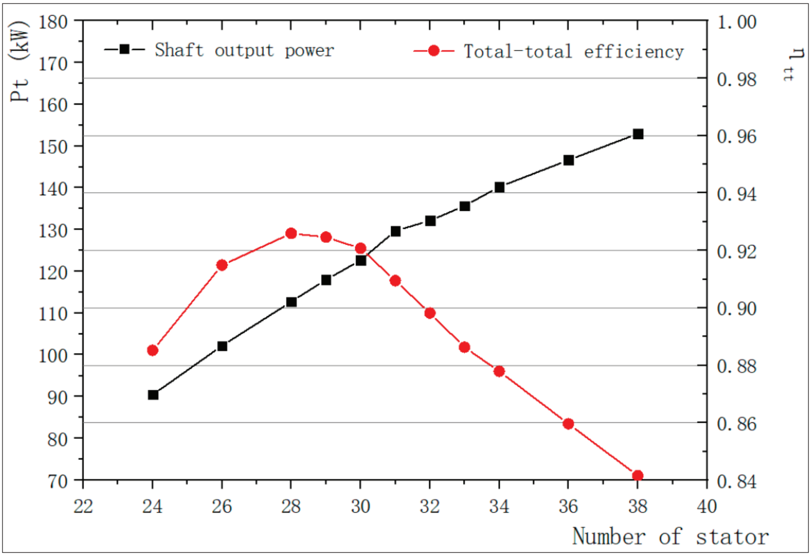
$$\eta = 2\bar{u}_1\left(\varphi\cos\alpha_1\sqrt{1-\Omega} - \bar{D}_2{}^2\bar{u}_1 + \bar{D}_2\psi\cos\beta_2\sqrt{\Omega + \psi^2(1-\Omega) + \bar{D}_2{}^2\bar{u}_1{}^2 - 2\bar{u}_1\varphi\cos\alpha_1\sqrt{1-\Omega}}\right) \quad (2.2)$$

Where :

$\bar{u}_1$	=	Velocity ratio
D_2	=	Wheel diameter ratio
Ω	=	Degree of reaction
α_1	=	Impeller inlet mounting angle
β_2	=	Nozzle outlet mounting angle
φ	=	Coefficient of velocity of impeller
ψ	=	Coefficient of velocity of nozzle.

Chen et al. (2022) investigated the effect of nozzle blade installation angle and turbine internal flow field on turbine performance. According to the results of the analysis, the pressure and enthalpy increase as the nozzle blade installation angle increase. On the other hand, the power of the turbine shaft decreases with the increase of the nozzle blade installation angle. As the vapor velocity at the nozzle exit increases, the rotor will be damaged faster. However, if the vapor velocity at the nozzle exit is too low, the reverse flow and vortex flow will occur at the rotor inlet. Chen et al. (2022) concluded that 30.5° is the most optimal nozzle blade installation angle to optimize pressure fields and vapor speeds to maximize power output, efficiency, and durability.

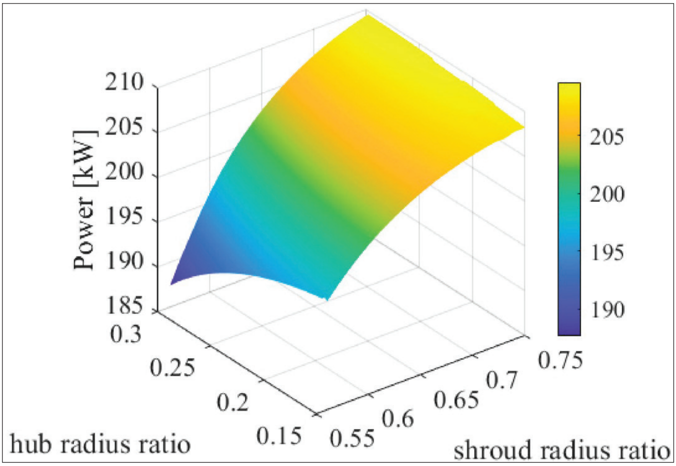
The number of blades on the stator has a significant impact on turbine efficiency. The large number of stator blades makes the fluid flow more uniform, allowing the vapor to expand optimally in the stator. However, as more stator blades are added, friction loss rises with the high contact between the vapor and the blades. Based on research by Chen et al. (2021), the total enthalpy loss of the turbine increases as the number of stator blades increases, while the reaction rate and enthalpy of the rotor decrease. In addition, the pressure at the stator outlet decreases as the number of stator blades increases, resulting in an increase in pressure drop. The increase and decrease in efficiency with the number of stator blades is shown in Figure 2.14, where it can be seen that the shaft output power increases as the number of stator blades increases, but the efficiency reaches its peak values at 27 blades.



Source: Chen et al. (2021)

Figure 2.14 Effect of Number of Stator Blades on Turbine Shaft Power and Overall Efficiency

In addition to the number of blades, the shroud radius ratio and the hub radius ratio of the turbine stator also affect the turbine power output in the OTEC cycle. The shroud radius ratio has more influence on the turbine power output than the hub radius ratio (Alawadhi et al., 2020). As shown in Figure 2.15, for higher shroud radius ratio, the turbine power output increases with increasing hub radius ratio, while for lower shroud radius ratio, the turbine power output decreases with increasing hub radius ratio.



Source: Alawadhi et al. (2020)

Figure 2.15 Variation of the Power with Shroud Radius Ratio and Hub Radius Ratio

6. Available power of OTEC

In general, the calculation of the net power output and efficiency of the OTEC system is based on the amount of heat provided by the seawater in the system, as shown in Equation (2.1). On the other hand, Wu (1987) introduced a method to calculate the OTEC cycle efficiency in maximum power (η_{Pmax}) using surface seawater temperature (T_{WS}) and deep seawater temperature (T_{CS}) as shown in Equation (2.3). Wu's formula applies the finite time reversible heat engine proposed by Novikov (1958) as well as Curzon and Ahlborn (1975).

$$\eta_{Pmax} = 1 - \sqrt{\frac{T_{CS}}{T_{WS}}} \tag{2.3}$$

Johnson (1983) proposes the exergy from seawater and compared the various cycles including closed and open cycles. The result shows the multistage open cycle will be the highest exergy efficiency. Yasunaga et al. (2021) shows the relationship between thermal efficiency and the work of heat engines in OTEC and propose to use the exergy efficiency for performance evaluation in OTEC by comparing the thermal efficiency and exergy efficiency in various designs of OTEC. Ikegami and Bejan (1998) theoretically expressed the relationship between the net power and thermal efficiency and exergy efficiency in OTEC. Yasunaga and Ikegami (2020) proposed the normalization of thermal efficiency to solve the discrepancy of the thermal efficiency and the work of heat engines. In short, the available power from the ideal heat engine W_m is expressed in Equation (2.4)

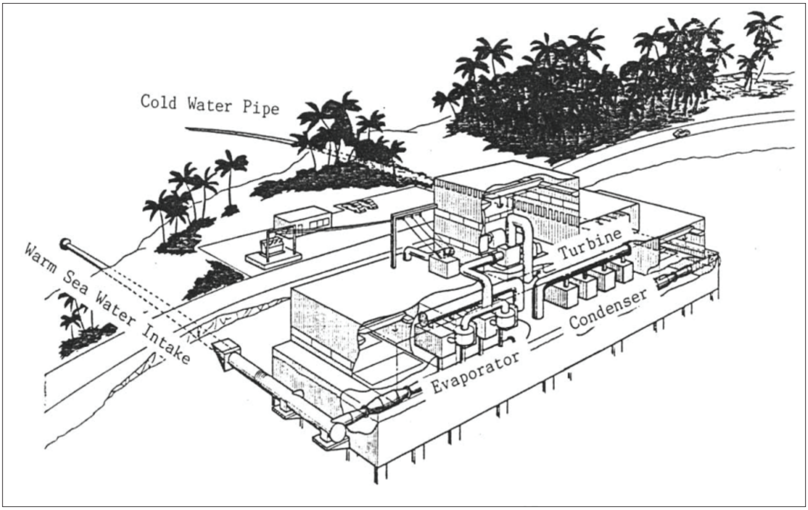
$$W_m = mc_p\left(\sqrt{T_{WS}} - \sqrt{T_{CS}}\right)^2 \qquad (2.4)$$

where the mass flow rate and specific heat of surface and deep seawater is assumed same m (kg/s) and c_p (kJ/(kgK).

C. OTEC Supporting System

Almost all of the equipment at the land-based OTEC facility is installed onshore. This eliminates the need for electrical power transmission cables from power plants and mooring systems for cold water pipes (CWP) and floating platforms, as shown in Figure 2.16. Onshore plants also make it easier to distribute and use the desalinated water. However, the seawater pipe required in onshore plants is longer, requiring a pipe structure reinforcement system that can increase construction and maintenance costs.

The 10 MWe onshore OTEC model of the Panchal and Bell (1987) system can produce 2.25 million liters of desalinated water for every 1 MWe of electrical energy produced. This system is designed to increase desalinated water production by 60–80% by increasing heat transfer by 90% or by shutting down one of the turbines so that



Source: Uehara et al. (1988)

Figure 2.16 Onshore OTEC Power Plant

ammonia vapor can flow directly into the condenser. However, in terms of electrical energy production, the cycle efficiency is only 1.6%.

All equipment in offshore facilities is located offshore or on floating platforms, unlike onshore facilities. With the use of floating platforms, CWPs are positioned vertically. As a result, their length and diameter are much smaller than those of onshore plants. However, due to the unstable nature of the ocean waves, floating platforms and CWPs' safety must be ensured during the operational life. To ensure that the floating platform and CWP are secure and will last throughout its operational life, a good mooring system design is required. Thus, OTEC floating platforms are often built on a large scale to increase structural stability, increase seakeeping, and minimize strain on the CWP (Wang et al., 2011).

As shown in Figure 2.17, Dr. Alfred Yee designed a floating platform to house the OTECs heat exchanger system and the turbine of the steel barge. In his design, the CWP is made of plastic and is 825 meters long. It was designed to reach deep ocean water off the coast of the island of Hawaii. The plant became known as the Mini OTEC. It was capable of producing 50 kW gross power and 18 kW net power (Vega, 2002). The simple design of Mini OTEC then became a benchmark for several researchers to develop floating OTEC platforms.

1. Cold Water Pipe

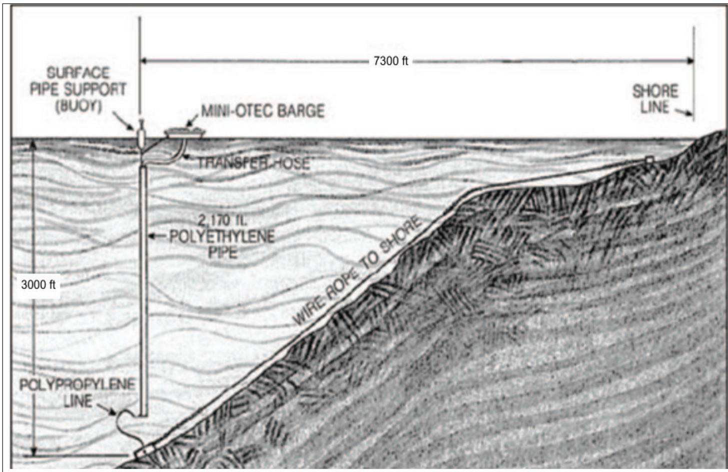
One of the most important supporting components in OTEC plants, both onshore and offshore, is the cold-water pipe (CWP). CWP is used to supply water to the cooling system in the condenser. To obtain water at the correct temperature for condensing the working fluid vapor, a CWP of approximately 600–1,000 meters in length is required for both onshore and offshore plants. Power output affects the fluid flow required in the OTEC CWP (Nihous, 2007).

The first development of a CWP was made by Claude in 1933, Brazil. The CWP's diameter was 2.5 m and able to reach a depth of approximately 700 m in a vertical position (Avery & Wu, 1994). However, the CWP was destroyed in a storm, and the project was abandoned. Previously, Claude had also carried out experimental construction of a land-based facility in Cuba, but this also failed during the CWP installation phase. The failure occurred because the geography of the proposed site, which consists of a gentle underwater slope, would not allow the pipe to be laid all the way as planned. Problems with the CWP also led to the abandonment of the OTEC project in the port of Bengal, India (Avery & Wu, 1994; Miller & Ascari,, 2011).

The development of the OTEC CWP began after the 1973 oil crisis. The development also considered several important issues, such as material, connection system to the hull, and installation. As a result, pipes made of fiber reinforced polymer (FRP) using a sandwich-structured wall design were considered the most promising for installation and use, as shown in Figure 2.18. One of the successfully operating CWPs has a limited diameter of only 1–2 m and is used for a demonstration of power plants (Miller et al., 2012). CWPs with the desired diameter to produce the right amount of energy are still very challenging to made in the overall OTEC system and components, compared to other components, such as the floating structure and deep water mooring (Hisamatsu & Utsunomiya, 2022).

The CWP must be both strong and lightweight to withstand continuous loads and movements, yet easy to install (Xiang et al., 2013). In the CWP design process, studies on strength analysis, pipe coupling movement analysis, and floating structure analysis, as well as the effect caused by internal flow analysis, are extremely important and are strongly considered. Adiputra and Utsunomiya (2019) state there are three main problems of OTEC CWP: analysis of strength either for general and in extreme collapse condition; analysis of CWP and vessel joint; and vibration occurs in the pipe, specifically vibration due to vortex and effect caused by internal flow.

Griffin (1981) proposed a tube design for a net power of 40 MW. Griffin proposed an OTEC with a diameter of 9.2 m and a length of 1,000 m, as shown in Figure 2.19. The CWP has a rigid wall with a flexible joint configuration with several supporting components in the CWP, such as hydraulic seal, center support, wall support, and pin connector. The design did not state the exact material properties but only mention the materials under consideration for CWP construction including steel, concrete, fiber reinforced plastic (FRP), thermoplastics and elastomers/fabrics. In this way, when released, the OTEC will be able to withstand the existing forces, such as the hydrodynamic force, as well as the forces generated by the floating platform (Griffin, 1981).



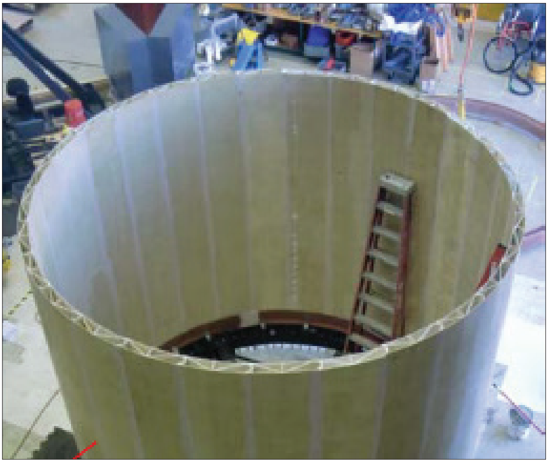
(a)

(b)

Note: (a) Cold water pipe model; (b) Floating platform

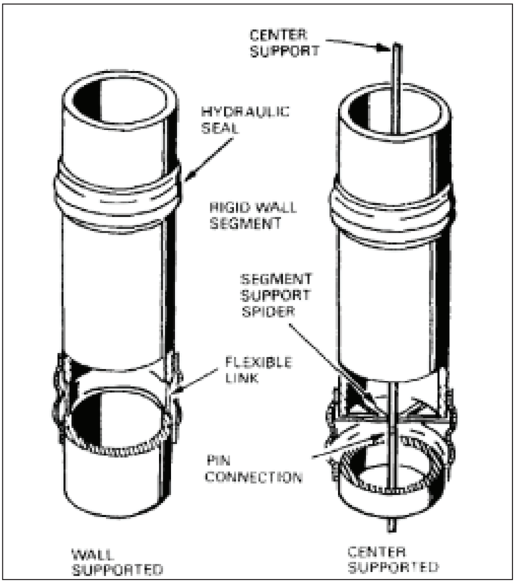
Source: Wang et al. (2011)

Figure 2.17 Offshore MINI OTEC Power Plant



Source: Miller et al. (2012)

Figure 2.18 OTEC CWP with FRP and Sandwich Structure Design



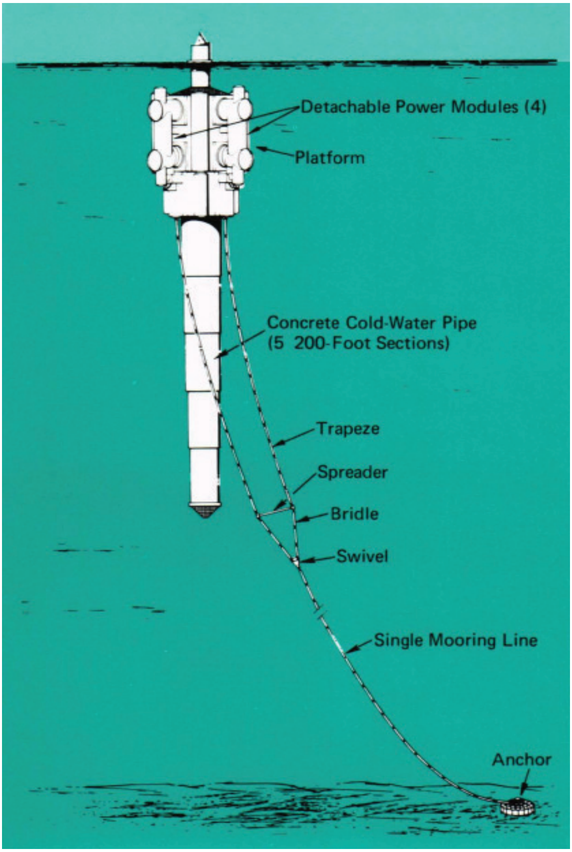
Source: Griffin (1981)

Figure 2.19 Rigid Wall CWP Concept

2. Floating Platform

In the OTEC system, especially in offshore plants, floating platforms function to house all the system equipment used to produce electrical energy (Gava et al., 1978). The floating platform structure is designed to be self-stabilizing even when exposed to external forces due to waves and wind, and to have good seakeeping performance. In addition, the floating platform is also designed to minimize the stress caused by the connection between the system and the CWP.

The floating platform structure is designed according to the size of the plant to be made, so that all equipment can be accommodated without compromising the safety of the structure. In addition, the sea condition in which it operates is also an important consideration. Throughout its development, OTEC, especially on floating platforms, has had many types of designs. One of the simplest is the rectangular shape as found in the Mini OTEC plant as shown in Figure 2.17b. As an alternative to the quadrilateral design on the Mini OTEC, a spar buoy design was proposed by Lockheed Martin. The design was primarily of reinforced-concrete construction, and the cold-water pipe reaches 460 m depth, as shown in Figure 1.20 (Dugger et al., 1975).



Source: Dugger et al. (1975)

Figure 2.20 Spar Type OTEC Plant by Lockheed Martin

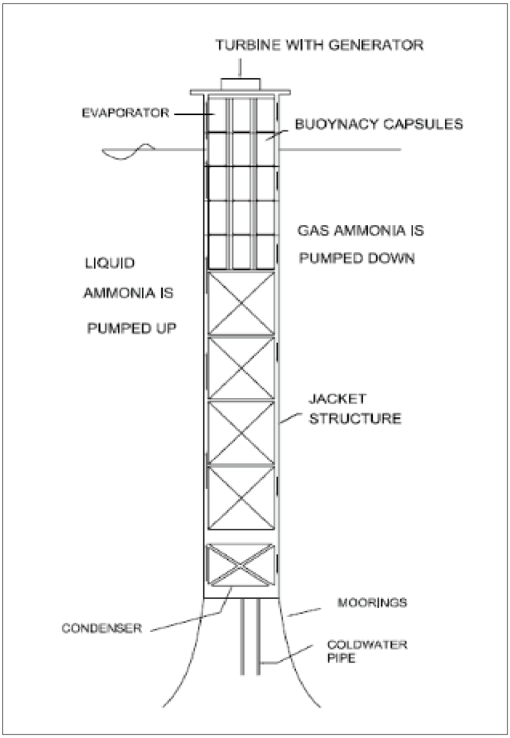
In addition to the type of cycle and plant size, the location of the floating platform is also an influential variable. To withstand strong ocean currents at its site, the University of Massachusetts designed a floating platform using the basic design of a submerged catamaran. Another platform design proposed by Johns Hopkins University's Applied Physics Laboratory uses ship-like propulsion to move the floating OTEC plant across the Pacific and Atlantic Oceans in search of the desired temperature differential. The hull is planned to be approximately 60 m (Dugger & Francis, 1977; Sasscer & Ortabasi, 1979). To withstand severe wind and wave conditions, Dr. Alfred Lee also proposed an OTEC platform based on the honeycomb concrete framing system as shown in Figure 2.21.

Source: Wang and Wang (2015)

Figure 2.21 Honeycomb Concrete Framing System Based OTEC Plant

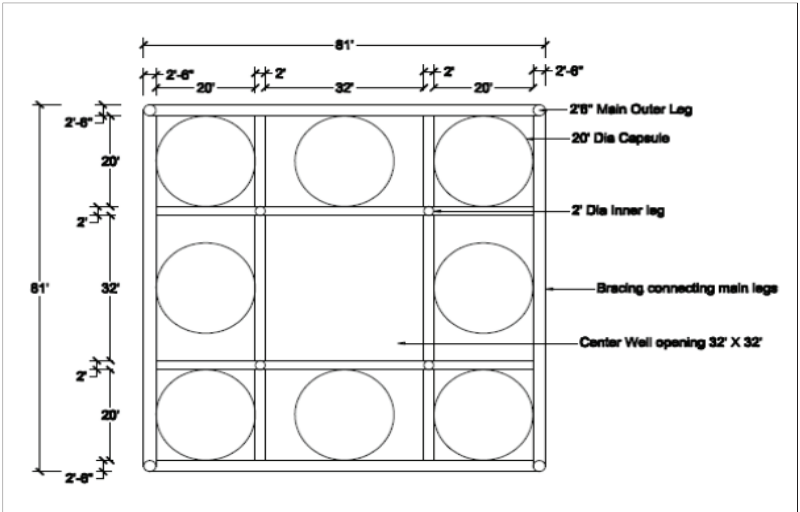
Another development related to OTEC floating platforms have been carried out in Japan by considering the design of the ship surface as well as the design of the submerged cylinder. It is designed to withstand the rough sea of Japan. Calculations on the platform design were made with the maximum wind speed of 60 m/s, a current at sea level of 2 knots, and a wave height of 18.5 m (Kamogawa, 1980).

Srinivasan proposed a floating structure called J-Spar, shown in Figure 2.22. This configuration allows the condenser to be located at sea depth. The J-Spar in this design uses welded tubular sections like a conventional jacket structure. The deck section has an eight-foot base on the bottom. The turbine and generator are placed on the deck, as shown in Figure 2.23. A buoyancy capsule is added to the structure to keep it afloat. As designed, the J-spar is the simplest floating platform design and fabrication process among spar designs. In addition, the J-spar configuration is naturally unaffected by whirlpools caused by underwater currents. Additionally, the suspended cold water pipe configuration makes this installation configuration more stable (Srinivasan, 2009).



Source: Srinivasan (2009)

Figure 2.22 J-Spar Design

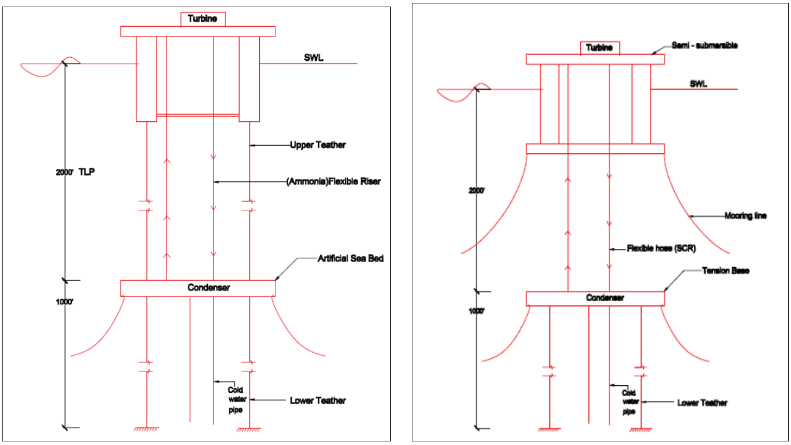


Source: Srinivasan (2009)

Figure 2.23 Cross Sectional of J-Spar Platform Configuration

In addition to J-Spar, the strain-based foot concept can also be used as an alternative for offshore OTEC facilities. This design uses an artificial seabed at a sufficient depth from the actual seabed to reinforce additional systems on the OTEC platform. The artificial seabed consists of a plate structure with a mooring system. In addition, a tensile-based foot system was created and connected to all four corners of the artificial seabed. With this system, condensers can be placed at a depth of around 610 m below sea level. Placing the condenser far below sea level can increase condenser efficiency due to cooler seawater temperatures (Srinivasan, 2009).

The condenser used can also be larger depending on the space available in the clamping base. In addition, the length of the chilled water pipe can be reduced. Another configuration of the tension leg platform is to replace the tension leg platform with a semi-submersible vessel in the OTEC CWP. The mooring system is replaced by a mooring system that allows the semi-submersible to move around. A dynamic positioning system with disconnectable risers is used on the semi-submersible so that the floating plant can be moved in case of adverse weather conditions. The platform with semi-submersible replacement can be seen in Figure 2.24 (Srinivasan, 2009).



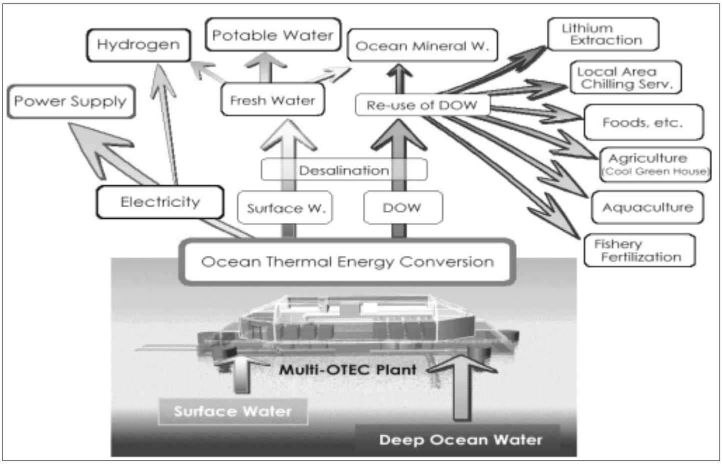
Source: Srinivasan (2009)

Figure 2.24 Cross sectional of J-Spar platform configuration

Another platform being considered for use in the OTEC system is a platform with a reinforced concrete honeycomb frame system. By integrating precast concrete cylindrical components with a top and bottom slap and side wall on the outside of the platform, this platform is considered suitable as a support for OTEC system containers and other components. As an example, the platform application system is the use of a concrete island drilling system (CIDS) in the process of oil exploration and drilling in the US and Russia, precisely in the Arctic Circle area, where the main part for the ice impact resistance on the CIDS platform is the honeycomb module. Where with the use of a honeycomb framing system in the OTEC plant, there will be a large space without columns, so there can be a large and flexible space without obstacles that can be used for an organized and efficient equipment layout. Another research by Adiputra and Utsunomiya (2018) proposed a floating structure design for an OTEC power plant with a capacity of 100 MW. The design of the plant ship proposed by is to use a commercial oil tanker, which is then converted into an OTEC power ship.

D. OTEC Environmental Impact

OTEC is renewable and does not produce pollutants because it does not require the combustion of fuel to generate electricity (Ma et al., 2022). Further analysis is conducted to determine whether there is an impact on the environment, either positive or negative. Positive impacts are generally in the form of byproducts, as shown in Figure 2.25. Kobayashi et al. (2001) describe several byproducts that can be utilized from the multi-OTEC plant. The development of desalination with surface water sources can be utilized in ocean mineral water, potable water, and hydrogen. Meanwhile, the reuse of deep ocean water (DOW) obtained from certain depth depending on the site location can be used for aquaculture activities, food production, and lithium extraction since the deep ocean water rich with nutrients.



Source: Kobayashi et al. (2001)

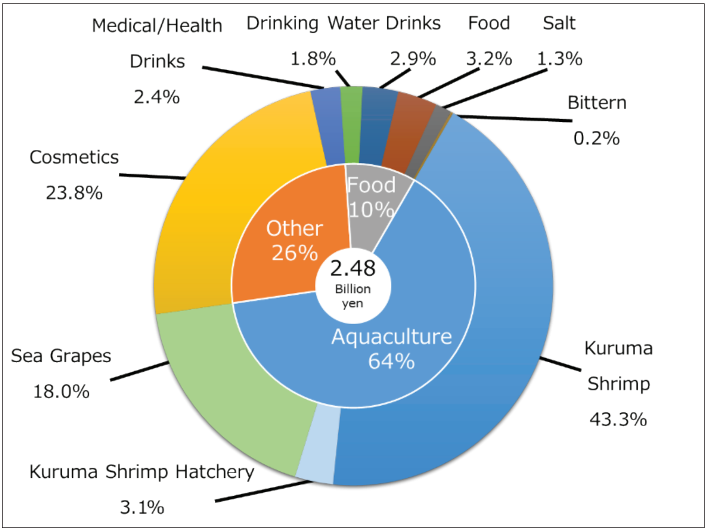
Figure 2.25 Benefit from Multi-OTEC Plant

Koto and Negara (2016) state that at a scale of 1 MW, OTEC can produce 4,500 m^3/day of fresh water and can meet the water needs of 20,000 people. Research conducted by Saga University shows that by developing a flash spray system, 100 MW OTEC can produce 1 million m^3/day of water (Kobayashi et al., 2001; Chan et al., 2020). In his research, Kobayashi et al. (2001) stated that only about 1% of raw seawater was desalinated as fresh water, or around 10,000 m^3/day with 1MW OTEC approximately. In addition, freshwater can be converted into several other forms, such as hydrogen, potable water, and seawater mineral water. In the case of hydrogen production, this is a major discovery that can change industrial usage habits from fossil fuels to environmentally friendly hydrogen.

Freshwater produced by the OTEC cycle could also be processed into potable water. This development can reduce the clean water crisis, where a study conducted by Ma et al. (2023) provides data that 1 MW OTEC can provide 2.28 million liters of potable water. This will certainly be mutually beneficial as coastal areas are generally OTEC development areas and areas that often lack fresh water (Welsh & Bowleg, 2022). In addition to the production of seawater, the mineral content and low levels of pollutants in DOW are also used for aquaculture or mariculture activities. DOW was used in regard that it contains almost no contaminated or disease-carrying organisms. A shared system between OTEC and aquaculture could reduce pumping costs. Besides, DOW OTEC has several advantages, such as high-water quality, elevated levels of inorganic nutrients, and the ability to reduce water pumping costs due to OTEC (Mencher et al., 2009). Mencher et al. (2009) used DOW to determine the biological effects on edible seaweed using OTEC in Hawaii. The results of his experiments showed that the edible seaweed developed was of the same quality as high-quality Japanese edible seaweed in a short growth period (3–4 weeks).

Cold seawater left over from OTEC can also be used to support the cooling system in a building (Prawira et al., 2017). In an open-cycle OTEC system, the cold seawater output from the condenser can be used for the air conditioning system. Koto (2016) estimates that the use of air conditioning systems by utilizing the remaining DOW of the OTEC system can be applied on a large scale and reduce the cost of electricity consumption. In addition to meeting the challenge of electricity demand, OTEC can also meet energy demand. In line with Koto, Chan et al. (2020) estimate that the air conditioning of open cycle OTEC can reduce the impact caused by hotels on Cozumel Island, Mexico.

Currently, the use of OTEC has reached the food, cosmetic, and medical markets. In addition to its use in mariculture, DOW OTEC can also be used in the cosmetic and pharmaceutical industries (Arias-Gaviria et al., 2020). In fact, since 2001, it has been documented that Kumejima (a town in Okinawa, Japan) has utilized the potential of DOW to open a new industry, of which approximately 24% is the cosmetic industry (Martin et al., 2022), as shown in Figure 2.26. The seawater interval used ranges from 15 m for surface seawater to 612 m for deep seawater. And each seawater's maximum flow rate is 13,000 m^3/day.



Source: Martin et al. (2022)

Figure 2.26 DOW in Kumejima Town, Okinawa is mainly used for aquaculture (64%).

In the food sector, Kumejima has developed the cultivation of sea grapes through aquaculture. The combination of DOW and surface ocean water is done because of the temperature-sensitive nature of sea grapes. Following the development, an eco-park will be built in Mexico, to meet the growing food demand around Cozumel Island, Mexico (Tobal-Cupul et al., 2022). This will be done by developing OTEC-Offshore Seaweed Aquaculture through the cultivation of *Ulva* spp. as cultivated seaweed for food sources. In 2018, a study conducted by Liu (2018) announced that South China has also started to develop OTECs DOW applications as an alternative energy and food source that can support life.

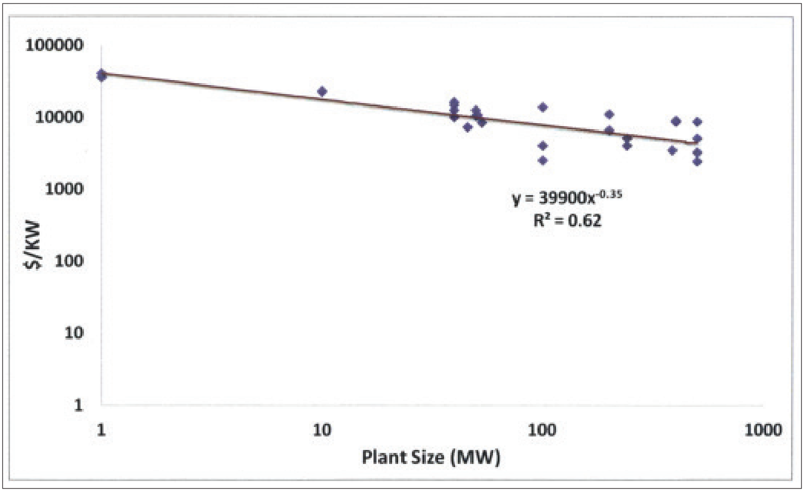
Figure 2.26 shows that one of the uses of DOW from OTEC development is lithium extraction. This is supported by studies conducted by various researchers (Semmari et al., 2012; Zulqarnain et al., 2023). According to a study conducted by Yoshizuka et al. (2007), lithium as a battery source can be obtained from seawater by ion exchange technique. Among other methods, this method was chosen because it has advantages from an economic and environmental point of view.

Petterson and Kim (2020) mentioned in their study that the use of OTEC side products needs to be further developed, as OTEC development is a form of activity that supports the Sustainable Development Goals (SDGs) as a global success and is a practice of SDG 7 (affordable and clean energy). Suppose by-products—such as desalination, aquaculture, cooling systems, as well as food production, cosmetics, and medical needs—can be developed in addition to lithium extraction, then OTEC development will also contribute to the realization of SDGs 6 (clean water and sanitation), 9 (industrial innovation and infrastructure), and 13 (climate action). In addition, the processing of food, cosmetics, lithium, and medical needs will certainly create jobs, especially for local residents, so that SDGs 1 (no poverty), 2 (zero hunger), 8 (decent work and economic growth), and 11 (sustainable cities and communities) can also be indirectly realized.

However, besides all the advantages and benefits of OTEC development, there are several environmental issues that need attention. As with the choice of working fluid, Jung et al. (2019) compared different types of working fluids such as R32, R125, R134a, R143a, and R410a. According to their study, R134a is the most environmentally friendly type. On the other hand, R32 and R143 are excluded because they are flammable. Working fluids with organic types such as ammonia must also be considered for use because they are toxic substances and can explode under thermodynamically unexpected conditions (Liu et al., 2020). This is certainly very dangerous for the survival of marine flora and fauna, as well as settlements around coastal areas.

E. OTEC Capital

Cost scenario analysis conducted by International Renewable Energy Agency (2014) stated that large-scale OTEC (>100 MW) development is more economically advantageous. In comparison, small-scale OTEC (1–5 MW) requires USD 16,400–35,400/kW, while large-scale (based on feasibility study) ranges from USD 5,000–15,000/kW or even as low as USD 2,500/kW for large-scale floating OTEC. In addition, the cycle selection has a significant difference, where the cost for the open cycle is about USD 2,300/kW higher than the closed cycle (International Renewable Energy Agency, 2014). More detailed cost comparison data is provided based on a study conducted by Muralidharan (2012), which shows a comparison of cost projections with a range of OTEC plant scales in Figure 2.28. Based on Figure 2.27 and Table 2.1, it can be seen that there is a downward trend in capital costs as the capacity of OTEC plants increases.



Source: Muralidharan (2012)

Figure 2.27 Trend line of capital costs of OTEC plant for increasing plant sizes. The bigger plant, the cheaper the capital cost.

Table 2.1 Cost Estimates for OTEC and Hybrid OTEC

Size (MW)	Source of LCOE (USD/kWh)[2]				
	(Vega & Asso, 2007; Vega, 2013)	(Energy and Environment Council, 2011)	(Straatman & Van Stark, 2008)	(Upshaw, 2012)	(Muralidharan, 2012)
1–1.35	**0.60–0.94**	**0.51–0.77**			
5	**0.35–0.65**				
10	**0.25–0.45**	**0.19–0.33**			
28				0.13–0.65	
50	**0.08–0.20**	**0.10–0.16**	**0.11–0.32**		
50 (combined with offshore pond)	**0.03–0.05**		0.04–0.06		
100	**0.07–0.18**				**0.19**
200					0.16
400					0.12

Source: International Renewable Energy Agency (2014)

Muralidharan (2012) performed a sensitivity analysis on this comparison and then related the two with a linear equation formula, as shown in Equation (2.3).

$$\text{Capital Cost (\$/kW)} = 39{,}900 \times MW^{-0.35} \qquad (2.3)$$

Based on the trend and the formula, there is a one-fifth reduction in capital cost for each doubling of the OTEC plant. When the capacity of the plant is compared to the capital cost required, the capital cost decreases as the capacity of the OTEC plant increases.

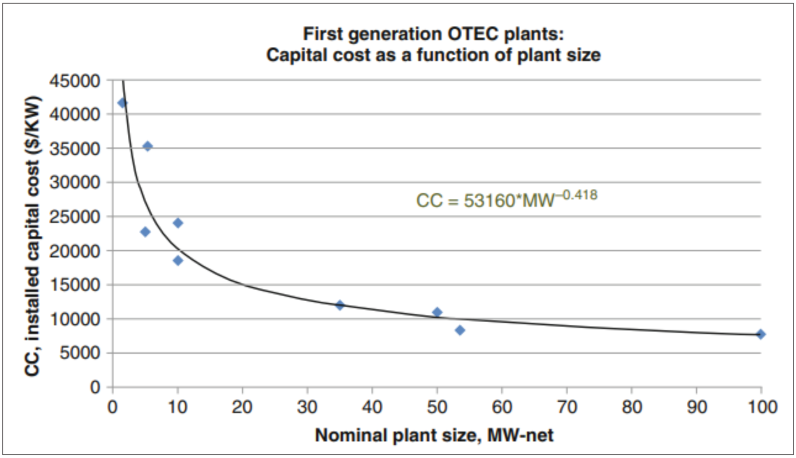
A similar study was also conducted by Vega (2013) which compared OTEC capital costs from various literature as shown in Table 2.2 and Figure 2.28. In the presented data, the capital costs have been converted and adjusted to 2013 costs. When comparing the capital costs between 1.4 MW and 100 MW, the differences reaching about as high as USD 34,000/kW. In contrast, a significant decrease applies to 1.4–10 MW plants. For developing less than 1.4 MW, the decrease is less significant and tends to remains stable. In his research, Vega also formulated a function to determine the capital cost using variable plant capacity in an exponential function, as shown in Equation (2.4).

$$\text{Capital Cost (\$/kW)} = 53{,}160 \times MW^{-0.418} \qquad (2.4)$$

Table 2.2 OTEC Plant Capital Cost Estimates

Plant size (MW-net)	Installed capital cost ($/kW)	Land/Floater	Source
1.4	**41,562**	L	(Vega, 1992)
5	**22,812**	L	(Vega, 2010)
5.3	**35,237**	F	(Vega, 1994)
10	**24,071**	L	(Vega, 1992)
10	**18,600**	F	(Vega, 2010)
35	**12,000**	F	(Vega, 2010)
50	**11,072**	F	(Vega, 1992)
53.5	**8,430**	F	(Vega, 2010)
100	**7,900**	F	(Vega, 2010)

Source: Vega (2013)



Source: Muralidharan (2012)

Figure 2.28 Capital cost estimated for OTEC plants.

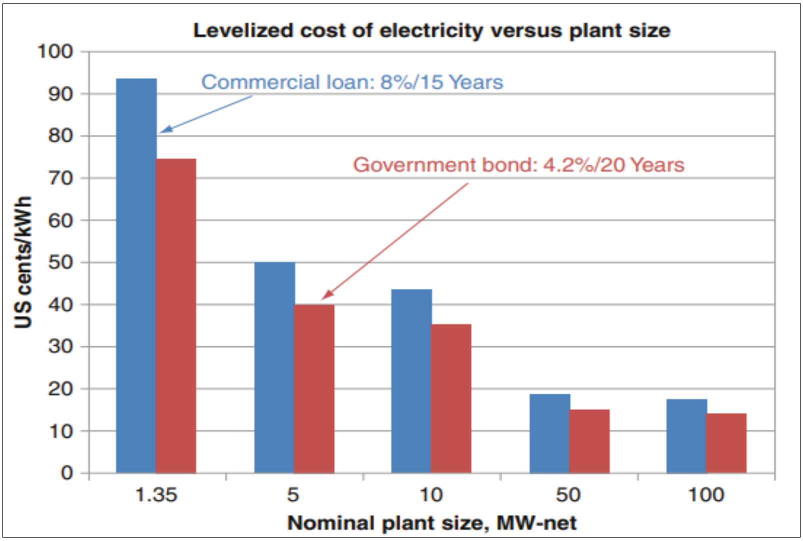
To advance the economic assessment, the levelized cost of electricity (LCOE) must also be estimated in the economic calculation which is one of the parameters used to forecast energy supply and demand (Muralidharan, 2012; Kearney, 2010). As shown in Table 2.3, based on Vega (2013), the LCOE data is amortized with a loan of 8%/15 years and annual inflation of 3%.

The cost of electricity (COE) data presented in Table 2.3 are presented in a graph and compared with the scenario in which the OTEC development is financed by the government with a realistic rate of 4.2%/20 years. In the data comparison shown in Figure 2.29, the COE value can be reduced using the government funding scenario. In addition, the current development of OTEC in different regions is still on a small scale. As can be seen, significant differences occur at the smallest scale, where the difference reaches about 20 cents/kWh. Although the cost difference decreases as the plant capacity increases, the government funding scenario can mitigate and reduce the COE.

Table 2.3 Levelized Cost of Electricity (US-cents/kWh) for CC-OTEC Plants with Capital Costs (CC)

Identifier nominal size (MW)	Capital cost ($/kW)	Operation & maintenance ($M/year)	Repair & replacement cost ($M/year)	Cost of electricity considering capital cost (c/kWh)	Cost of electricity considering operation, maintenance, repair & replacement cost (c/kWh)	Cost of electricity (C/kWh)
1.35	**41,562**	**2.0**	**1.0**	**60**	**33.7**	**94.0**
5	**22,812**	**2.0**	**3.5**	**33**	**17**	**50.0**
10	**18,600**	**3.4**	**7.7**	**26.9**	**16.8**	**44.0**
53.5	**8,430**	**3.4**	**20.1**	**12.2**	**6.7**	**19.0**
100	**7,900**	3.4	36.5	11.4	6	18.0

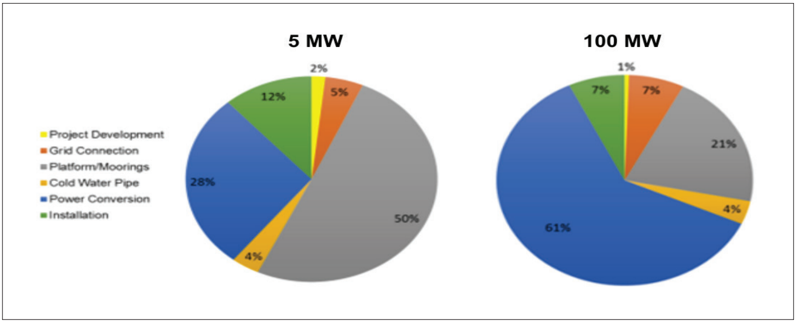
Source: Vega (2013)



Source: Vega (2013)

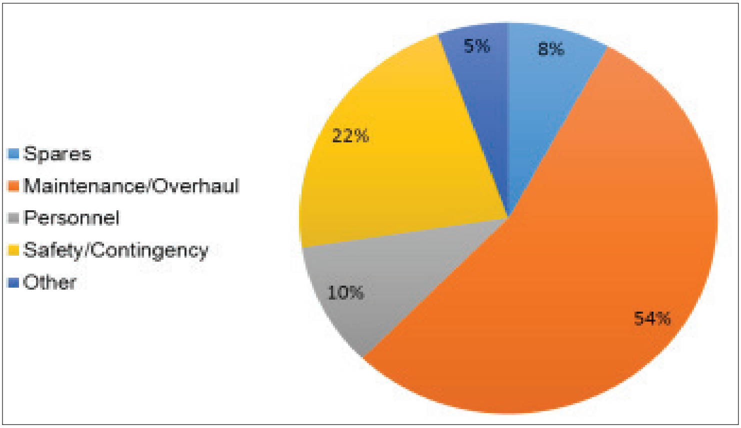
Figure 2.29 Cost of Electricity (Capital Cost Amortization + OMR&R Levelized Cost) Production for First-Generation OTEC Plants

Ocean Energy Systems (2015) conducted an economic analysis of ocean energy technologies, including OTEC, through the International Levelized Cost of Energy for Ocean Energy Technologies. The calculation of capital expenditure (CAPEX) and operating expenditure (OPEX) are described in Figures 2.30 and 2.31, respectively. In the CAPEX cost breakdown, there is a difference in cost allocation, where at the 5 MW scale, platforms/moorings have the largest percentage. While at the 100 MW scale, power conversion is the largest contributor to CAPEX, up to 61%. In other cases, as shown in Figure 2.31, maintenance is the largest contributor at 54% in the case of 100 MW OTEC. This is due to the significant amount of power-generating equipment, such as heat exchangers.



Source: Ocean Energy Systems (2015)

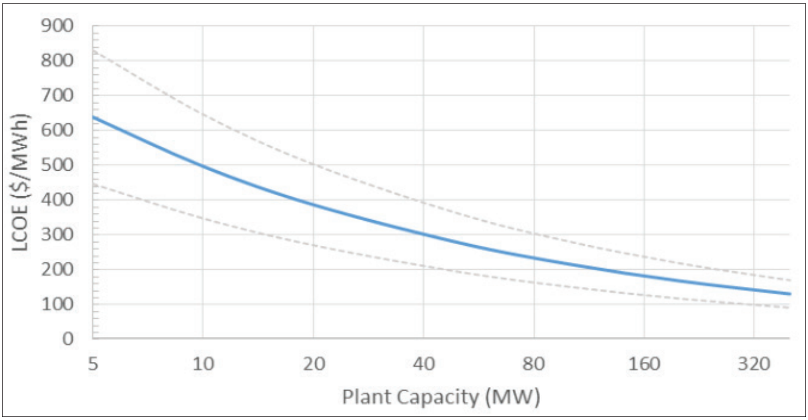
Figure 2.30 CAPEX Cost Breakdown at 5 MW Deployment Scale and 100 MW Deployment Scale



Source: Ocean Energy Systems (2015)

Figure 2.31 Representative OPEX Cost Breakdown for a 100 MW OTEC Plant

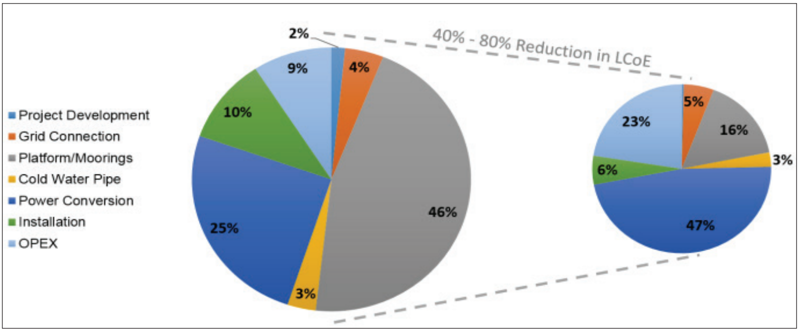
Ocean Energy Systems (2015) obtained LCOE by processing plant capacity data and comparing it with LCOE, as shown in Figure 2.32. Similar results are seen in the comparison with capital cost, the comparison with LCOE also shows a decrease in LCOE as the OTEC plant capacity increases.



Source: Ocean Energy Systems (2015)

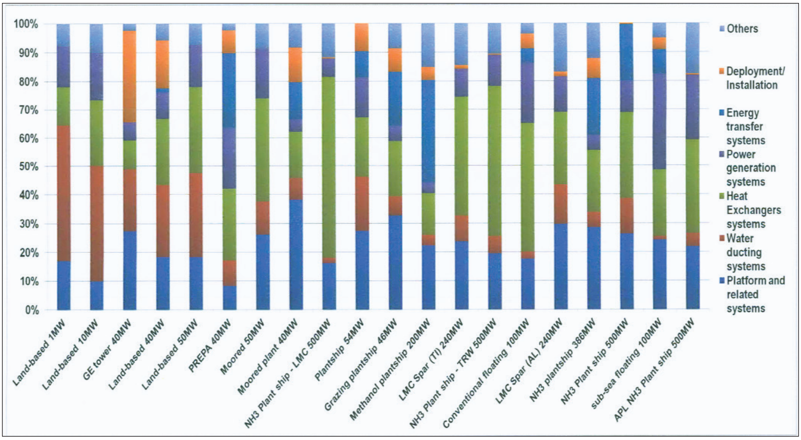
Figure 2.32 LCOE as a Function of Plant Scale

In addition to decreasing LCOE, increasing plant capacity will also affect the distribution of LCOE cost centers, as shown in Figure 2.33. Increasing the capacity from 5 MW to 100 MW will reduce the LCOE from 40% to 80% (Ocean Energy Systems, 2015). This change will shift the LCOE cost breakdown from almost half of the total for platform/mooring to power conversion. This is in line with the study by Muralidharan (2012), where the platform structure and the heat exchange system are the major cost contributors for different types and sizes of OTEC plants, as shown in Figure 2.34.



Source: Muralidharan (2012)

Figure 2.33 LCOE Cost Centers for 5MW Plant (left) and 100MW Plant (right)

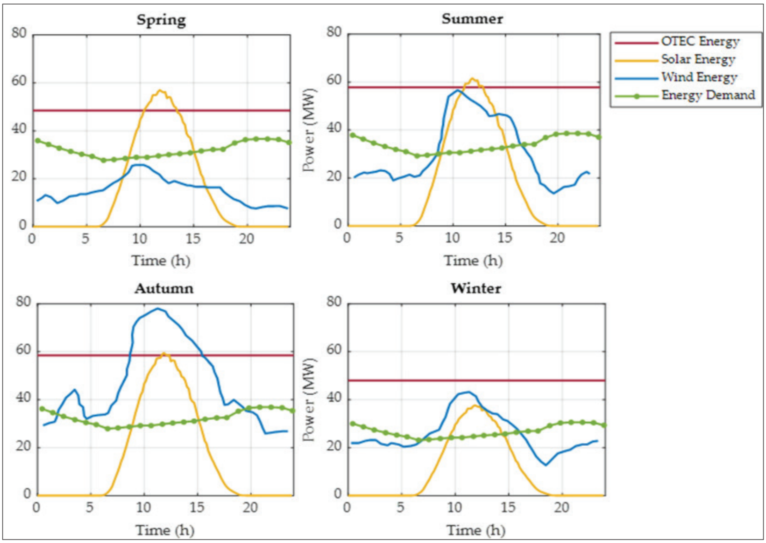


Source: Muralidharan (2012)

Figure 2.34 Proportion of Cost in Historical OTEC Designs

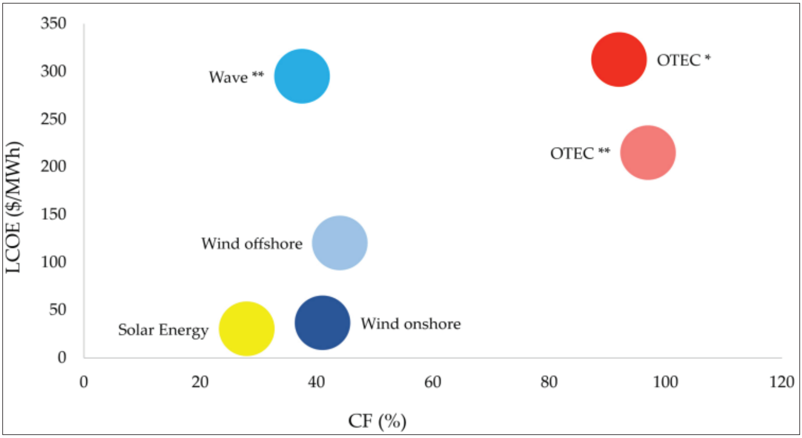
In the feasibility study conducted by Tobal-Cupul et al. (2022) on the OTEC eco-park in Cozumel Island, a comparison of LCOE between OTEC and other types of alternative energy sources was made. Initially, the potential was assessed. From Figure 2.35, it can be seen that OTEC is a stable renewable energy with the highest energy security. The electricity product is the most stable in all four seasons compared to other energy sources with the energy potential in a range between 45–60 MW.

The LCOE comparison is made by considering the capacity factor (CF) value, as shown in Figure 2.36. The (*) and (**) represent the source of the data, while the circle represent the difference between OTEC plant based on the data. The CF is the ratio of the energy produced in a given period to the energy produced at full capacity in the same period at the same power output. Although the OTEC 60 MW floating plant in Cozumel Island has the highest LCOE, both the OTEC plant in Cozumel Island and the OES has the highest CF of about 90%. The LCOE of OTEC can be reduced by increasing the capacity factor of the plant, as discussed above. The production of byproducts and non-energy needs can also be a solution to reduce the LCOE. Thus, economically wise, the LCOE of OTEC can be reduced, and other economic activities can be formed due to the presence of OTEC.



Source: Tobal-Cupul et al. (2022)

Figure 2.35 Comparison of Seasonal Power Generation in Cozumel Island, Mexico: OTEC, Solar and Wind Energies



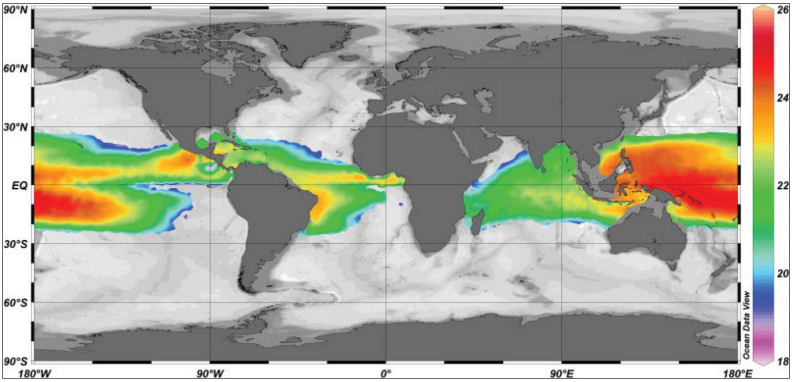
Source: Tobal-Cupul et al. (2022)*, US Energy Information Administration (2022), and Ocean Energy Systems (2018)**.

Figure 2.36 Comparison of the LCOE and CF for OTEC and Other Renewable Energies

F. OTEC in Indonesia

Indonesia has great potential of sea temperature to be exploited for OTEC. This potential can be seen from the high temperature difference between the surface and the deep sea level. As shown in Figure 2.37, the sea temperature difference in the central and eastern regions of Indonesia is 24°C on average. The temperature difference is very suitable for OTEC systems, especially the Rankine cycle, which requires a temperature difference of 15–25°C to achieve a thermal efficiency of about 3% (Nakaoka & Uehara, 1988).

To corroborate the temperature difference map as shown in Figure 2.37, several researchers have investigated the potential of OTEC in Indonesia. Research by Sinuhaji (2015) on the potential of OTEC in Bali shows that a plant with a capacity of 125 kW and a temperature difference of about 20.5°C can produce a net power of 69.4 kW, with a cycle efficiency of 3.1%. Based on the study of Syamsuddin et al. (2015), as shown in Table 2.4, the average value of Carnot cycle efficiency for OTEC systems in several locations in Indonesia is more



Source: Rajagopalan and Nihous (2013)

Figure 2.37 Mean Temperature Difference between Water Depths of 20 m and 1000 m

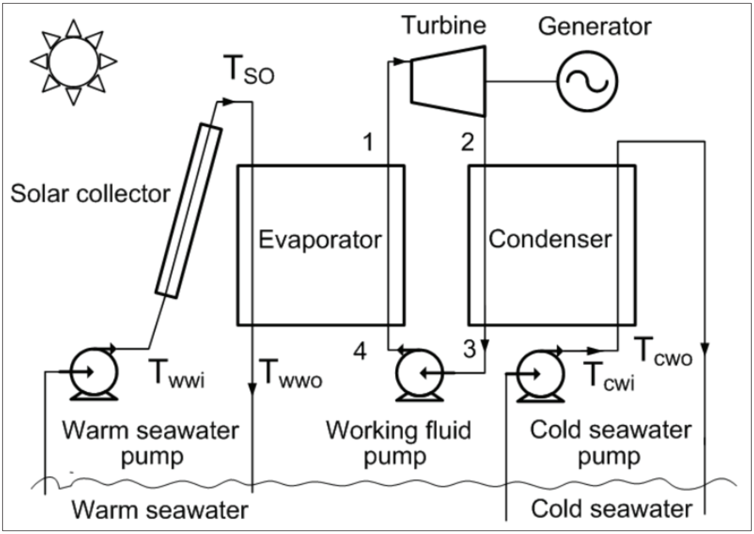
than 0.75. This shows the great potential of OTEC in Indonesia, given the average Carnot cycle values in several of these locations.

Several researchers have also conducted investigations on OTEC in Indonesia. Setiawan et al. (2017) optimized the Kalina closed cycle with ammonia working fluid to be implemented in Mamuju, West Sulawesi. The optimization was carried out by adding a flat plate solar collector with an area of approximately 6,023 x 106 m^2, as shown in Figure 2.38. The solar collector is used to heat the warm seawater to 33.5°C before it enters the evaporator. It is concluded that for plants with a capacity of 33 MWe and an efficiency of 7.1%, the capacity can be increased to 144,155 MWe with an efficiency of 9.54% by adding a flat plate solar collector. However, the effects of the installation of the flat plate solar collector on LCOE had not been included in analysis.

Table 2.4 Carnot Efficiency System OTEC in Several Locations in Indonesia

Location	Tw (°C)	Tc (°C)	ΔT	Depth (m)	Carnot Efficiency
South Kalimantan	28.82	7.71	21.11	500	0.73
North Sulawesi	29.22	7.44	21.78	500	0.74
Timur Strait	28.83	6.72	22.11	600	0.76
Makassar Strait	28.83	6.72	22.11	600	0.76
South Sulawesi	28.47	6.18	22.29	700	0.78
West Papua	28.16	6.76	21.40	600	0.75
Morotai Sea	28.47	6.82	21.65	600	0.76

Source: Syamsuddin et al. (2015)



Source: Setiawan et al. (2017)

Figure 2.38 OTEC Plant with a Flat-Plate Solar Collector Design

Adiputra and Utsunomiya (2018) made a design of a 100 MW OTEC power plant for Mentawai Island, Indonesia, using the basic Suezmax oil tanker type as the plant ship. It was concluded that the Suezmax oil tanker ship is sufficient to accommodate the 100 MW

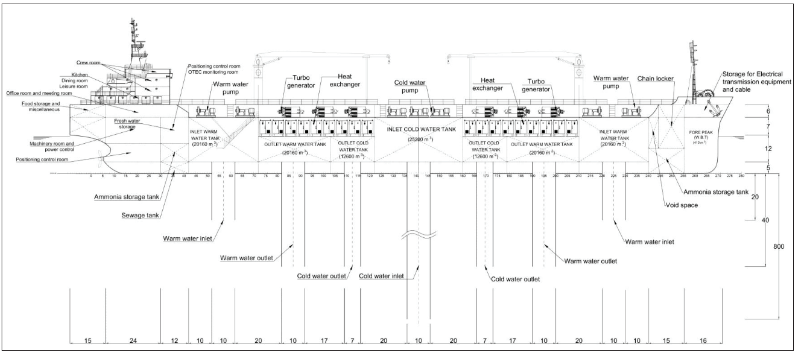
OTEC power plant. Adiputra et al. (2020) set some limitations as considerations to determine whether certain cases are acceptable or not. The limitations that have been taken into consideration are the space available, the allowable weight, and the net power output. Considering the fixed variables as well as the limitations set, it was concluded that a Suezmax-type oil tanker with a seawater displacement of 3 m/s is the most appropriate type. The outline of the ship is drawn with reference to the book "Principle of Naval Architecture," with the same size tendency in the parameters used. The drawing is shown in Figure 2.39. The main dimensions of the ship are given in Table 2.5.

Table 2.5 Suezmax Main Dimension of the Plant Ship

Parameter	Value
Type	Suezmax
Length between perpendicular (m)	275
Length overall (m)	285
Breadth (m)	50
Height (m)	30
Draft (m)	17
Coefficient block	0.945
Tonnage (ton)	200000

Source: Adiputra et al. (2020)

Regarding the main dimension of the required CWP, Adiputra and Utsunomiya (2019) stated that to generate 100 MW-net of energy, the OTEC CWP required a configuration of 800 m in length and a 12 m diameter pipe connected to the plant ship. With this specified configuration, the connection between the OTEC CWP and the platform will be the main support for the OTEC CWP component (Adiputra et al., 2020). In further research, based on the manufacture limitation, Adiputra estimated that, by considering recent manufacture capability of the related industry, the maximum diameter pipe that can be attached to the platform is a 3 m-diameter pipe (Adiputra & Utsunomiya, 2021).



Source: Adiputra et al. (2020)

Figure 2.39 Layout of 100 MW net of OTEC Plant Ship Design

Adiputra and Utsunomiya (2021) are attempting to design a CWP on a commercial scale, focusing on the effects caused by the internal flow of the pipeline which may cause instability. The analyses carried out in the design process also aimed to select suitable materials for the pipe, the configuration of the pipe joint and floating platform, and the selection of ballast at the inlet end of the pipe, through numerical and analytical analysis. It was found that the most suitable material for the OTEC CWP is fiber reinforced polymer (FRP), considering that FRP tends to be lightweight, strong, and can withstand high levels of stress. The pinned joint installation configuration is also the best installation configuration as it has the least stress at the joint but tends to remain stable. The addition of clump weight was also considered as it helps to stabilize the pipe (Adiputra & Utsunomiya, 2021).

Currently, Indonesia is pursuing a goal of generating 52% of its electricity from new renewable energy sources by 2040. Based on the report of the Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas), as of March 2021, there were 634 offshore oil and gas platforms in Indonesia, of which 100 were no longer operational. Hence, the offshore oil and gas platform can be used to become a prospective floating platform OTEC power plant.

Additionally, a pilot project of 1 MW-net OTEC platform had been successfully built which encouraged the OTEC development (Petterson & Kim, 2020). As a country with huge OTEC potential of about 4,000 GW, it is a big opportunity for Indonesia to accomplish net zero-emission in 2060 by establishing a strength collaboration between the government, industries, researchers, and universities to work on OTEC. The government is to establish regulations for providing a long-term investment and initiate the pilot projects for development activities. The national and private companies work on the OTEC supply chain. The research body conducted investigations on the technology advancement and the universities produced human resources with intellection capital on OTEC.

Despite its high potential in Indonesia, OTEC power plant also possess some environmental damage potential. OTEC power plants, like other types of power plants, can generate noise. Noise measurements at the 1 MW OTEC plant in Keahole, Hawaii, showed that the noise generated by the seawater pump, the plant's main noise source, did not exceed 10 dB, although this could increase if the plant were larger (Spellman, 2016). The discharged water could potentially pose a threat to the environment. A 100 MW plant would require 10–20 billion gallons of warm surface water and cold water per day (NOAA, 2010). Discharging water with varying temperatures and nutrient levels can be harmful to the environment and the species that live in it. The extraction of minerals from seawater could potentially cause an imbalance in the marine ecosystem. Before OTEC power plants are commercialized in Indonesia, their potential environmental impact needs to be further investigated.

G. Closing

Based on the type of cycle, OTEC systems can be divided into three main categories: closed-cycle, open-cycle, and hybrid cycle. Closed-cycle OTEC is based on the Rankine cycle with a pure working fluid operating under isolated conditions. Open-cycle OTEC operates under vacuum conditions using warm seawater as the working fluid and can produce desalinated water. The hybrid cycle OTEC uses a combination of open and closed cycles to produce working fluid vapor, which is then distilled and used as potable water.

In the OTEC cycle system, the turbine is the main component that can convert thermal energy into mechanical energy and then into electrical energy by the generator. In general, the OTEC cycle uses radial flow turbines. This is because radial flow turbines still have high efficiency even though the mass flow of fluid is minimal.

In the offshore OTEC plant, there are several proposed potential models, such as the tanker model, J-spar, and tension-based system. The OTEC's cold water pipe (CWP) is a critical component of the OTEC platform system. The CWP is used to discharge cold seawater required for the OTEC cycle. CWP made of fiber reinforced polymer (FRP) and sandwich wall structure in pinned joint at the top is the most preferable configuration.

The development of OTEC offers several co-products, such as the development of water desalination by producing fresh water, drinking water, and hydrogen from surface seawater. Meanwhile, the use of deep-sea water, which is highly nutritious and low in pollutants, can be used for aquaculture, food production, cosmetics, and lithium extraction. However, environmental impacts such as the use of working fluids that have the potential to damage the environment need to be examined. When used optimally, OTEC development supports many aspects of the SDGs goals.

The capital cost and LCOE of OTEC show a decreasing trend as OTEC plant capacity increases. Although the LCOE value of OTEC is high compared to other types of renewable energy, the CF value of OTEC is the highest. The potential for by-product development can be a solution to reduce the LCOE and create the potential for economic activities.

The commercialization of OTEC power plants in Indonesia can be the key to achieving Indonesia's renewable energy target by 2040. The development of OTEC in Indonesia is currently underway. With all the potential that exists, it is only a matter of time before a commercial scale OTEC power plant can be realized. However, without the impetus and acceleration, OTEC power plants cannot be commercialized before 2040.

The OTEC power plant has great potential in Indonesia. The environmental damage that may occur in Indonesia has not been thoroughly studied. This must be an important consideration in the development process of the OTEC power plant. In this way, the journey towards renewable energy does not sacrifice the safety of the ecosystem.

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Part 2
The Efforts for Successful Energy Transition

Chapter 3

Is Indonesia Really Prepared for The Energy Transition? An Analysis of Readiness for Regulations, Institutions, Finance, and Manpower Aspects

Hanan Nugroho, Nur Laila Widyastuti, & Dedi Rustandi

A. Energy Transition Challenges

The global landscape of energy production and consumption is undergoing a significant transformation. With the increasing concerns about climate change, the depletion of fossil fuel reserves, and the need for sustainable energy sources, countries around the world are exploring options for transitioning towards cleaner and more efficient energy systems. Indonesia, as a rapidly developing nation and one of the largest archipelagic countries in the world, is not exempt from this paradigm shift.

Indonesia is a fossil fuel country having adequate fossil fuel reserves, and it has long been dependent on fossil fuels, particularly coal and oil, for its energy needs. It exports natural gas (mainly LNG)

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Nugroho, H., Widyastuti, N. L. & Rustandi, D. (2023). Is Indonesia really prepared for the energy transition? An analysis of readiness for regulations, institutions, finance, and manpower aspects. In A. Kiswantono & R. M. Shoedarto (Eds.), *Indonesia's energy transition preparedness framework towards 2045* (89–122). BRIN Publishing. DOI: 10.55981/brin.892.c813, E-ISBN: 978-623-8372-41-6

and coal on a world scale and was once an OPEC member country. Indonesia's position, which is rich in energy resources, is unique compared to Southeast Asian countries, let alone East Asian industrialized countries that are heavily dependent on fossil fuel imports. Historically, this condition has provided energy security and fuelled economic growth. However, it has also led to environmental degradation, air pollution, and vulnerability to global energy price fluctuations. In light of the Paris Agreement and international commitments to reduce greenhouse gas emissions, Indonesia has recognized the urgency of transitioning to cleaner and more sustainable energy sources. This transition presents both challenges and opportunities, including the need to diversify energy sources, increase energy efficiency, and engage in renewable energy development.

Indonesia is preparing an energy transition to welcome "Golden Indonesia 2045". Meanwhile, another related scenario is setting up the country's net zero emissions (NZE) to be achieved by 2060.[1] The energy sector's greenhouse gas emission reduction targets in these scenarios are quite ambitious, the largest among ASEAN member economies (ACE, 2022; IEA, 2022). This energy transition plan that Indonesia is preparing, as will be shown in the next section, emphasizes the use of renewable energy and reduces coal consumption as the backbone of achieving the energy sector's emission reduction targets. Such a dramatic transition, however, is not easy to make. This includes how to transform ingrained energy consumption patterns depending on fossil fuels to the dominant projected use of renewable energy. Many aspects need to be prepared to guarantee the success of such an energy transition plan, which will be a gigantic project of change within society.

This chapter presents an in-depth analysis of Indonesia's readiness for energy transition, examining the background to the subject, the

[1] No new formal law/regulation on energy transition has been published yet. The plan is under serious discussion among energy stakeholders especially within the government. In the draft of the National Long-Term Development Plan 2025–2045, it is stated that "net zero emissions is to be achieved by the golden year 2045".

current conditions of its energy sector, and the methodologies used to assess its preparedness for this critical transformation. Considering those topics, the chapter discusses how Indonesia faces the challenges to make the energy transition work. In summary, it shows Indonesia's experience in making an energy transition in the form of reducing dependence on petroleum. After showing the current conditions related to renewable energy development, analyses were carried out on several factors to support the implementation of the energy transition plan. The factors analyzed are regulation/legislation, institutions, finance, and manpower, which are fundamental factors in development planning.[2] Based on the analysis, several policies/actions were recommended.

B. The current condition

The spirit of reducing dependence on fossil fuels has been developed in Indonesia for quite a long time (Nugroho, 2018). This is based on the awareness that Indonesia has quite a lot of renewable energy sources.[3] Hydropower has been developed on a rather large scale since the 1960s, followed by geothermal since the 1980s. Various other renewable energy, such as micro-hydro and solar power (especially solar home systems) were introduced in the Five-year Development Plan (*Rencana Pembangunan Lima Tahun* - Repelita) era in the late 1980s.

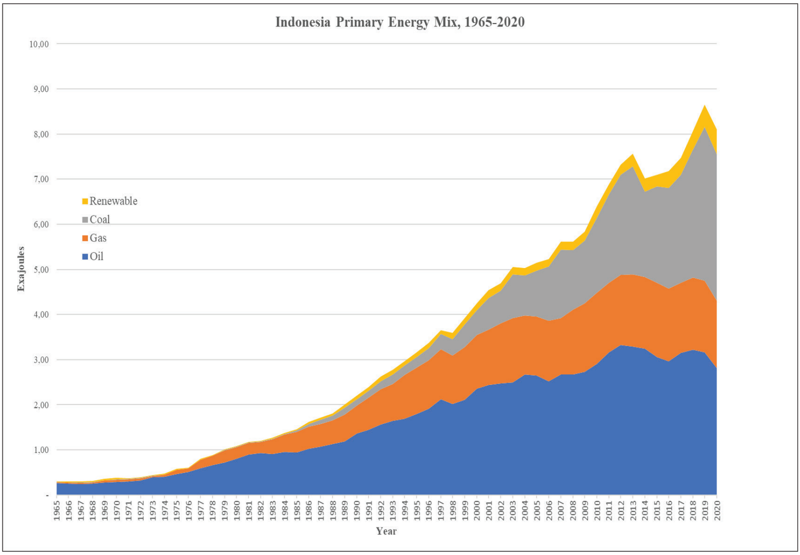
In an era when petroleum production was relatively large (1.7 million barrels production per day in the mid-1970s) but domestic consumption was small, Indonesia's General Energy Policy (*Kebijakan Umum Bidang Energi* - KUBE)[4] had directed to reduce the country's

2 The aspects are usually reviewed when preparing the Indonesia's National Medium Term Development Planning, carried out every five years.

3 Among the potentials of renewable energy for electricity are solar (3,294 GW), hydro (95 GW), wind (155 GW), bioenergy (57 GW), and geothermal (23 GW). Only 0.3% of the potentials have been exploited (Directorate General of New & Renewable and Energy Conservation, 2023).

4 The policy was issued by the National Energy Coordination Board (Badan Koor-

dependence on petroleum by developing non-petroleum energy sources. Due to the immature renewable energy technologies (except for hydropower and geothermal power plants) and the lack of pressure on environmental considerations, while the price of renewable energy was still expensive, the development of the energy sector was limited to other fossil fuels, namely natural gas (since the 1970s) and coal (since the 1990s).



Source: Graphed from Energy Institute (2023)

Figure 3.1 Indonesia Primary Energy Mix (1965–2020)

As a result, shown in Figure 3.1, Indonesia is quite successful in reducing its dependence on petroleum. However, it was achieved through the rapidly increasing development of other fossil energy, especially coal. Meanwhile, despite the increase in utilization, the

dinasi Energi Nasional - Bakoren) which comprise of several ministers having responsibilities in energy-related issues. After being inactive for a long time since the 1998 Reformation Movement, the role of Bakoren was then officially taken up by the National Energy Council whose formation was mandated by Energy Law No. 30 of 2007.

share of renewable energy in Indonesia's energy mix remains low (11.5% in 2021, and even declined to 10.4% in 2022) (IESR, 2022).[5] Hydro and geothermal contribute the most to the share of renewable energy, particularly in electricity.

To understand Indonesia's energy transition readiness, it is crucial to assess the current conditions of its energy sector. This analysis will consider various factors, including:

1) **energy mix**: an overview of Indonesia's current energy mix, highlighting the dominant role of fossil fuels and the share of renewables;
2) **energy consumption**: examination of energy consumption trends, sectors driving demand, and per capita energy consumption;
3) **energy policy**: an overview of existing energy policies, regulations, and commitments related to clean energy adoption and emissions reduction;
4) **infrastructure**: assessment of the state of energy infrastructure, including electricity generation, transmission, and distribution networks; and
5) **environmental impact**: an evaluation of the environmental impact of Indonesia's current energy mix, including air and water pollution and greenhouse gas emissions.

Indonesia's energy landscape is characterized by a heavy reliance on fossil fuels, particularly coal and natural gas, which account for a significant portion of the country's energy consumption. While there have been efforts to increase the use of renewable energy sources, progress has been uneven, and the country faces obstacles such as policy gaps, infrastructure limitations, and financial constraints. Understanding the current energy conditions in Indonesia is crucial for assessing its readiness for an energy transition.

5 The decline was due to the high growth of nickel smelters in Sulawesi which requires a lot of electricity which is then supplied by the cheap coal power plants.

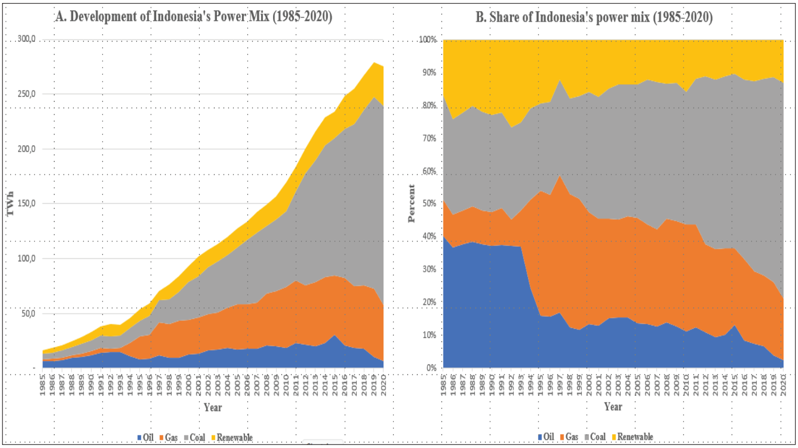
C. How to assess Indonesia's energy transition readiness

The assessment of Indonesia's energy transition readiness is based on a multi-dimensional methodology. This involves:

1) **data collection**: gathering data from various sources, including government reports, international organizations, energy companies, and research institutions;
2) **policy analysis**: reviewing and analyzing the existing energy policies, regulatory frameworks, and government initiatives related to energy transition;
3) **stakeholder interviews**: conducting interviews with key stakeholders, including government officials, industry representatives, environmental organizations, and experts in the field;
4) **scenario modeling**: developing scenarios to project potential energy transition pathways and their socio-economic and environmental implications; and
5) **comparative analysis**: comparing Indonesia's energy transition progress with other nations that have undergone similar transformations.

By combining these elements, this chapter aims to provide a comprehensive understanding of Indonesia's energy transition readiness. It will highlight the challenges and opportunities facing the nation as it strives to shift towards a more sustainable and cleaner energy future in alignment with global environmental goals.

The increase in coal utilization is seen mainly for electricity generation (Figure 3.2). In the early 2000s, in an age when the world began to intensify its efforts to combat global climate change, Indonesia started accelerating the use of coal.



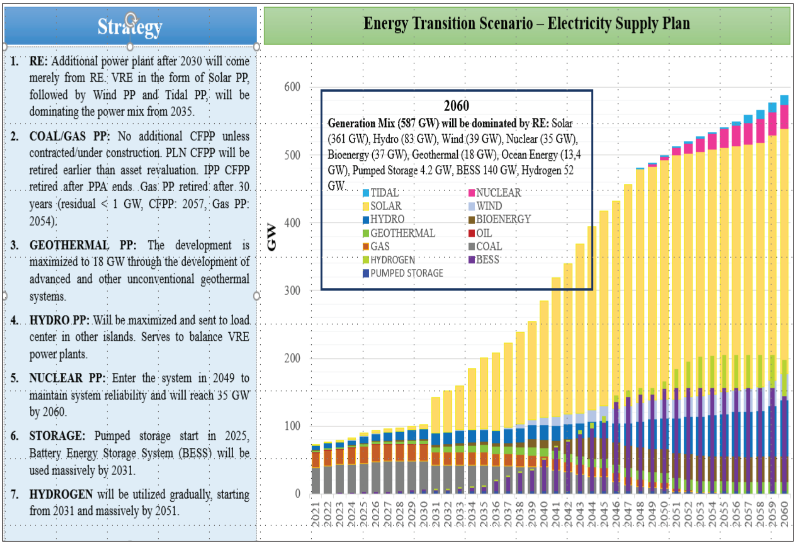
Source: Graphed from Energy Institute (2023)

Figure 3.2 Development of Indonesia's Power Mix and Its Fuel Share

The current positive law, Government Regulation No. 79 of 2014 on National Energy Policy, directs Indonesia's energy mix in 2050 to be composed of coal with a share of 25% or less, petroleum with 20% or less, natural gas with 24% or less, and renewable energy for 33% or more. The NZE/energy transition proposal that is being developed strongly prioritizes the use of renewable energy. Meanwhile, the plan is still focused on the use of renewable energy in electric power. Figure 3.3 shows the major proposal, developed by the Ministry of Energy & Mineral Resources.

Although there are plans to accelerate the development of renewable energy, including those listed in the recent medium-term development plans, and there is an increase in the amount of energy contributed by renewable energy, there are several obstacles remain to increasing the share of renewable energy in Indonesia's energy mix (Nugroho, 2020).

The "Energy Transition Readiness Index 2021" puts Indonesia in the 71st position among 115 countries in the world (WEF, 2021).



Source: Modified from Ministry of Energy and Mineral Resources (2022)

Figure 3.3 Indonesia's Energy Transition Plan

Compared to the factors analyzed in the Energy Transition Readiness Index of WEF, this paper examines only four main factors, namely legislation, institutions, financing, and labor about the development of renewable energy. Rather than trying to present it quantitatively, this chapter describes the conditions encountered in each aspect analyzed, to provide an in-depth description of the challenges faced and to gain insightful ideas regarding strategic steps that must be taken.

1. Regulations on energy, renewable energy, and climate change

Table 3.1 presents the laws and regulations that have been developed in Indonesia regarding energy and climate change policies in recent decades. After the 1998 Reform Movement, many laws and regulations were born, marking their differences from the previous period when democratic rule was not yet developed in the country.

For oil and gas, since its inception, laws and regulations have been developed to support their activities. The Oil and Gas Law 22 of 2001 liberalized the downstream business of Indonesia's oil and gas industry which was previously carried out only by the state oil and gas company Pertamina. Meanwhile, on the upstream side, Pertamina's authority, which according to Law 8 of 1971 includes tendering for oil and gas blocks, is taken over by the government, and Pertamina is classified as one of the upstream business entities.

Coal is regulated simultaneously with the law on mineral and coal mining, which the current law in force is Law No. 3 of 2020. The spirit of this law is to provide clarity regarding the operation of coal and minerals and encourage them to protect their development. Unlike petroleum, natural gas, and coal, laws directly related to the regulation of renewable energy have not yet been issued.[6] There is only one law that specifically regulates geothermal, which is Law No. 27 of 2003.

Table 3.1 Law/regulation on Renewable Energy and Climate Change

Year	Law/Regulation	Note
1997	Law #10 of 1997 on Nuclear Energy	There are Government regulations derived from the Law.
2001	Law #22 of 2001 on Oil and Gas	Replaced Law # 8 of 1971 on Oil and Gas Company
2002	Law #20 of 2002 on Electricity	Replaced Law # 15 of 1985 on Electricity. Rejected by the Constitutional Court
2003	Law #27 of 2003 on Geothermal	The only law on Renewable Energy that has been issued. Renewed by Law #21 of 2014.
2004	Law #7 of 2004 on Ratification of the Kyoto Protocol	Indonesia is a Non-Annex Country

[6] Currently under rigorous and protracted discussions in the House of Representatives.

Year	Law/Regulation	Note
2006	President Regulation #5 of 2006 on National Energy Policy	Introducing national energy mix goals/targets
	President Instruction #1 of 2006 on Provision and Utilization of Biofuels	The basis for the development of biofuels in Indonesia, especially that palm oil.
2007	Law #30 of 2007 on Energy	The mandate is to establish a National Energy Council and to formulate a National Energy Policy.
2008	President Regulation # 26 of 2008 on the establishment of the National Energy Council	The council's main task includes formulating a national energy policy
	President Regulation # 46 of 2008 on the National Council of Climate Change	This was followed by the establishment of the Indonesia Climate Change Trust Fund in 2009.
2009	Law #30 of 2009 on Electricity	Replaced Law # 20 of 2002 on Electricity
	Law #4 of 2009 on Coal & Mineral Mining	Renewed later by Law #3 of 2020
2010	President Regulation # 24 of 2010 on Position, Duties, and Functions of the Ministry of Energy and Mineral Resources	Established the Directorate General of New Renewable Energy and Energy Conservation
2011	President Regulation # 61 of 2011 on National Action Plan for GHG Emission Reduction.	Derived from President SBY 2009 Pittsburgh Pledge. Followed by the launch of the National Action Plan for Climate Change Adaptation.
2013	President Decree # 5 of 2013 on Reducing Emissions from Deforestation and Forest Degradation (REDD+) Institution.	The REDD+ Management Agency was formed
2014	Government Regulation in Lieu of Law # 79 of 2014 on National Energy Policy	Set targets for the share of the national energy mix (by 2050: Oil < 20%, Natural Gas < 24%, Coal < 25%, and Renewable Energy > 31%)

Year	Law/Regulation	Note
2016	Law # 16 of 2016 on Ratification of the Paris Agreement to The United Nations Framework Convention on Climate Change.	Indonesia has submitted its Nationally Determined Contribution to the United Nations Framework Convention on Climate Change (UNFCCC) and has even submitted several updates. The last is by the end 2022.
2017	President Regulation # 22 of 2017 concerning the General Plan of National Energy (RUEN)	The RUEN has been translated into Regional Energy General Plan (RUED). Not all provinces already have their own RUED (the General Plan of Regional Energy)
	President Regulation # 59 of 2017 concerning the Implementation of Achieving the Sustainable Development Goals	A quite comprehensive development program under the SDGs framework, incorporated into programs in the RPJMN (National Medium-Term Development Plan)
2020	President Regulation # 18 of 2020 concerning the Medium-Term Development Plan 2020-2024	The last version of the five-year development plan for Indonesia
2022	Presidential Regulation Number 112 of 2022 concerning the Acceleration of the Development of Renewable Energy for the Provision of Electricity	As an extension of the Regulation of the Minister of Energy and Mineral Resources Number regarding a similar matter.
NA	Law on New and Renewable Energy	In the progress of drafting.
	Law on Energy Transition	Under discussion. Being proposed under the new Government Regulation on National Energy Policy.
	Law on Net Zero Emissions	Under discussion.

2. Institution

The Directorate General of New Renewable Energy and Energy Conservation is a government agency responsible for the development of renewable energy in Indonesia. It was established in 2010 (through President Regulation No. 24 of 2010 on Position, Duties, and Functions of the Ministry of Energy and Mineral Resources). Another institution leading the climate change movement is the Ministry of

Environment and Forestry. The institution that deals with climate change has undergone several changes in the structure and hierarchy of its organization within the central government.

After the 1998 Reform Movement, Indonesia developed a Regional Autonomy Law which is then continued to be refined. The implementation of the law on the local government resulted in the abolition of the Regional Offices of the Central Government, and the establishment of *Dinas*/Regional Offices within the regional/local governments. The development and naming of local government offices are independent, determined by each local government considering their needs and priorities, and often do not refer to those in central government.

Within the central government itself, there are no sectoral agencies with the name "climate change" and "energy transition" except the Ministry of Environment & Forestry for "climate change" and the Ministry of Energy & Mineral Resources for "new, renewable energy and energy conservation". Within the Ministry of Energy and Mines, the energy transition plan does not seem to have caught the attention of the Directorate Generals in charge of oil, gas, and coal, which still list increasing the production of fossil fuels as their main target.[7]

If the business in the fields of petroleum, natural gas, and coal are encouraged to develop through the formation of large-scale state-owned enterprises (SOEs)—such as Pertamina (oil and gas), PGN (gas), and PT Batubara Bukit Asam (coal)—then there is yet to exist SOE that specifically engaged in the development of renewable energy. Pertamina and PLN (electricity) may have developed organizational units for renewable energy development, but the scale is too small compared to their main businesses in the fields of oil and gas and electricity (which rely on coal-fired power plants).

The private enterprises that are struggling to develop renewable energy are still limited to several EPC companies that assist in the construction of small-scale government-owned projects. Private

7 In fact, coal production for the last decade or so has always been above what was planned in the National Medium Term Development Plan.

companies that have their renewable energy projects, for example as IPPs, are still very rare, limited for example to geothermal power plants. Institutions that support research for the development of renewable energy are very limited to a few universities or agencies, such as National Research and Innovation Agency (BRIN). However, until now it is unclear whether there is a direct link between the research work carried out by these institutions and the energy transition or net zero emission program that is being prepared by the government.

3. Finance

Funds for the development of renewable energy in Indonesia so far come from (i) grants from bilateral and multilateral institutions, (ii) governments, both central and regional, (iii) private companies engaged in the development of commercial renewable energy, and (iv) non-governmental organizations.

Grants from international bilateral and multilateral institutions are generally provided for the construction of small-scale or pilot projects, such as photovoltaic, wind power plants, or micro-hydro installations in rural areas or outer islands of the archipelago. These grants are typically only for the physical construction of the project, excluding maintenance, which is usually carried out by the community, who will also collect cash from the use of electricity provided by the facility. Most grant projects like this are not guaranteed to be sustainable. A large part of them operated only in the early years after their installation. After the physical project was built, the transfer of ownership and responsibility of the project usually becomes a problem.[8]

The government, particularly the central one, is the largest source of funding for renewable energy development in Indonesia. It provides money for the construction of renewable energy, especially when it relates to rural electricity and development projects.[9] The most com-

8 The challenges of developing renewable energy projects, from planning to post-construction, can be further seen in Nugroho (2023a).

9 Funds are sourced from the state budget (APBN), spent annually after being reviewed by the National Development Planning Agency and the Ministry of

mon energy technologies installed are photovoltaic and micro-hydro. Agencies in the central government implementing the program are not only the Ministry of Energy & Mineral Resources, but also other ministries, such as Assessment and Application of Technology Agency (BPPT)[10], Ministry of Cooperative, Ministry of Marine and Fisheries, and so on. The works were carried out mainly in the past two or three decades. Meanwhile, local governments follow to implement the same work in their respective areas but with a smaller financing capacity. Given the need for renewable energy development particularly in remote areas, the funds provided by the government are insufficient.

Later, the central government reactivated the Special Allocation Fund (*Dana Alokasi Khusus* - DAK) for renewable energy development in the regions, having previously been stopped due to inadequate performance of renewable energy development in the regions. There are various funds with green or clean energy labels offered by several financing institutions, mostly international. However, this opportunity has not been effectively captured. Some things can be noted as obstacles.

First, the domestic bureaucratic procedures. Not only it is known for the long process, but it also makes the offered cheap funds look unattractive. There are several entities (focal points) that manage the funding with different procedures and schemes. This often causes headaches for renewable energy project proponents who are seeking access to funding. *Second*, the ability to implement the full cycle of renewable energy projects is inadequate, even, for example, only preparing a proper project proposal. There are many cases where project proponents, especially from the regions, do not have sufficient capacity to make good project proposals, including funding proposals.

Finance. The annual funding allocation stated in the Government Work Plan is part of the Medium-Term Development Plan with adjustments to the challenges encountered.

10 Since 2021, BPPT has merged into BRIN. From Repelita IV until the 1998 Economic Crisis, BPPT played an active role in renewable energy development projects, especially solar power in the form of solar home system (SHS) in rural areas.

Third, Indonesia lacks financial institutions that can act as agents for channeling sources of low-interest funds from abroad and at the same time maintaining a minimum interest rate for domestic renewable energy project developers. This impedes the flow of funds because overseas funding institutions usually do not want to provide funds on a project-by-project basis, while domestic funding institutions are constrained by local regulations so they cannot provide low-interest rates to projects that submit requests for funding assistance.

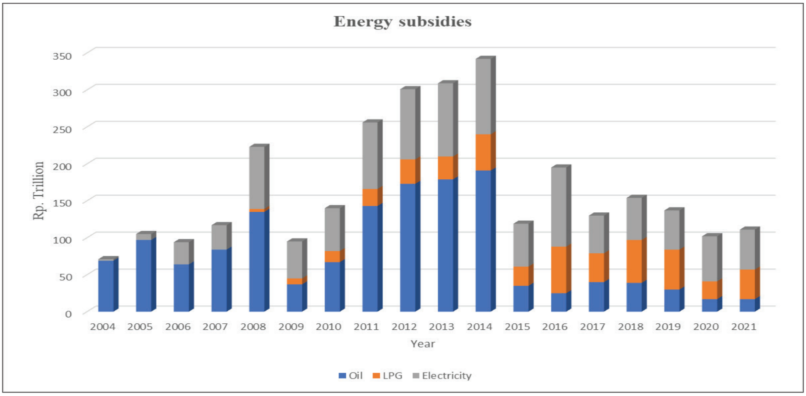
The funding that was available adequately and has been used effectively for the construction of renewable energy projects so far is for hydropower and geothermal power plants, most of which are handled by SOEs, namely PLN and Pertamina. In the scheme, the government seeks loans from multilateral financial institutions and forwards the loans (with subsidiary loan agreements) to the SOEs implementing the project. The bureaucracy took a long time, caused SOEs (whose equity had grown larger) to abandon this scheme and seek their own financing sources (including from the capital market and national and international banks). Later, the construction of hydropower and geothermal power plants was also carried out by IPPs which sought to finance their projects.

In addition to the Infrastructure Fund (SMI) which was developed earlier, the Indonesia Sustainable Finance Initiative (IKBI) has also been developed with dozens of national banks joining. However, like SMI, IKBI focuses on not only on facilitating the distribution of funds for renewable energy development, but also the development of fossil fuels, even including coal (IESR, 2022). Recently, the government has collaborated with several foreign financial institutions to launch the Energy Transition Mechanism (ETM) and Just Energy Transition Partnership (JETP)[11] programs, with a focus on funding the early retirement of a number of coal power plants. However, the challenge of this program in terms of energy security is ensuring that renewable

[11] The ETM and JETP for Indonesia were both launched in November 2022. See, for example, https://fiskal.kemenkeu.go.id/fiskalpedia/2022/11/10/21-energy-transition-mechanism, and https://web.pln.co.id/pln-jetp/jetp-home

energy facilities can be built before the early retirement of coal power plants is feasible.[12]

The Indonesian government has so far allocated considerable funds for energy subsidies. Figure 3.4 shows the development of energy subsidies in recent years. The figure shows that energy subsidies are given for oil products (gasoline and diesel), LPG, and electricity in considerable amounts (with about USD 2 billion at the peak in 2014). The latter is basically to secure the purchase of coal by PLN. It is not pointed out that energy subsidies are also provided for renewable energy development.



Source: Ministry of Finance (2023)

Figure 3.4 Indonesia's energy subsidies (Rp. Trillion)

[12] In terms of energy security, "supply disruption" is something that should not happen. In the 2025–2045 National Long-Term Development Plan, Indonesia is planned to become an industrial country and is projected to experience an increase in energy demand. The energy supply for this development needs to be secured. Early retirement of coal power plants, aside from disrupting the security of energy supply, will also cause significant employment problems. Moreover, most of the construction of new coal power plants was carried out in the era of President Joko Widodo with his "35,000 MW" program; most of the coal power plants in Indonesia are still relatively young. These things are a challenge for programs such as ETM and JETP to participate in answering them.

It has been suggested that energy subsidies, provided by the state budget, can also be used for the development of renewable energy. However, until now, despite the worry of the growing amount of energy subsidies during post Covid-19 pandemic, the subsidies specifically allocated to accelerate the development of renewable energy have not been provided.

4. Manpower

The workforce in Indonesia is characterized by low or middle skills and low education; only about 10% of them are classified as highly skilled workers. The total number of manpower in 2021 was 141 million (Pusditek, 2022).

Indonesia has good experience in constructing and operating hydropower and geothermal power plants. However, for solar and wind power plants (which are projected to grow dramatically in the future), Indonesia's workforce is very limited, even only for the installation works. Indonesia's current solar and wind power plants capacity is small, compared to Malaysia or Thailand in South-East Asia (ACE, 2022; IRENA, 2021a). The domestic production capacity of solar power equipment, such as solar panels, is very small. Therefore, it is still highly dependent on imports although there is a plan to reduce this dependency (Kemenperin, 2015).

Training and skill development are highly regarded by the Indonesian workforce. However, the Job Training Center of the Government of Indonesia (Ministry of Manpower) has not targeted to increase manpower skills in the renewable energy sector in its training program. The largest education and training facility operated by the Ministry of Energy and Mineral Resources is for oil and gas, while the Ministry of Manpower provides training mainly for prospective workers in the automotive industry (especially motorcycles), computer operators, and beauty and fashion. So far, training for workers in renewable energy development is directly provided by companies that build renewable energy facilities, such as PLN or its contractors, in the form of on-the-job training.

Indonesia has the potential to develop renewable energy, not only downstream as a user, but also upstream as a producer of mining materials needed for components of renewable energy technology, such as batteries for solar power or materials for propellers in wind power. However, the labor requirements for these fields, especially those with high skills in the mining and processing industry, are still very small. The employment aspect in the field of renewable energy also needs to pay attention to manpower in the energy sector as a whole, especially for coal which will be greatly affected by the implementation of the energy transition plan. The manpower of the energy sector in Indonesia is around 1.3 million people, or one percent of Indonesia's workforce. About half a million work in the production and transportation of coal is limited to only a few provinces, especially on the island of Borneo and parts of Sumatra.

The oil and gas industry, for example, is characterized as capital and technologically intensive, while the labor need is scanty. Likewise, the electricity industry built so far is more characterized as capital and technologically-intensive. However, until now the number of workers in the fossil fuel industry in Indonesia is still far larger than those working in the field of renewable energy. Employment aspects are still rarely studied in the discussions of renewable energy development in Indonesia, probably because the scale of renewable energy development, so far, is still small.

In the scenarios developed by the National Energy Council (DEN) and the Ministry of Energy and Mineral Resources, several energy technologies that will be developed have been identified. However, the current energy transition plan to achieve a net zero emission target has not yet identified the workforce that will be needed, while the need for the future development of solar and wind power is certainly very large.

The development of renewable energy technology in the future, such as for solar and wind power, is projected to grow very large. It requires highly specialized experts whose procurement must also be prepared, for example through postgraduate education or research at universities and research institutions such as BRIN. Cooperation for the preparation of experts like this within the framework of Indonesia's current energy transition has not been sufficiently developed. The need for manpower for the development of more specific technologies in the energy transition plan, for example for the construction of nuclear power plant and battery energy storage system (BESS), is also not well identified.

D. Indonesia's level of readiness

Indonesia has made efforts to maintain its energy security, including by securing domestic energy supplies and increasing the use of clean and renewable energy (Nugroho, 2015). However, to support the energy transition plan that is now being discussed, several works, including accelerating the deployment of renewable energy, must be carried out.

To be able to develop, renewable energy requires several supports, including regulation, institution, finance, and manpower aspects (Nugroho et al., 2021). The analysis taking these factors into account is briefly shown below.

1. Regulation

Analysis of legislation looks at whether the law prioritizes the development of renewable, or puts renewable energy on a level playing field with the much more mature fossil fuels, or let both of them compete with each other. Laws and regulations regarding renewable energy are compared to those about overall energy development, especially with fossil fuels.

The main question is whether the existing law is sufficient to encourage the development of renewable energy ahead of fossil energy. Furthermore, the analysis also looks at the readiness of laws regarding the energy transition and even net zero emissions.

Based on a search of the legislation as shown in Table 3.1, it is found as follows.

1) No specific law regarding renewable energy has been issued, while oil & gas, and coal have long had it.

2) The current law on energy and electricity has not emphasized the strong priority of using renewable energy.
3) The current legislation on national energy policy (Government Regulation No. 79 of 2014) targets the share of renewable energy as only small compared to the share of fossil fuels.
4) The ratification of several international agreements on climate change was not all followed up with laws to regulate their implementation at the project level, let alone for their implementation at the regional/local level.
5) Neither energy transition nor net zero emissions laws have been developed.[13]

Indonesia at the national level supports international agreements on global climate change including ratifying the Paris Agreement (2016). However, the law on the ratification of such international agreements has not been relegated to technical regulations under it, including facilitating implementation and encouraging compliance with the agreement.[14] In order to accelerate the development of renewable energy, shortcut of legal efforts have been made by enacting a presidential regulation, compared to struggling to stipulate laws regarding the development of renewable energy or regarding reducing greenhouse gas emissions. This can be seen, for example, by the enactment of Presidential Regulation Number 112 of 2022 concerning the Acceleration of Development of Renewable Energy for the Provision of Electricity.[15]

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[13] According to the Energy & Climate Change Intelligence Unit, Indonesia is at the bottom of the "race to zero", especially in terms of the readiness of the law on net zero emissions. See Nugroho (2023b).

[14] Indonesia submitted its Nationally Determined Contribution and Long-Term Strategy as requested by the Paris Agreement to the UNFCCC. However, how this is translated into domestic legislation is not entirely clear.

[15] The enactment of this President Regulation can be understood as a correction to the previous ESDM Ministerial Regulation, namely ESDM Ministerial Regulation Number 50 of 2017 concerning the use of renewable energy sources for electricity supply, which proved to have discouraged development of renewable energy later. Pricing policy was among the weakest factors. See Nugroho, 2022.

Based on the findings, it can be concluded that existing laws and regulations do not yet support the implementation of the energy transition plan. The development of renewable energy is still placed in a far weaker position than that of fossil fuels. There is a clear absence of laws that support the development of renewable energy, the energy transition, and efforts to achieve net zero emissions. Weaknesses in the regulatory aspect need to be corrected immediately because they will become the foundation for future renewable energy development and accelerate the energy transition and the move towards net zero emissions. It is impossible for a major change, such as an energy transition, to be carried out without the support of laws that facilitate it.

2. Institution

Is the existing energy institution in favor of promoting renewable energy development than fossil energy? Are not the institutions in the field of developing renewable energy, both in government and business entities, too small compared to those that have been established to develop fossil fuels?

The analysis of the institution also focuses on "who leads/coordinates the renewable energy and net zero emission program and how effective it is". Are the existing institutions strong enough to support the goals of the energy transition plan? What things are still missing and need to be improved? Our survey of data in 37 provinces and 514 regencies and cities in Indonesia found that agencies with the main task of "developing renewable energy" were either scarce or almost nonexistent. The existing agencies/institutions are not equipped with adequate human resources and funding related to renewable energy development. Development of renewable energy and mitigation/adaptation to climate change is not a high priority for local government institutions, compared to the development of basic infrastructures such as village roads, primary schools, electricity supply, and public health facilities.[16]

[16] This is clearly stated by local government offices in the national development deliberation meeting which is held annually by the National Development Planning Agency. Almost all of the problems that local governments complain about

A similar pattern occurs in the issue of global climate change. The agency that acts as a focal point or leading sector is the Ministry of Environment and Forestry. However, this agency is limited in its ability or authority to carry out inter-sectoral coordination between central government offices and government offices in provinces and districts/cities.[17]

The Directorate General of New Renewable Energy and Energy Conservation is still a relatively young institution and does not have the experience that has been possessed by other Directorates-General, especially the Directorate General of Oil and Gas, and the Directorate General of Mineral and Coal. The Directorate General of New Renewable Energy and Energy Conservation does not have strong control over local government agencies in the development of renewable energy in their area; its role is more limited to the dissemination of what is planned by the central government. As a result, in addition to some miscommunication, what has been planned by the central government often takes a long time to be implemented in areas where renewable energy development is carried out.

The target of reducing carbon dioxide emissions or achieving net zero emissions is not clear and should be done by what offices or institutions, as the organizational units in the government, have their own key performance indicators (KPIs) which sometimes conflict with reducing carbon dioxide emissions goal. This can be seen for example in the coal production target and development of electricity production.

Compared with the oil and gas and coal business, the ability and scale of business in the existing Indonesian renewable energy sector are still very weak or small. There are no business institutions in the

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are still related to basic infrastructure such as roads and electricity. The issue of global climate change has not yet become a concern. Small survey was usually conducted as a preparation part for the national development plan deliberations.

17 In some cases, the role as a "leading sector" is taken over by the National Development Planning Agency, for example in issuing the National Action Plan for Reducing GHG Emissions, as well as ensuring the projects are included in the National Medium-Term Development Plan.

field of renewable energy, both government-owned and private, whose scale is large enough to be compared, for example with Pertamina or PT Bukit Asam, two government-owned companies engaged in the oil and gas and coal sectors.

Research institutions, such as those owned by several universities in Indonesia or even BRIN have research in the field of renewable energy, but it is too early to confirm that they are connected to the energy transition or net zero emission program that is being discussed. It can be summarized that the current institutions are not strong enough to support the ambitious target of the energy transition plan.

3. Finance

As stated above, Indonesia is still practicing energy subsidies, which is quite huge. So far, almost all of the energy subsidies have been spent to finance the provision of fossil fuels so that they can be consumed cheaply by the public. This is certainly an unhealthy symptom (Beaton et al., 2015). Although the debate, including in parliament, for the use of a portion of energy subsidy funds for renewable energy development, has not been quite successful so far, efforts to do so must continue. It will be dangerous if subsidies continue to be provided for the use of fossil fuels, while not providing a significant amount of funds for the development of renewable energy. The need for renewable energy funding especially for solar and wind power will be very large as their demand will grow dramatically.[18]

The continuous drop in renewable energy costs, such as for solar and wind power, provides an excellent opportunity to boost their development.[19] However, the current level of Indonesia's investment in

[18] It is estimated that investment for solar and wind power alone will reach USD 400 billion by 2060, or require an average of USD 10 billion over the next 40 years. This is larger than the current investment in power plant construction which is around USD 6 billion/year (PLN, General Plan for Electricity Provision 2021-2030)

[19] It is also important to note that the technological cost of solar (or wind) power does not necessarily lower the cost of producing electricity from it. In the case of Indonesia, land acquisition is an increasingly expensive

renewable energy is still inadequate, even though some investment in coal is diverted to renewable energy development. Therefore, investment in the development of renewable energy must be sourced more aggressively and the effectiveness of its utilization must be increased.

The government must also be more assertive in realizing the net zero emission target, including in the form of allocating funds for the energy transition plan and reducing the share of funds for fossil fuel subsidies. The role of several ministries, such as the Ministry of Finance, the National Development Planning Agency, as well as the Ministry of Environment and Forestry, both as National Designated Authorities and as focal points from various international funding sources, must be translated into more effective operations and larger targets.

Coordination with local governments to jointly achieve the goal of net zero emission development needs to be continuously strengthened, including that the central government assists in financing and increasing the capacity of local governments in developing renewable energy. The Special Allocation Fund for renewable energy development provided by the central government to local governments needs to be continued, especially for some local governments in the eastern and island regions with low fiscal capacity.

Indonesia needs to develop institutions that concentrate on developing renewable energy, including for its capacity building and financing national targets. One example is International Renewable Energy Development Agency (IREDA) in India. The new institution is tasked with providing easy access to finance and technology for various renewable energy projects spread across Indonesia. The institution might raise funds from the government and other sources, especially international ones, which are now underutilized. This institution is to channel sources of finance with renewable energy projects in need of them all over the country with attractive terms and conditions.

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component of costs. Meanwhile, with the increasing capacity of solar and wind power to be built, the need for more land will increase.

When setting targets for their emission reductions, developing countries such as Indonesia use the terms "unconditional" and "conditional", where unconditional refers to target sets based on their resources, while conditional refers to targets the country would undertake if international aid is provided. Because, for example, the Paris Agreement is open for financial assistance from developed to developing countries, and such funds are available quite a lot (OECD, 2022), the Indonesian institutions tasked with finding funds for renewable energy development must work harder to be able to utilize these funds.

In addition to continuing to provide direct funds for the energy transition program, the government must also provide incentives for the development of renewable energy by the private sector, for example in the form of tax breaks or prioritizing energy from renewable sources. Other innovative alternative financing methods, such as blended finance or public-private partnership schemes for renewable energy development, must also be developed.

4. Manpower

Renewable energy development is labor-intensive compared to capital-intensive fossil fuel industries. However, renewable energy that creates more jobs is not the same for every type of technology (IRENA, 2021b). Each of the renewable energy technologies has its structure and supply chain. Manpower requirements are different, for example between photovoltaic and geothermal, or between wind and hydro. The need for manpower is also different in each stage of their development (installation, operation, sales, etc.).

In Indonesia, the selected renewable energy technologies such as hydro, geothermal, and solar PV could create about 3.7 million direct jobs by 2030, whereas about 2.1 million direct jobs would be with PLN (GGGI, 2020). The energy transition plan under the current proposal would require much more manpower. Challenges will be faced in the supply of manpower for the development of renewable energy to meet the target of net zero emissions. This problem needs to be overcomed by increasing the capacity and quality of training in the field of renewable energy which will be carried out not only by central ministries, but also by local governments, vocational schools and universities, and even the private sector.

Does the need for manpower also consider what manpower is needed for industrial development, such as photovoltaic components or batteries in the country? Indonesia proclaimed that developments in the field of renewable energy must also encourage the manufacture of its components domestically (The Republic of Indonesia, 2020). This will certainly create a lot of additional workers, where the industry for manufacturing renewable energy components is still underdeveloped, particularly in the outer islands of the country.

Indonesia lacks the capacity, including in the field of manpower, for the development of renewable energy industry, which will be very likely to increase largely in the future. This problem needs a quick solution. In addition to calculating the workforce that will be needed for renewable energy development or making energy transitions, it is also important to formulate how to prepare them. The Ministry of Energy and Mineral Resources' capacity-building program should increase the allocation of activities and funding for renewable energy training, compared to the current trend of prioritizing training activities in oil and gas and coal mining. Investments in training workers in the field of renewable energy need to be increased so that they are on par with or even better than the facilities that have been built for training in the fields of oil and gas and coal, such as Oil and Gas Training Center in Cepu, Central Java.

It is important to strengthen coordination with other ministries, especially the Ministry of Manpower so that the major work of preparing the workforce to meet the energy transition goals can be carried out smoothly and more widely. This will be pursued, for example, by filling out training in Job Manpower Centers under the Ministry of Manpower with more renewable energy content.

Developers of renewable energy facilities cannot be expected to directly address the labor problem for the energy transition plan. For example, on-the-job training will no longer be sufficient due to the large workforce requirement, while the basic capabilities of Indonesian workers in this field are not yet adequate.

Can we expect a shift in the workforce from those currently working in the fossil fuel industry to the renewable energy industry? Things like this are also important to observe, especially for coal, although coal's large role occurs only in a few regions in Indonesia, in particular South and East Kalimantan. However, this problem should not only be a concern of the central government but also local governments, especially those with coal mining areas, including its transportation.

D. Closing

To conduct a comprehensive assessment of Indonesia's long-term energy transition preparedness, extending our analysis to encompass the years 2045 and beyond, possibly up to 2060, it's essential to summarize the key findings and present actionable recommendations for policymakers and stakeholders. This is important, considering that Indonesia is a country with significant energy transition potential, abundant renewable energy resources, but there are needs to address environmental and energy security problems.

There are several things that can be underlined as important findings in assessing Indonesia's readiness to face year 2045.

1) **Renewable Energy Potential**. Indonesia possesses abundant renewable energy resources, including solar, wind, hydro, and geothermal. These resources can play a crucial role in reducing the country's reliance on fossil fuels and mitigating climate change.
2) **Energy Security Concerns**. Indonesia's heavy dependence on fossil fuels, especially imported oil, poses significant energy security risks. Reducing this dependency is vital for ensuring stable and affordable energy supplies in the future.
3) **Environmental Challenges**. The country faces substantial environmental challenges, including air pollution, deforestation,

and biodiversity loss, largely driven by its reliance on fossil fuels. Transitioning to cleaner energy sources can help address these issues.

4) **Policy Framework**. Indonesia has made significant strides in developing a policy framework to support renewable energy development and energy efficiency. However, there is room for improvement in terms of regulatory clarity and consistency.
5) **Investment Opportunities**. The energy transition presents substantial investment opportunities, both domestically and through international partnerships. Attracting investment in renewable energy projects can drive economic growth and job creation.
6) **Infrastructure Development**. Investment in infrastructure, including grid expansion and modernization, is essential to support the integration of renewable energy sources into the energy mix.

The discussion above shows that Indonesia is not yet well prepared to carry out energy transition work that will last until 2045 and even 2060 in the future. There are considerable challenges in terms of regulation, institution, finance, and manpower that must be resolved within the available time frame. To be implemented smoothly and achieve its goals, the concept of the energy transition plan as proclaimed by the Government of Indonesia, i.e. NZE 2060, requires several careful preparations.

1) On Regulation
    a) Issue the law on renewable energy as soon as possible.
    b) Prepare a law on energy transition and its derivative technical regulations.
    c) Include key points of the Energy Transition Plan into Indonesia's 2025–2045 Long-Term Development Plan.[20]
    d) Replace the current National Energy Policy with a new one more aligned with the energy transition plan and net zero emissions target.

[20] The long-term plan is currently in the initial phase of preparation.

2) On Institution
    a) Appoint or form a commission/agency that will be responsible for leading the overall climate change and energy transition activities.
    b) Develop government organizations at the central and regional levels with units that are responsible for renewable energy development, energy transition, and climate change issues.
    c) Form an SOE with a focus on renewable energy development. Its size is to be equivalent or larger to that which has been developed for oil and gas development, and coal.
3) On Finance
    a) Reduce (or even eliminate) subsidies for fossil fuel use. Use a part of the energy subsidies for developing renewable energy and financing energy transition projects.
    b) Develop a special agency that handles financing specifically for renewable energy development and energy transition plans, and at the same time attract funding from domestic and international sources. Training on the preparation of financing for renewable energy development implementers in the regions is one of the main tasks of this agency.
4) On Manpower
    a) Anticipate the need for manpower for energy transition activities that will grow gradually in the future. Identify the specific skills to be prepared.
    b) Prepare training/skill enhancement facilities through Job Training Centers and other educational institutions, including their offices in the regions. Develop cooperation with universities and research institutions such as BRIN to prepare high-skilled specialists.

c) Anticipate the need for manpower for the development of the manufacturing industries related to the energy transition plan.
d) Plan for shifting manpower in the coal industry to renewable energy.

In preparing regulatory, institutional, financial, and labor aspects, other supporting steps are also required, as seen below.

1) **Diversify the Energy Mix**. Develop and implement a clear strategy to diversify Indonesia's energy mix, focusing on increasing the share of renewables while gradually reducing dependence on fossil fuels.
2) **Strengthen Regulatory Framework**. Enhance the regulatory framework to provide consistency and transparency for investors. Ensure that policies and incentives are conducive to renewable energy development.
3) **Invest in Research and Development**. Allocate resources to research and development in renewable energy technologies to improve efficiency, reduce costs, and adapt solutions to Indonesia's unique geography and climate.
4) **Infrastructure Development**. Prioritize the expansion and modernization of the electricity grid to accommodate the integration of intermittent renewable energy sources. Invest in energy storage solutions to enhance grid stability.
5) **Energy Efficiency**. Implement energy efficiency measures across various sectors, including industry, transportation, and buildings, to reduce overall energy consumption and minimize waste.
6) **International Collaboration**. Collaborate with international partners and organizations to access expertise, technology, and financing for energy transition projects. Engage in knowledge sharing and capacity building initiatives.
7) **Public Awareness and Education**. Launch public awareness campaigns and educational programs to inform citizens about

the benefits of renewable energy and the importance of energy conservation.

8) **Incentivize Investment**. Create attractive incentives for private sector investment in renewable energy projects, such as tax incentives, subsidies, and streamlined permitting processes.
9) **Monitor and Adjust**. Establish robust monitoring and evaluation mechanisms to track progress and make necessary adjustments to energy transition plans as needed.
10) **Climate Adaptation**. Develop strategies for climate adaptation and resilience, considering the potential impacts of climate change on energy infrastructure and resources.

In conclusion, Indonesia stands at a crucial juncture in its energy transition journey. By embracing renewable energy sources, improving regulatory frameworks, and fostering international collaborations, Indonesia can significantly enhance its energy security, reduce environmental impacts, and promote sustainable economic growth. Implementing these recommendations will be essential to achieving a successful and smooth energy transition in the country.

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Chapter 4

Harmonious Blueprint for a Fair and Enduring Energy Evolution

Kirstie Imelda Majesty & Benita Dian Purnamasari

A. Collaborative Governance

Over the next decade, energy systems worldwide will be affected by changes in policies, technological advancements, and uncertain shifts in supply and demand. The focus would be the transition from fossil fuels to renewable energy. To achieve an equitable and sustainable energy transition, it requires a type of governance which invites collaboration from all elements of society: from civil service, state-owned enterprises (SEOs), private multinational and local companies, start-ups, academia, think-tanks, grassroots activism, non-governmental organizations (NGO), and media. This initiative to create collaborative governance is necessary to fully tap into the transformational opportunities that energy transition can create.

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Collaborative governance or joint public, private and community actions is a critical path forward to shape our better future collectively nowadays. The spirit of collaborative governance is aimed towards decision makers across all sectors, such as public, private and communities at different vertical and horizontal levels. In Indonesia, this concept is not novel as it is closely related to the traditional principle of *gotong royong*. The framework was implemented during the Covid-19 response measures, in which Indonesia managed to address the socio-economic crisis and distributed more than 439 million vaccine doses and contained economic stability in the country at the same time.

The process of collaborative governance is one that is human centered and thus begins with an understanding of a particular situation from different points of view. It comprises three stages: empathy and problem synthesizing; stakeholder and resource mapping; ideation to action. Through these different stages, the benefits of the collaborative governance framework are three-fold and can be used agnostically across different topics to:

1) create not only better solutions, but also a stronger, more resilient system that transforms challenges into opportunities;
2) provide all sectors and generations with proportional access to resources and responsibilities; and
3) optimize digital advancements to address economic, environmental, and social concerns comprehensively.

While there is no one-size-fit-all approach, this chapter presents findings on several potential collaboration areas to safeguard an equitable and sustainable energy transition in Indonesia that facilitate better regulatory efforts, structural processes, market practices, and financing schemes.

B. Challenges

The world is at a critical juncture. Even before Covid-19, the world had already experienced a myriad of structural shifts, from climate change pressures, increasing geo-economic tensions, to supply chain shifts. Pursuing the energy transition is a critical reminder that governments alone cannot solve all the challenges society faces and that we cannot resort to governance as usual. As G20 President in 2022, Indonesia has selected energy transition as one of its three priorities. Combined with its inherent characteristics as the world's fourth largest population, Southeast Asia's largest economy, and the ASEAN Chair in 2023, Indonesia has the unique opportunity to amplify global momentum towards cleaner energy sources and lower emissions while fostering equitable socio-economic development.

ASEAN countries had faced its energy trilemma: the need for secure, affordable, and green energy. Recognizing the environmental and economic benefits of transitioning to clean energy sources, ASEAN countries have implemented various measures to promote renewable energy deployment and reduce carbon emissions through greater energy cooperation. Through collaborative initiatives such as the ASEAN Plan of Action for Energy Cooperation 2016–2025 (APAEC) and the ASEAN Renewable Energy Policy and Measures Database, member states are sharing knowledge, best practices, and policies to accelerate the adoption of renewable energy technologies, which is expected to stimulate the energy integration, security, and decarbonization in Indonesia (Diaz-Rainey et al., 2021).

APAEC 2016–2025 strongly emphasizes ASEAN energy market integration and connectivity to accelerate the realization of the ASEAN Economic Community, outlining seven priority programs with action plans, namely: 1) ASEAN Power Grid, 2) Trans-ASEAN Gas Pipeline, 3) Coal and Clean Coal Technology, 4) Energy Efficiency and Conservation, 5) Renewable Energy, 6) Regional Energy Policy and Planning, and 7) Civilian Nuclear Energy (Andrews-Speed, 2016).

Among ASEAN countries, Indonesia, Malaysia, Thailand, and Vietnam have the highest energy needs (Diaz-Rainey et al., 2021). Indonesia has issued bold energy transition commitments, including 23% renewable energy in the national energy mix by 2025, and 31% by 2050. This aligns with the country's goal of reaching net zero by 2060 and achieving the Sustainable Development Goals (SDGs) by 2030. These commitments are strengthened by Indonesia's newly issued policies on carbon economic value and, on a global level, Indonesia's decision to join the Accelerating Coal Transition program at the Conference of Parties (COP)-27. It is noted that Indonesia's energy transition should be based on two key principles: energy sovereignty and energy security.

Energy sovereignty is the ability of a nation to independently decide the structure and sources of its energy supply, as well as its energy policies. National interests should remain the foundation of energy transition measures. This definition acknowledges that energy sovereignty entails the empowerment of local communities (Schelly et al., 2020), while also enhancing the capability of nations to sustain external supply chain disruptions (Cherp et al., 2012) amid global political energy constellations.

Energy security on the other hand, is defined as optimizing a nation's energy potential and ensuring adequate energy supply for socio-economic growth, either through domestic generation or external sources, accompanied by affordability and ease in terms of access. Energy security is critical for Indonesia to achieve its development goals, such as Vision 2045 to become one of the five largest economies by its centenary. Geo-political tensions have increased in recent years, serving as a stark reminder that energy sovereignty and energy security are still essential principles to uphold in the energy transition process.

Indonesia's global agenda and commitments to energy transition must be embedded into its national agenda. A nation's energy needs naturally increase as it grows in terms of economy and population. The challenge now is how Indonesia can continue to have a sufficient energy supply while increasing renewable energy generation and transforming its economy, from reliance on fossil-based material to a more value-added economy.

It is no longer contested that the energy transition contributes to Indonesia's overall reduction of greenhouse gas (GHG) emissions, helping avoid irreversible damage to our people and planet. The implementation of an equitable and sustainable energy transition requires actions on many fronts. This includes the formation of policy framework, diversification of alternative forms of renewable energy sources and infrastructures, financial support, technology and innovation, stakeholder engagement to promote cleaner manufacturing processes and business models, and decarbonization—both in the energy sector and of end-use products.

We use four frameworks when analyzing the case of Indonesia, all of which could safeguard the nation's energy transition process. This includes regulatory efforts; structural processes; market practices; and financing schemes, as illustrated in Figure 4.1.

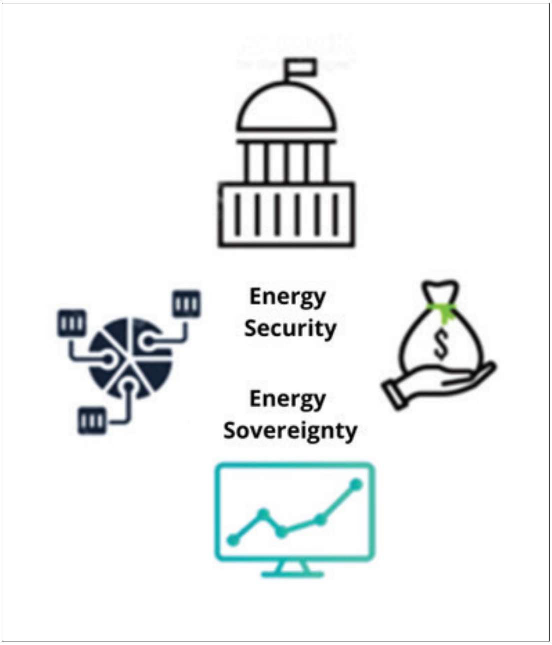

Figure 4.1 Principle of Energy Transition

1. Regulatory efforts

In short, regulatory challenges are related to governance processes that promote the creation of an enabling environment for Indonesia's energy transition. There has yet to be a comprehensive regulation that supports the development of renewable energy in Indonesia. They are often fragmented and made in silos, often resulting in inconsistencies with existing regulations. With the absence of an umbrella regulation covering the different aspects of incentives, permits, risks, subsidies, and tariffs, it is difficult for stakeholders involved to coordinate with one another. This condition has hampered effective implementation and has led to delayed deployment of renewable energy alternatives. The summary of key renewable energy policies and initiatives in Indonesia currently in force by year is shown in Table 4.1.

Table 4.1 Renewable Energy Policies in Indonesia

Year	Title	Policy Status
2014	Presidential Regulation No. 71/2014: Establishes a feed-in tariff scheme to support the development of renewable energy projects, including solar, wind, biomass, biogas, and hydropower.	In Force
2017	Presidential Regulation No. 22/2017: Sets a target of achieving a 23% share of renewable energy in the national energy mix by 2025.	In Force
2020	Presidential Regulation No. 55/2020: Sets targets for renewable energy utilization, aiming for a renewable energy mix of 23% by 2025 and 31% by 2050.	In Force
2020	Ministerial Regulation No. 13/2020: Introduces a competitive selection mechanism for renewable energy projects to ensure transparency and efficiency in project development	In Force

With the progress made so far by many researchers to establish biodiesel as a viable engine fuel, coupled with the ability to eradicate environmental issues, like global warming and sustainability, it is evident that biodiesel is designed to make a future energy investment and significant addition to the domestic and industrial automobile economy (Ogunkunle at al., 2019). The Indonesian government initiated its biodiesel policy in 2015, and this policy has been periodically updated. In September 2018, Indonesia introduced the B20 rule, which was further upgraded to B30 in January 2020. The goal was to transition to B50 by the end of 2020. The concept of sustainability revolves around the integration of environmental and economic considerations. An essential aspect of sustainable development regarding biodiesel B30, B40, and B50 is the need to balance economic growth with environmental preservation. This involves ensuring the long-term sustainability of biological resources, enhancing agricultural system productivity, maintaining population stability, imposing limitations on economic growth, and enhancing the overall quality of the environment and ecosystem (Dimawarnita et al., 2021)

2. Structural processes

This refers to the non-economic barriers to the development of renewable energy. This includes hard infrastructure, from the availability of energy transition facilities to soft skills that enhance human resources. With more than 17,000 islands across the archipelago, one of the primary challenges Indonesia faces is how to fully integrate renewable energy infrastructure to distribute electricity. This has also been the reason for low electrification rates in parts of the country.

In 2021, Indonesia set the highest record for infrastructure spending. For the first time in 6 years, infrastructure spending exceeded IDR400 trillion (Asian Development Bank, 2022). Even with such remarkable spending growth, Indonesia is still facing infrastructure gaps, especially to support the delivery of the Enhanced Nationally Determined Contributions (e-NDCs) goal. Besides hard infrastructure, the energy transition process also requires quality human resources to promote innovation on clean energy, low emission, and carbon neutral technologies.

3. Market Practices

Following on from the previous frameworks, the biggest driver of change will be market forces. Market practices in this framework refer to two main elements: pricing and behavior. Pricing refers to the value of green solutions for investors and consumers, while behavior includes public acceptance, social commitment, trust, and buy-in from consumers, communities and organizations. When it started, energy transition-related technologies were not cost-competitive, making Indonesia need to implement strong policies to drive integration and renewables. However, the costs of renewables and associated storage and grid technologies, such as HVDC interconnectors, have significantly decreased in recent times. As a result, renewable energy sources have either reached or are nearing grid parity, even in the Asian and Pacific regions (IRENA, 2018). The economic factors and market dynamics will play a crucial role in propelling the energy transition forward, with households, companies, investors, and cities exerting pressure on national governments.

a. Pricing

The price of green solutions is impacted by the energy subsidies. Energy subsidies undoubtedly have played a role in driving Indonesia's economic growth. Low fuel prices maintain the price stability of products and services that protect purchasing power of low-income households. However, energy subsidies have become less effective because, along with Indonesia's economic growth and development, it is harder for the government to track down subsidy distributions. A World Bank report indicates that Indonesia's energy subsidies mainly benefitted the middle and upper-class households, as they make-up a large portion of fuel consumption, and use around 42%–73% of fuel subsidies (World Bank, 2022).

In the electricity sector, the over-optimistic demand growth forecast in the electricity sector has led to overinvestment in coal-powered generation capacity. The Java-Bali Grid is now structurally oversupplied, thus not only increasing the amount of electricity subsidies but also hindering the deployment of renewable energy in the area, such as photovoltaic (PV) rooftops. State Electricity Company (PLN) is reluctant to connect PV rooftop projects in the Java Bali grid, making the permitting process time-consuming. In contrast to the conditions in Java-Bali, other locations in Indonesia still experience low electricity supplies. For example, small islands in East Indonesia only enjoy 12 hours of electricity supply per day. However, private sectors are hesitant to invest as the environment is still unattractive, with high-interest rates and low government incentives. The same challenge can also be seen in the case of EVs, where lack of government incentives and charging infrastructure, high prices, as well as the scarcity of spare parts and maintenance services have hindered the adoption of EVs.

b. Behavior

While the urgent need for a green transition has become more potent than ever, a greater understanding of the underlying societal changes should be addressed. Although global trends reflect a shift towards more sustainable options, it has yet to be the case in Indonesia. The government needs to engage citizens who may not understand the urgency of climate actions and garner support of those concerned. This is especially true in the case of electric stoves, an initiative that was met with hard rejection by citizens on social media, and thus aborted by the government. From our interview in August 2023 with one key person from ride-hailing services, it is found that there is a low awareness among citizens, which is shown in approximately less than 2% of active users (from a total of around 400,000) turning on the "go green" option. Also, the fact that less than 1% of the new vehicles sold are EVs shows how the market perceives green solutions. For large renewable energy projects, social opposition has highlighted the detrimental effects on human health, biodiversity loss, landscape degradation, and negative impacts on tourism and property prices. It has even reached the extreme opinion of asset destruction. Several other relational factors that contribute to shaping social acceptance are necessary to note, such as the low levels of trust in public authorities, the distribution of quality information to the public, and the lack of public involvement in the green transition process. Indonesia should thus consider creating a framework that will increase local acceptance, public trust, and ultimately reduce the opposition that have in the past been a barrier of renewable energy deployment.

4. Financing schemes

As the world aims to limit the global temperature increase to 1.5–2°C under the Paris Agreement, countries face the challenge of taking concrete steps to achieve this goal. In order to make the necessary changes in all aspects of society, temperature increase must be limited. A global consensus is needed to support this initiative. According to CPI (2021), financing needs are estimated to be between USD 4.5 Trillion and USD 5 Trillion annually from 2021 until 2050 which is roughly 6% of global GDP in 2020.

It is estimated that Indonesia requires USD 322.8 billion worth of climate-compatible infrastructure and climate assets by 2030, with around 75% in the energy and transportation sector (Asian Development Bank, 2022). Despite the availability of financing support and incentives for green solutions, Indonesia is still behind on its green transition targets.

One of the main reasons is the unattractive investing environment for green projects. The government has capped the tariff for most renewable energies based on PLN's generation product cost. While this works for some renewables, it is not alluring enough for investments in smaller projects outside PLN's main grid, where renewables are actually more needed.

Renewable energy regulations require high local content, prior to the establishment of a market large enough to achieve domestic manufacturing economies of scale. The same case happens in EVs, where traditional vehicles are produced at a mass level and reach a better economical level than EVs. The regulations also limit foreign investments and prohibit PLN from purchasing renewable power at prices higher than conventional alternatives.

However, this is not to say that there are no interested investors in Indonesia's green transition. International organizations are open to distributing loans for Indonesia to advance its transition. The challenge is that not many project developers are aware of these funding support, especially at the local and small developer levels. No national green initiative assessment standard by the Indonesian Financial Services Authority (*Otoritas Jasa Keuangan* - OJK) can be followed by national and local banks. Banks are also still reluctant to invest because they lack data and expertise in small-scale green investments. Support from the state budget can help balance the risk for green investments in the form of incentives. Currently, only 4% of the total stimulus funding has been allocated towards the green sector (Asian Development Bank, 2022). The Government should thus focus on investment strategies that do not undermine achievements made in fossil fuel dependency reduction. Indonesia's efforts to promote the green financial ecosystem include the Energy Transition Mechanism Country Platform towards clean energy transition and emission reduction towards zero emissions, the SDG Indonesia One for financing SDGs projects, climate change expenditure mechanisms in the state and regional budgets, tax facilities to encourage investments in Renewable Energy (EBT) and clean technology, the Indonesian Green Taxonomy and ASEAN Green Taxonomy version 2, encompassing early cessation of coal-fired power plants, economic value carbon instruments, an ESG manual in the Public-Private Partnership scheme, innovative financing through sovereign green *sukuk*, blue bonds, and SDG bonds. Additionally, there is international support for Indonesia's energy transition efforts through a USD 500 million Climate Investment Fund and a USD 20 billion Just Energy Transition Partnership.

C. Collaboration Areas

There are several collaboration areas that have potential to be implemented. These areas are discussed below.

1. Experience sharing and showcasing of successful energy transition projects

Stakeholders assessed the issuance of regulations have been done prudently, which on one hand is done to avoid future problems (e.g. carbon trading brokers), but on the other hand, has slowed implementation of energy transition efforts. To this end, a collaboration area related to regulatory efforts should be in the form of experience sharing and showcasing of success stories on energy transition policies and projects. The goal is to accelerate experience sharing through forums to overcome two main issues: lack of knowledge and examples of success, and an absence of a common narrative on particular topics. These forums will invite strategic policy stakeholders to openly discuss topics that could enhance an enabling environment for the energy transition. Topics will vary, covering issues such as but not limited to: investment in clean energy & efficiency, retrofitting and decarbonization of buildings, direct subsidies, carbon market and carbon pricing, EV development, reutilization of old wells, domestic level components, waste management, decarbonization of steel, plastics and cement, aviation, shipping, halting deforestation, degraded lands restoration, public transport increase, biking and walking, more consumption of plants and less meats, as well as retiring coal plants. By promoting experience and knowledge sharing, more actors—from government institutions, non-governmental organizations to the media—can be exposed to the information needed to seize opportunities related to energy transition. In the transition to net-zero, experience sharing will also allow for companies to take actions to mitigate emissions beyond their value chains.

Through experience sharing, it is hoped that the following initiatives will be created as a result.

1) Creation of a hub to push regulations that create an enabling environment, with participation of the Coordinating Ministry of Maritime and Investment Affairs, the Ministry of Energy and Mineral Resources, and the Ministry of Environment and Forestry, as key stakeholders.

2) Exploration of other low-carbon alternatives, such as natural gas or nuclear power, which produce less greenhouse gas emissions than coal. Indonesia must also set targets for the deployment of renewable energy and implement policies to support the transition, such as feed-in tariffs, carbon pricing, and energy efficiency standards. The government must encourage investment in renewable energy by providing subsidies, tax incentives, and other forms of financial support.
3) Active participation from associations, government agencies, business chambers, local communities, businesses, NGOs, academia, international associations, property developers, etc. to implement regulations (e.g. on carbon trading and calculation of carbon pricing; waste management; integrated energy planning). Ensuring inclusivity and participation in decision-making processes helps address social, economic, and environmental concerns and ensures the equitable distribution of benefits.

We believe that the impetus for change can be accelerated through the integration of knowledge between actors (Geels, 2002). Hence, this collaboration area would facilitate the identification of policy gaps, which would ultimately create integrated energy plans, suggest reward and punishment mechanisms, and accelerate delayed energy transition policies.

2. Development of electric vehicle stakeholders to accelerate decarbonization for end users.

An identified cause of delay for the deployment of renewable energy in Indonesia is due to lack of hard infrastructure. Discussions revealed that the development of EV infrastructure should be a main collaboration area, given the immaturity of the market in Indonesia and the still relatively high cost compared to conventional cars. These shortcomings present an opportunity for collaboration that expands beyond the concentrated role of PLN, which will ultimately accelerate the government's political will. Collaboration on EV infrastructure development could take shape through the following initiatives.

1) Provision of financial assistance from the government, such as incentives for EV development and procurement; as well as incentives for individual EV users.
2) Encourage investment from the private sector to encourage market infrastructure with more producers of EVs or spare parts (beyond PLN, who is currently the main actor).
3) Technical assistance and policy support on EVs. Policy support must be more practical by opening up private sector investment opportunities on this topic.
4) Discussion on the possibility of a tax holiday for EVs raw materials for. This would help easing the high cost of EV raw material costs when transferred to Indonesia.
5) Electric mobility, when powered by renewable energy, could play an important role in reducing air pollution in cities and in reducing the reliance on liquid fuels in transport. Thus, policy support for EV should be one of the main focus areas in the country's structural processes, given the immaturity of the market in Indonesia and the relatively high cost compared to conventional cars.

3. Creation of a pool of experts on energy transition to avoid local and national brain drain

Technical assistance and the exchange of experience and knowledge fundamentally require quality human resources, who can promote regulatory efforts, enhance structural processes, and spur innovations. Encouraging research, development, and innovation in renewable energy technologies can drive cost reductions and improve the efficiency and effectiveness of renewable energy systems. Collaboration with local and international experts can facilitate technology transfer and knowledge exchange. We encourage the creation of a pool of local experts and talents on energy transition to avoid a "brain drain". Such a network would lead to the following:

1) Availability of integrated knowledge on energy transition, such as Carbon Capture Utilization Storage (CCUS), Low Carbon Hydrogen, and Solar Energy Storage.

2) Connection between scientific experts to collaborate on specific projects, for example Australian National University (ANU) Indonesia Project and UK Indonesia Consortium for Interdisciplinary Sciences (UKICIS).
3) Establishment of connectivity amongst diaspora through associations of Indonesian scientists—such as Ikatan Ilmuwan Indonesia Internasional (I4Indonesia), Indonesia Mengglobal, and Persatuan Pelajar Indonesia—as well as experts on energy.
4) Incentive for experts that study or work abroad to return and promote energy transition in their own communities.

The creation of this pool of experts is intended to build linkages with stakeholders, policy makers and politicians related to the energy transition. The goal is that the ideas resulting from the network can be implemented on a practical level and not only lead to the form of scientific work that are still under-utilized.

4. More collaborative media and public education campaigns between different sectors to foster capacity building and behavioral change

For Indonesia's energy transition to succeed, considerable changes in terms of the behavior of individuals, communities and public and private organizations are required. Consumers need to shift their view from energy being a constantly accessible resource to a resource that is subject to availability. Currently, the knowledge of climate change is only distributed among segments of populations with higher levels of education. Giving priority to a fair transition is of utmost importance to ensure that the transition to renewable energy does not leave marginalized communities or workers behind. This entails helping and creating opportunities for affected communities and facilitating the smooth shift of workers from fossil fuel industries to renewable energy sectors.

It is essential to invest in capacity building programs and educational initiatives to equip individuals, communities, and organizations with the necessary skills and knowledge to participate in the renewable energy sector. The proposed collaboration idea is to create a Collaborative Media and Public Education Campaign, promoting a narrative of energy transition conveyed to all levels of society. This includes providing training, vocational programs, and educational campaigns to promote renewable energy awareness and understanding. The media campaign will:

1) collaborate with national and local media, religious leaders, well-known public figures, and property developers to develop narratives on net-zero carbon, energy transition and its benefits;
2) research and experience have shown that community leaders can set priorities, influence ownership, and design and implement investment programs responsive to their community's needs;
3) allow companies to educate others on how to take actions to mitigate emissions beyond their value chains;
4) include a hub/app where people can access information on energy transition topics more easily;
5) include incentive schemes for consumers to increase the uptake of green solutions; and
6) distribute the narrative of energy transition across all communities through "the right information". The campaign should be tailored to each segment's characteristics to ensure that the information shared is well received and understood.

The increase in information can impact the evaluation of green solutions. However, knowledge of green solutions will have limited effects when people are not motivated to engage in sustainable energy behavior, or when they do not feel able to engage in such behaviors. An enabling environment such as policies, financial incentives, and infrastructure needs to be developed in parallel to this campaign.

5. Explore innovative financing schemes to accelerate alternative forms of funding.

Ensuring adequate green investment for a sustainable future is an economic imperative as much as it is an environmental one. Sufficient financial support mechanisms are required to attract investments in renewable energy projects. The deployment of renewable energy requires funding, and a potential collaboration area is to explore innovative financing schemes from the private and community sectors to accelerate alternative forms of funding. The main goal is to ensure stakeholders can access a pool of funds, as well as avoid a mismatch between funding instruments and projects implemented. This can be achieved through the following initiatives:

1) accelerate availability of loans for renewable energy users;
2) provide inducements like feed-in tariffs, grants, and affordable financing choices to mitigate the financial obstacles associated with the development of renewable energy;
3) encourage tax holiday ratification by the government on green projects;
4) a remove income tax through a global agreement for investment in qualified securities linked to green project investments in developing countries;
5) establish connectivity between the source of funds and project owners;
6) encourage cross border financial flows towards environmentally friendly investments in developing nations;
7) build connection between project owners and community-owned enterprises for local/small initiatives;
8) promote loan interest discounts for developers with green building certification; and
9) provide information on potential sources of funds to stakeholders regularly.

Various alternative financial instruments have been created to advance climate action, including green bonds, ESG bonds, sustainability bonds, and the most recent addition, Sustainability Linked Bonds (SLBs). Unlike green bond, which specifically funds environmentally friendly projects; sustainability bond, which is a mix of green and social initiatives; and ESG bond which is linked to environmental, social, and governance factors, SLBs are distinctive for their ability to finance projects that may not neatly fit into predefined categories but still align with the Paris Agreement goals. The purpose of SLBs is to complement green bonds, providing issuers with more effective access to the sustainable financial market.

Notably, SLBs differ from other instruments in that they are not use-of-proceeds designated; rather, they are performance-based. SLBs come with Key Performance Indicators (KPIs) that must be achieved, incorporating step-up and step-down mechanisms. A step-up results in an increased coupon value as a penalty for the issuer if the target is not met, while a step-down entails a decreased coupon value as an incentive for the issuer if the target is achieved earlier or more effectively. The extent of these adjustments varies by issuer, with common practices indicating step-ups around 25 basis points.

Compared to other instruments, SLBs are relatively recent in the financial market, with the first issuance occurring in 2019 by the Italian energy company ENEL. ENEL's SLB, worth $1.5 billion, aimed to increase the proportion of EBT from 45.9% in 2019 to 55% in 2021, with a 25-basis point coupon increase if the target was not met. In 2021, ENEL successfully achieved the Sustainability Performance Target set for its SLB.

Sovereign SLBs have also been issued by Chile and Uruguay in 2022, with specific emission reduction and environmental goals, subject to coupon adjustments if targets are not met. Several countries, including Rwanda, the Netherlands, and those surrounding the Amazon rainforest, are exploring sovereign SLBs. Additionally, beyond assisting issuers in securing funds, SLBs can aid investors in contributing to climate-aligned projects, and the Climate Bond

Initiative is actively developing an SLB database to help investors avoid projects engaged in greenwashing.

Indonesia's state budget alone will not be enough to close the funding gap needed for the deployment of renewable energy. To mobilize private capital and aid green energy initiatives, innovative blended finance schemes in the geothermal project can be employed, like the one proposed by PT Sarana Multi Infrastruktur (PT SMI), PT Penjaminan Infrastruktur Indonesia (Persero) Tbk and PT Indonesia Infrastructure Finance as a special mission vehicle (SMV). In addition, the Indonesia Green Taxonomy by the Financial Services Authority (OJK) launched in January 2022 should be followed by a more detailed regulation and standardization on the system and assessment of green initiatives. There is also a need for technical assistance for financial institutions that are willing to invest in green initiatives to help increase their awareness, provide information on risk management, and secure their initial engagement in green investments. However, given the limited funds and availability of experts, a gradual transition toward a fee-based system for technical assistance would improve its long-term sustainability.

On a different note, Bank Indonesia has instituted a macroprudential liquidity incentive policy, effective from October 1, 2023. This targeted policy is designed to promote intermediation in sectors that have a leverage effect on the national economy, notably in the inclusive finance and green financing sectors. Bank Indonesia is actively supporting the transition to a green economy, ensuring that this shift is not only environmentally responsible but also equitable, well-organized, and economically viable. The policy reflects the central bank's commitment to fostering sectors that contribute meaningfully to economic development while aligning with sustainable and inclusive principles. By encouraging liquidity in these strategic areas, Bank Indonesia aims to play a pivotal role in driving the nation towards a more just, well-structured, and economically feasible green economic landscape. The policy underscores the central bank's proactive stance in aligning financial incentives with national economic goals, particularly in sectors that are crucial for inclusive growth and environmentally sustainable practices.

Figure 4.2 shows stakeholder mapping on Indonesia's energy transition with importance-accessibility matrix analysis. There are four categories, namely Category I, (low importance, easy accessibility), Category II (high importance, easy accessibility), Category III (low importance, hard accessibility), and Category IV (high importance, hard accessibility). Stakeholders that are both important and easily accessible, such as the Coordinating Ministry for Maritime Affairs and Investment Affairs, Chambers of Commerce, Ministry of National Development Planning should be given top priority during the implementation.

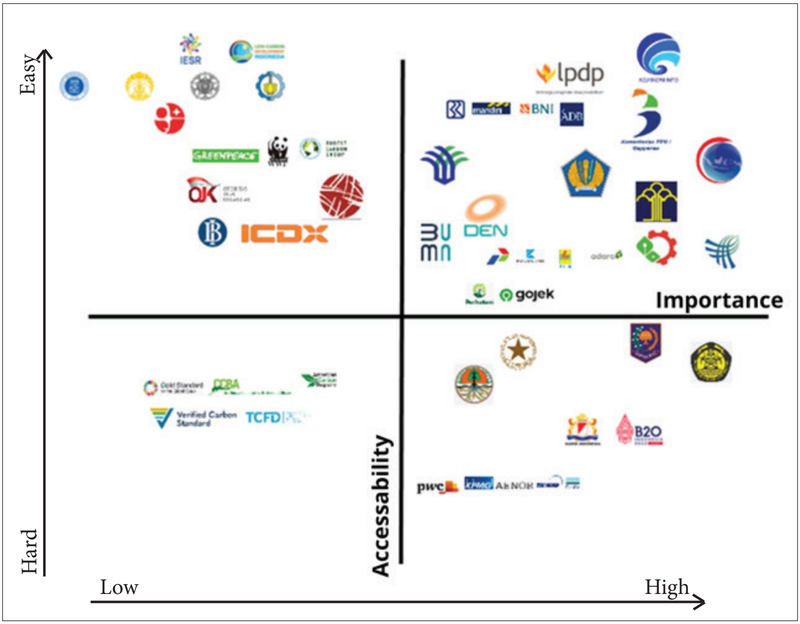

Figure 4.2 Stakeholder Mapping on Indonesia's Energy Transition

D. Closing

Indonesia has ambitious energy transition targets; however, the equability, speed and sustainability of the process will improve with greater collaborative governance between public, private and community sectors. The results of collaborative governance speak for themselves. The collaborative areas includes multinational experience sharing and showcasing of successful energy transition projects to promote sustained dialogues among all stakeholders including policymakers, international standard setting bodies and private sector, development of electric vehicle stakeholders to accelerate decarbonization for end users, creation of a pool of experts on energy transition to avoid local and national brain drain, education campaigns between different sectors to foster capacity building and behavioral change, and exploration of innovative financing schemes to accelerate alternative forms of funding. For example, the roll out of Covid-19 vaccines in record time in under three years exemplifies what we can achieve when the public, private and community sectors work in a harmony.

We have a clear momentum to extend this same principle to the energy transition, including the decarbonization of the power sector as a crucial element. As G20 2022 President and 2023 ASEAN chairman, Indonesia has a unique opportunity to promote economic pathways that speak to both growth and climate. With the complex and multi-faceted nature of the energy transition, this is an apt time to include a whole of society approach where public, private and community sectors all take proportionate responsibility, leveraging and contributing their unique modalities.

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Chapter 5

Clean Power for Indonesia: Leading the Way in the Energy Transition

Indri Hapsari

A. Indonesia's Energy Transition Program

The Indonesian government has ambitious plans regarding the Indonesia Energy Transition in 2045. The program includes several important aspects, namely achieving carbon neutrality, meaning that greenhouse gas emissions produced by the energy sector and other sectors will be offset by efforts to reduce emissions and absorb carbon. The government focuses on developing clean energy sources, such as solar, wind, hydro, and biomass. This effort involves the construction of power plants based on renewable energy with significant capacity to reduce dependence on fossil energy. As for the fossil energy being used, the government is pushing for energy efficiency in all sectors, including industry, transportation, and buildings. These steps include

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using more efficient energy technologies, setting energy efficiency standards, and public awareness campaigns on wise energy use. In addition, the government plans to accelerate transportation electrification by promoting electric vehicles and developing the necessary charging infrastructure.

There are efforts to manage limited natural resources sustainably, including forest management, developing renewable energy in remote areas, and reducing environmental pollution. For this reason, it is necessary to open international cooperation to achieve the energy transition goal. For example, in China, they successfully use an evolutionary game model between electric power companies and solar investment companies under the background of energy reform in rural areas (Wenlong & Yunfeng, 2023). This involves cooperating with other countries, international organizations, and the private sector in technology development, knowledge exchange, and investment in the clean energy sector.

Amid Indonesia's vibrant energy scene, a multitude of energy suppliers, both public and private, intricately shape the nation's energy trajectory. Key among these players is PT PLN (Persero), the state electricity provider charged with distributing power nationwide. National energy giant PT Pertamina (Persero) contributes significantly, focusing on essential fossil fuels like oil, gas, and coal. Global players such as Chevron Indonesia actively enriches the oil and gas sector with international expertise. PT Adaro Energy Tbk stands out in coal mining, pivotal in coal production and marketing. This diverse energy landscape extends beyond these names, with various others actively engaging to drive Indonesia's energy advancement. At the forefront is Tangguh LNG (Liquid Natural Gas), managed by British Petroleum Berau Ltd. This LNG venture is converting natural gas into a liquid form for practicality and commercial viability. As Indonesia charts its energy course toward diversification and sustainability, these collaborations and innovations underscore the nation's commitment to a greener future.

As energy supply companies in Indonesia, they must declare themselves clean power companies. This will support the government's plan to implement the Indonesia Energy Transition program in 2045. Indonesia can significantly reduce greenhouse gas emissions, increase energy sustainability, create jobs, and improve people's quality of life when these companies turn into clean power companies.

The benefits of operating as clean power companies are they can adopt environmentally friendly technologies and practices to increase operational efficiency, reduce the consumption of resources such as energy and water, and optimize the use of raw materials. These benefits will reduce long-term energy costs, bearing in mind that energy from fossil sources can experience price fluctuations. Clean power companies will also attract consumers who are increasingly aware of environmental issues and get better support from the government and society. Another benefit is an increase in the reputation and image of the companies, and it is easier to influence employees to be more committed. These benefits can encourage innovation and creativity in finding sustainable solutions. Companies can have better relationships with related parties such as the government, the community, and non-governmental organizations. In the long run, they will positively affect the environment and society. Thus, clean power company is the main pillar to achieve a sustainable and environmentally friendly energy transition in Indonesia 2045.

This chapter delves into the concept of a clean power company, explaining its significance as an entity committed to environmentally sustainable energy practices. Indonesia's energy landscape is multifaceted, encompassing various sources, from conventional fossil fuels to burgeoning renewables. The imperative to transition from fossil fuels to renewable energy sources is imperative, given the pressing global concern of climate change. This transition, set to materialize by 2045, necessitates comprehensive preparations. Notably, the chapter outlines twelve strategic pathways to achieve the expected status of a clean power company, encompassing large-scale renewable energy projects, novel energy technologies like biomass, ammonia, and hydrogen co-firing, and infrastructural advancements such as inter-island transmission and smart grids. As Indonesia embarks on this transformative journey, it must confront various challenges, including technical intricacies and policy complexities, while capitalizing on emerging opportunities in the sustainable energy sector. The chapter concludes by emphasizing the importance of an integrated and collaborative approach in realizing Indonesia's vision of becoming a clean power company and contributing to global environmental preservation.

B. Clean Power Company

Clean power companies focus on the production, procurement, and distribution of clean or renewable energy. The definition of a clean power company can vary, but fundamentally, these companies are committed to reducing environmental impact and assisting in the transition to cleaner and more sustainable energy.

Clean power companies use renewable energy sources, such as solar, wind, hydro, geothermal, or biomass energy. They also apply environmentally friendly technology and have a production process that is more efficient in producing energy. The main goal of clean power companies is to reduce greenhouse gas emissions and reduce dependence on limited fossil fuels that negatively impact the environment. Research by Jiaojiao and Feng (2022) on the carbon emission reduction efficiency and potential for clean energy power in 58 countries underscores the importance of clean energy companies. Clean energy companies can also be integrated energy solutions providers, including developing infrastructure and technology for energy storage, intelligent grid management, and digital technologies to monitor and optimize energy use.

Clean power companies have an essential role in reducing air pollution, maintaining environmental quality, and creating a more sustainable energy system. Through their efforts, clean power companies contribute to meeting society's energy needs in ways that are environmentally friendly, sustainable and have the potential to generate long-term benefits for people and our planet.

Investing in clean energy sources must precede efforts that companies can make to become clean power companies. They can invest heavily in constructing and operating power plants using clean energy sources, such as solar, wind, hydro, or biomass. Companies might also build infrastructure that supports clean energy, including building environmentally friendly power grids and using efficient grid technology. For example, they optimized power supply system scheduling and clean energy application to make the process more efficient (Ling et al., 2022). The companies continue to conduct research and development to establish more efficient and economical clean energy technologies. They adopt digital and intelligent technologies for more effective energy management and monitoring. An example is the research of Kat (2023), who uses a techno-economic analysis with a high-resolution power expansion model to support the clean energy transition in the Turkish power sector. Another is from Tao et al. (2023), who uses the same method to examine and optimize a combined solar power and heating plant to achieve a clean energy conversion plant.

Companies need to focus on increasing energy efficiency in producing, distributing, and using electrical energy. They use more efficient technologies to optimize energy use and reduce waste. Companies also need to implement measures to reduce emissions of greenhouse gases such as carbon dioxide (CO_2). They can use carbon capture technologies and cleaner fuels and transparently monitor and report emissions.

Regarding human resources, the companies play a role in educating the public about the importance of clean energy and its positive environmental impact. They held an information campaign and invited the public to adopt environmentally friendly energy practices. Collaboration is needed with related parties such as the government, academic institutions, and environmental organizations to create policies and programs that support clean energy development. They participate in global and regional initiatives to tackle climate change. Climate change has become the concern of Lund's (2015) research using clean energy systems as mainstream energy options.

Companies need to be involved in developing renewable energy projects such as large-scale solar or wind power plants. They invest in these projects to increase clean energy capacity in Indonesia. Compliance with regulations and environmental standards must become part of operational integrity by complying with applicable environmental provisions. There is a long-term commitment to become clean power companies. They continue to evaluate and improve to ensure their operations comply with clean and sustainable energy principles. Through these efforts, electricity supply companies can contribute significantly to accelerating the energy transition towards a cleaner and more sustainable one.

C. Energy in Indonesia

Energy in Indonesia comes from rich natural resources. Indonesia has abundant natural resources, including reserves of oil, gas, coal, and renewable energy potentials, such as solar energy, wind energy, hydro energy, and biomass. These rich natural resources are essential for meeting the country's energy needs. Despite having great renewable energy potential, Indonesia is still heavily dependent on fossil fuels, especially oil, natural gas, and coal. The country's energy sector is dominated by fossil-fuel power generation and transportation that uses fossil fuels. Dependence on fossil fuels creates challenges regarding greenhouse gas emissions and energy security. This energy security is needed to support rapid economic growth, which impacts increasing energy demand. The ever-increasing demand for energy creates pressure on the existing energy infrastructure and natural resources.

Despite significant efforts to increase access to energy in Indonesia, there are challenges in providing adequate access to power for the entire population, especially in remote and inland areas. Not to mention the global problems regarding climate change and environmental sustainability because of greenhouse gas emissions.

The impact of climate change on the energy sector is in the form of a decrease in the availability of energy resources. Climate change can result in changes in rainfall patterns and temperature, which in turn can affect the availability of energy resources such as water and hydroelectric energy. Decreased rainfall and drought can reduce hydroelectric power generation potential, while rising temperatures can reduce the efficiency of fossil fuel power plants. The result is the vulnerability of energy infrastructure. The increase in intensity of extreme weather, such as floods, storms, and heat waves, can cause disruptions to the energy supply, damage to transmission and distribution networks, and risks of fire or damage to energy facilities. Such circumstances can increase energy demand due to higher temperatures and more significant cooling requirements. This can lead to an increase in the use of electrical energy, especially for air conditioning systems, which can increase the pressure on power generation capacity.

Climate change can also increase the risk of natural disasters, such as floods, landslides, and strong winds. This can disrupt the energy supply, including power plants and supporting infrastructure, and disrupt energy distribution to the public. As a result, adaptation and mitigation are needed to reduce greenhouse gas emissions. This includes developing renewable energy, increasing energy efficiency, reducing power generation and transportation emissions, and managing energy resources more sustainably.

In dealing with the impact of climate change on the energy sector, the Indonesian government has taken steps to develop sustainable policies and strategies. This includes increasing the use of renewable energy, reducing emissions, increasing energy efficiency, and increasing adaptation to climate change in the planning and management of the energy sector.

D. Energy Transition

The energy transition in Indonesia refers to the change in the country's energy system from energy sources that are predominantly derived from fossil fuels (such as oil, gas, and coal) to energy sources that are more sustainable and environmentally friendly, including renewable energy (such as solar, wind, water, biomass) and other clean energy technologies. This transition is essential because it can reduce negative environmental impacts. By switching to renewable energy sources and clean technologies, Indonesia can reduce greenhouse gas emissions, air pollution, and other environmental hazard.

Energy transition will create a diversification of energy sources, which might reduce the dependence on fossil fuels, thus decreasing the risk caused by fluctuations in price and supply. This can help achieve energy independence. By relying on abundant domestic energy sources, such as sunlight, wind, and biomass, the country can reduce its dependence on energy imports and improve energy security in the long term. Energy transition can also provide significant economic opportunities for Indonesia. Development of the renewable energy sector can create new jobs, drive sustainable industry growth, and increase investment in clean energy technologies. There has been an increase in people's access to affordable and sustainable energy. Renewable energy sources, such as solar and mini-hydropower plants, can be a solution for remote areas that are difficult to reach by conventional electricity grids.

To achieve a successful energy transition, collaboration between the government, the private sector, and society is required. Steps such as supporting energy policies, adequate infrastructure development, reducing barriers to investment, and public education on the importance of sustainable energy need to be taken to encourage an effective and sustainable energy transition in Indonesia.

E. Preparation for Energy Transition in 2045

Policies and regulations supporting Indonesia's energy transition are essential in directing and driving changes toward a more sustainable energy system. Several policies and rules that have been implemented in Indonesia are as follows.

1) **National Energy General Plan** (*Rencana Umum Energi Nasional* - RUEN). RUEN is a strategic planning document that regulates the direction of energy policy in Indonesia. RUEN aims to integrate sustainable energy policies, reduce dependence on fossil fuels, improve energy efficiency, and develop renewable energy resources.
2) **Law on New and Renewable Energy** (*Energi Baru dan Terbarukan* - EBT). The EBT Law is the legal basis for developing new and renewable energy in Indonesia. The law encourages investment in renewable power generation, including increased use of wind, solar, hydro, and biomass energy.
3) **National Energy Policy** (*Kebijakan Energi Nasional* - KEN). KEN is established to regulate sustainable energy policies and strategies in Indonesia. KEN emphasizes the development of renewable energy, energy efficiency, diversification, and reduction of greenhouse gas emissions.
4) **National Action Plan for Reducing Greenhouse Gas Emissions** (*Rencana Aksi Nasional Pengurangan Emisi Gas Rumah Kaca* - RAN-GRK). RAN-GRK is a policy framework for reducing greenhouse gas emissions in Indonesia. This plan covers the energy and other sectors and promotes clean energy, energy saving, and emission management.
5) **Local Government Policies**. Local governments also have an essential role in supporting the energy transition. Several regions have issued policies and regulations that support the development of renewable energy, such as setting targets for renewable energy, fiscal incentives, and permits that facilitate investment in the renewable energy sector.

In addition to these policies and regulations, there are also fiscal incentives, supporting permits, and cooperation with the private sector to encourage investment and development of clean energy technologies. This aims to create an enabling environment for a more sustainable energy transition in Indonesia.

How, then, clean power companies can be developed? These are the steps.

1) Development of renewable energy sources

The development of renewable energy sources in Indonesia has an essential role in reducing dependence on fossil fuels, reducing greenhouse gas emissions, and increasing the sustainability of the energy sector. In the development of renewable energy sources, things that need to be considered are the potential of natural resources. Indonesia has great potential to develop renewable energy, such as abundant sunshine, strong winds, and abundant geothermal resources. Optimum utilization of this potential can become the basis for developing renewable energy sources in Indonesia.

Some policies and regulations that support renewable energy development need to be implemented and strengthened. These include fiscal incentives, facilitating licensing, competitive electricity rates, and legal certainty for investment in the renewable energy sector. The development of renewable energy sources also requires adequate electricity infrastructure and networks. Building a solid and efficient grid and providing equitable access to electricity throughout the region is essential to support the use of renewable energy.

Capacity building in research, development, and application of renewable energy technologies needs attention. The result of efficient and affordable technology and increased skills and knowledge in the field of renewable energy will accelerate the growth of this sector in Indonesia. Cooperation between government, private industry, academia, and civil society is also needed. Good collaboration can result in innovation, adequate financing, and technology transfer to drive the growth of the renewable energy sector.

Developing renewable energy sources in Indonesia brings environmental benefits and can provide economic opportunities, create jobs, and increase access to sustainable energy for the whole society. Therefore, constant attention and commitment to developing renewable energy sources are essential for Indonesia's sustainable energy future.

2) Increasing the efficiency of energy use

Energy efficiency and energy conservation play an essential role in reducing energy consumption and increasing the sustainability of Indonesia's energy sector. Energy efficiency involves the more efficient and effective use of energy, in which greater energy output is produced using less energy. This helps reduce energy consumption, operating costs, and greenhouse gas emissions that contribute to climate change. The Indonesian Government has implemented policies and regulations to promote energy efficiency in various sectors. These include energy efficiency standards for household and industrial appliances, incentive programs for the efficient use of technology, and energy audits to identify opportunities for energy savings.

The energy conservation program involves ways to reduce energy consumption through wise use. This includes reducing energy waste, selecting efficient equipment, optimal temperature settings, using energy-efficient lighting, and education for better energy awareness. Implementing energy efficiency technologies and practices in the industrial sector can reduce energy consumption and operating costs and increase productivity and competitiveness. Another way is to pay attention to building designs that use efficient energy, good thermal insulation, efficient lighting, and cooling systems, and effective energy management can reduce energy consumption and optimize resource use. Energy efficiency and energy conservation provide multiple benefits, namely reducing energy consumption and operational costs, as well as having a positive impact on the environment. By adopting energy efficiency and conservation practices, Indonesia can achieve its goal of reducing greenhouse gas emissions and safeguarding the sustainability of the energy sector in the future.

As an example of increasing the efficiency of energy use, British Petroleum (BP) stands as one of the largest foreign investors in Indonesia, boasting a 70-year operational history and unwavering dedication to the country's energy needs (British Petroleum, 2018). Primarily engaged in oil and gas exploration and production, focusing on the Tangguh LNG refinery, BP's commitment extends to downstream and petrochemical industries. With a strategic emphasis on growing gas and oil in the upstream sector, BP has prioritized increasing efficiency in production. One noteworthy initiative is the introduction of oil tankers equipped with more efficient engines and advanced energy management systems. This strategic direction aligns with the fact that gas combustion produces significantly lower CO_2 emissions than coal, contributing to emissions reduction as evidenced in the US. The highlight is the synergy between gas and renewables, where gas serves as a low-carbon backup for the intermittency of renewable energy sources. Beyond power generation, gas is crucial for heating homes, businesses, and high-temperature industrial processes. BP's role spans gas exploration, production, transportation, storage, and sale, positioning the company to thrive in a burgeoning and competitive global gas market. BP's involvement also extends to environmental sustainability, addressing methane emissions to ensure the longevity of gas as a lower-carbon resource.

Tangguh LNG represents the culmination of a collaborative effort across six integrated gas fields within the Wiriagar, Berau, and Muturi Cooperation Contract Areas in the Gulf of Bintuni, West Papua. Managed by BP Berau Ltd., Tangguh LNG commenced operations in 2009. BP's process involves converting natural gas into liquid form for more efficient domestic transportation and international export, enabling regional countries to transition away from coal. Some of the gas supply is directed to China, while another share is exported to South Korea.

3) Energy infrastructure development

Environmentally friendly energy infrastructure is crucial in realizing Indonesia's sustainable energy transition. Some of the environmentally friendly energy infrastructures in Indonesia include renewable power plants. Renewable energy infrastructure, such as solar, wind, and hydropower, is a crucial focus for reducing dependence on fossil energy sources contributing to greenhouse gas emissions. The construction of renewable power plants in various regions of Indonesia is an essential step towards achieving the renewable energy target.

Related to infrastructure, it is necessary to build an efficient transmission and distribution network. Efficient and sophisticated electricity transmission and distribution network infrastructure is needed to support the widespread deployment of renewable energy. Developing a strong and integrated network will ensure stable and affordable energy distribution to various regions in Indonesia. Energy storage infrastructure, such as batteries and thermal storage systems, allows energy storage from renewable sources to be used when needed. This helps maintain a stable and reliable supply of energy, especially from volatile energy sources such as solar and wind. Environmentally friendly energy infrastructure plays an essential role in achieving Indonesia's energy transition goals and environmental protection. With suitable investment and infrastructure development, Indonesia can accelerate its transformation towards a cleaner, more sustainable, and more competitive energy system.

Sustainable transport infrastructure, such as an electrified rail network, an efficient mass transit network, and electric vehicles, plays an essential role in reducing air pollution and greenhouse gas emissions from the transport sector. By building infrastructure that supports sustainable transport, Indonesia can reduce its dependence on fossil fuels and promote more environmentally friendly mobility. The development of research and development infrastructure, as well as production and distribution facilities for new and innovative energy technologies, will drive the growth of the sustainable energy sector in Indonesia. This infrastructure supports the development and adoption of new technologies that are more efficient and environmentally friendly.

4) Research and technological innovation

Indonesia's energy technology research and innovation are critical in driving a sustainable energy transition. Establishing an energy research center that focuses on developing renewable energy technologies and energy efficiency is necessary. These centers conduct research and development to improve Indonesia's energy sources' performance, efficiency, and sustainability.

The research center can become a forum for collaboration with international research institutions and other countries to share knowledge and technology in the energy sector. Energy technology research and innovation can be accelerated through this collaboration, and the results can be implemented more effectively. Of course, funding support is needed for energy technology research and innovation through various programs and institutions. Programs such as sustainable energy research, renewable energy technology development, and clean energy initiatives support research and development of technologies that have the potential to reduce emissions and improve energy efficiency. Research from Zhang et al. (2020) does innovation in the wind power sector, while research from Lamichaney et al. (2020) has innovation in combine hydrogen power and fuel cells to clean energy technologies, while Jahangiri et al. (2019) develop clean hybrid solar-wind power plants in Iran.

Increasing knowledge and skills in the energy sector through education and training is essential in encouraging research and innovation. Universities and educational institutions in Indonesia organize programs focusing on renewable energy and technology to produce a skilled and qualified workforce in this field. There are also incubation and acceleration initiatives supporting energy technology development in Indonesia. These programs help start-ups and emerging energy companies to develop and accelerate the potential implementation of energy technology innovations.

With sustainable energy technology research and innovation in Indonesia, solutions and technological developments that are efficient, environmentally friendly, and competitive can be created. This research and innovation will help Indonesia achieve its more sustainable energy transition target and reduce its dependence on fossil energy sources.

5) Diversification of energy sources

Diversification of energy sources in the context of the energy transition for Indonesia refers to efforts to reduce dependence on one particular type of energy source and increase the use of various energy sources that are more sustainable and environmentally friendly. This is done by replacing or reducing the dominant use of fossil fuels (such as oil, gas, and coal) with cleaner, renewable alternative of energy sources (such as solar, wind, hydro, biomass and nuclear geothermal energy).

Diversification of energy sources has several significant benefits for Indonesia.

a) It reduces the risk of high dependence on imported fossil fuels, reducing vulnerability to global prices and supply fluctuations.
b) By leveraging abundant domestic energy sources, Indonesia can improve energy sustainability and reduce negative environmental impacts caused by the burning of fossil fuels.
c) Diversification of energy sources can create investment opportunities and new jobs in the renewable energy sector and other clean energy technologies, which have the potential to increase economic growth and strengthen the national energy sector.

In the energy transition context, diversification of energy sources plays an essential role in reducing greenhouse gas emissions, tackling climate change, increasing energy efficiency, and achieving sustainable development goals. Supporting policies and incentives are needed to encourage the diversification of energy sources, development of adequate infrastructure, investment in energy technology research and development, and cooperation between the government, the private sector, and the community. It triggered Buntaine and Pizer (2015) to find methods to encourage clean energy investment in developing countries.

The types of power renewables technologies to support Indonesia's economy are:

a) Solar Power:
   (1) Utilization of sunlight to produce electrical energy.
   (2) Installing solar panels on building roofs or open land.

(3) Great potential in Indonesia due to abundant sunshine throughout the year.

b) Wind Power:

(1) Utilization of wind energy to generate electrical energy.

(2) Construction of wind turbines in areas with strong winds.

(3) Great potential in several regions of Indonesia such as Sulawesi, Nusa Tenggara, and Maluku.

c) Water Power (Hydropower):

(1) Utilization of flowing water or waterfalls to generate electrical energy.

(2) Construction of hydroelectric power plant (PLTA) in big rivers or mountainous areas.

(3) Great potential in Indonesia, with many rivers and favorable topographical conditions.

d) Geothermal Energy (Geothermal):

(1) Utilization of geothermal energy to generate electricity.

(2) Construction of geothermal power plants in areas with high geothermal potential, such as around Sukabumi Temple and Ijen Crater.

e) Biomass:

(1) Utilization of biomass such as agricultural waste, industrial waste, and forest biomass to produce energy.

(2) Construction of a bioenergy factory to convert biomass into electricity or fuel.

f) Biogas:

(1) Utilization of methane gas from organic waste such as animal manure or agricultural waste.

(2) The use of biogas as an energy source for cooking or generating electricity.

g) Ocean Wave Energy:
   (1) Utilization of energy from ocean waves to produce electrical energy.
   (2) Construction of wave power plants on beaches with high wave potential.

h) Tidal Energy:
   (1) Utilization of tidal energy to produce electricity.
   (2) Construction of tidal power plants in areas with significant tidal differences.

6) Sustainability and energy security

Energy sustainability and security in the context of the energy transition for Indonesia refers to efforts to ensure a sustainable, reliable, and sustainable supply of energy in the long term while reducing negative impacts on the environment and achieving sustainable development goals.

Energy sustainability relates to using energy resources that can be maintained long-term without depleting or damaging the natural environment and considering social and economic aspects. This involves developing and utilizing renewable energy sources like solar, wind, hydro, biomass, nuclear, and geothermal energy. By using renewable energy sources, Indonesia can reduce its dependence on limited fossil fuels and contribute to reducing greenhouse gas emissions.

Energy security relates to a country's ability to deal with fluctuations in energy supply and ensure adequate energy availability under various conditions, including crises or supply disruptions. To achieve energy security, Indonesia needs to have sufficient diversification of energy sources, reliable energy infrastructure, responsive energy policies, and readiness to face changing global conditions.

In the energy transition context, sustainability and energy security are interrelated and mutually supportive. By developing sustainable energy sources, Indonesia can achieve long-term energy sustainability and reduce its vulnerability to fluctuations in energy prices and supplies. In addition, strong energy security will ensure a reliable and sustainable supply of energy during the transition to a cleaner and more sustainable energy system.

7) The application of digital technology

The application of digital technology has become a key factor in efficient and sustainable energy management and monitoring. Research and technological innovation in terms of the application of digital technology in the energy industry aim to optimize energy use, increase operational efficiency, and reduce environmental impact. In this context, digital technology involves using sensors, monitoring systems, data analysis, artificial intelligence, and other digital platforms to collect, analyze and optimize energy data.

In the energy industry, applying digital technology can assist in more effective management and monitoring of energy resources, such as electricity, gas, and water. Digital technology can be used to monitor energy consumption in real-time, detect energy anomalies or leaks, and provide accurate information for better decision-making regarding energy use. In addition, research and technological innovation also focus on developing integrated energy management systems in which digital technologies are used to link various energy components, including energy production, storage, and consumption. This enables more efficient and sustainable management of the energy system.

The application of digital technology in energy management and monitoring provides significant benefits, including energy savings, reduced operational costs, reduced greenhouse gas emissions, and increased reliability of energy supply. In addition, digital technology can also drive the adoption of renewable energy and facilitate better integration between renewable energy sources and the electricity grid.

8) Use of nuclear power

There are several reasons why nuclear power is included in clean power energy. The first is that nuclear power plants have high efficiency in producing electrical energy. Nuclear reactors can convert most atomic energy into electrical energy with relatively low losses.

This makes it more efficient than conventional energy sources such as fossil fuel power plants. The process of generating nuclear power uses nuclear fuel, such as uranium. These nuclear fuels have a very high energy density, meaning that the fuel needed to produce the same energy is much less than fossil fuels such as coal or oil. This reduces fuel procurement costs and dependence on unstable fuel supplies.

Nuclear power plants have relatively low operating costs. After a nuclear power plant is built, its operating prices are more stable and predictable than a fossil fuel power plant. This is associated with lower fuel requirements and lower maintenance requirements. One of the main advantages of nuclear power plants is that no CO_2 emissions are produced in the electricity generation process. Nuclear power produces no greenhouse gas emissions, essential in fighting climate change and achieving zero-emission targets. Sadekin et al. (2019) reviewed nuclear power as the foundation of a clean energy future.

9) Battery storage usage

Battery storage allows power plants to store energy generated in times of overproduction, such as from renewable energy sources, and use it when energy demand is higher. Thus, battery storage helps improve energy use efficiency and optimizes the utilization of available energy sources. Battery storage systems can help overcome the challenge of unpredictable fluctuations in renewable energy sources, such as solar and wind. By storing energy from these sources during overproduction, battery storage allows for more stable and reliable use of renewable energy, independent of weather conditions.

Using battery storage can reduce the need for fossil fuel power plants as a backup source. This helps reduce greenhouse gas emissions and air pollution generated by fossil fuel power plants, achieving the zero emissions target. Battery storage can reduce the operating costs of a power generation system by optimizing energy use, avoiding purchasing energy from more expensive sources, and reducing maintenance costs. Thus, battery storage can help maintain lower running costs in the long term. Battery storage systems are also adaptable to different power requirements and can be expanded as energy demand grows. This provides flexibility in meeting diverse energy needs and reduces the risks associated with unstable energy supplies.

10) Power with Carbon Capture and Storage (CCS) technology

CCS enables capturing and storing CO_2 from power generation and industrial processes. By keeping the CO_2 it produces, CCS helps reduce greenhouse gas emissions to the atmosphere, thereby supporting the goal of zero-emission. CCS allows using existing fossil fuels, such as coal or natural gas, without producing significant CO_2 emissions. In doing so, CCS maintains the potential use of existing energy resources while reducing environmental impact. As a result, CCS can help keep the stability of energy supplies from fossil fuel sources which are still the primary energy source in several countries. By maintaining the responsible use of fossil fuels through the capture and storage of CO_2, CCS helps prevent fluctuations in the energy supply that can affect economic and industrial stability.

CCS can provide new industry development opportunities, such as CO_2 capture and storage technology and related infrastructure development. This can create new jobs and stimulate economic growth. In the long term, CCS can help reduce operational costs by optimizing existing fossil fuels and reducing carbon emission offset costs. With technology development and more experience, the cost of implementing CCS will be lower.

11) Power with the use of hydrogen, ammonia, and biomass co-firing

Hydrogen, ammonia, and biomass are energy sources that can be produced cleanly and sustainably. When used as fuel in electricity generation, they make little or no greenhouse gas emissions. This supports efforts to achieve zero emissions. Combining all three in power generation can reduce dependence on limited fossil fuels and expand the diversification of energy sources. This can help maintain the stability of the energy supply and reduce the risk of fluctuations in fuel prices.

Along with technological advances and increased production scale, production costs and the use of hydrogen, ammonia, and biomass can become more efficient and affordable. In addition, the potential for utilizing waste biomass as fuel can reduce the cost of the required raw materials. SPX Flow Technology (2011) researched biomass energy production systems to do self-cleaning filters. In some cases, power with hydrogen, ammonia, and biomass co-firing can be used in existing infrastructure, such as coal-fired power plants that can be converted to take advantage of this clean fuel. This can reduce the cost of investing in new infrastructure, and using hydrogen, ammonia, and biomass as fuel can create opportunities for developing new industries and jobs in the renewable energy sector. This can drive economic growth and technological innovation.

12) Use of inter-island transmission

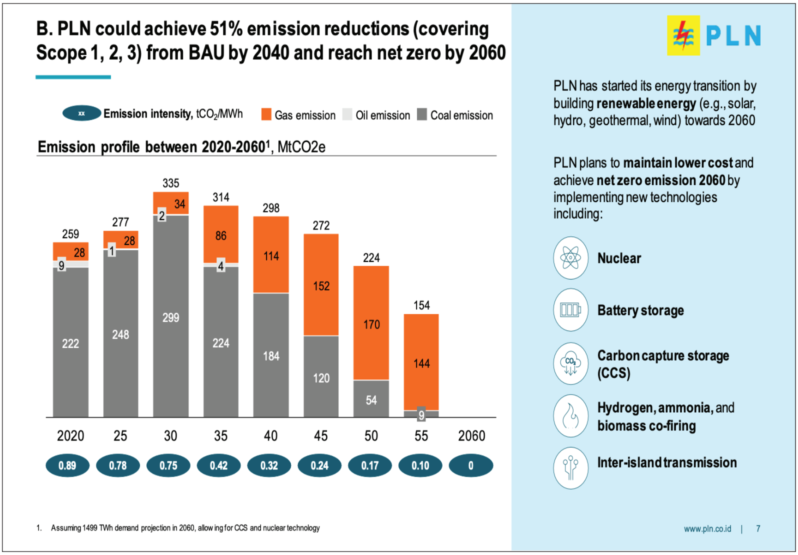
Inter-island transmission enables energy transfer from islands with abundant renewable energy potential to other islands in need. This allows the utilization of renewable energy sources, such as solar, wind, or hydro energy, which may be more abundant on some islands than others. Maximizing the utilization of renewable energy sources can achieve zero emissions. The inter-island transmission also enables energy system diversification by combining energy supplies from different sources and islands. Inter-island interconnection can reduce dependence on one energy source or island. This can help maintain the stability of the energy supply and reduce the risk of fluctuations in fuel prices.

With inter-island interconnections, power plants can be built on a larger scale. These economies of scale can result in higher efficiencies in energy production, reducing overall production costs and ultimately keeping costs lower for consumers. In some cases, inter-island transmission can take advantage of existing electrical infrastructure on the islands. This can reduce the cost of investing in new infrastructure and optimally use existing assets. Inter-island transmission can create new economic and industrial development opportunities on different islands. Developing interconnection infrastructure and using renewable energy sources can create jobs, increase investment, and promote economic growth in remote areas.

To provide a detailed example of the efforts carried out by a clean power company, PT PLN (Persero) could become an example based on the presentation made by this company at the State-Owned Enterprises (SOE) International Conference (Wahi, 2022). PLN is a state-owned electricity company in Indonesia and plays a vital role in developing renewable energy sources in the country. PLN has taken necessary steps towards achieving zero emissions by 2060 and has made significant progress through its five activities. *First*, PLN has built a large-scale renewable energy (RE) with an energy storage system on a battery. In 2021–2022, PLN will operate 900 MW of capacity from renewable energy. Furthermore, PLN has launched two new sub-holdings Generation Companies (Genco) to accelerate renewable energy development. *Second*, PLN has studied and implemented new energy (biomass, ammonia, hydrogen, co-firing, and nuclear) and new carbon capture, utilization, and storage (CCUS) technologies. Thirty-three locations have implemented co-firing of biomass, and trials of co-firing hydrogen and ammonia were carried out at PLTDG[1] Pesanggaran Bali (H_2) and PLTU[2] Gresik (ammonia). There are also five MoUs signed for developing green hydrogen and CCUS.

1 Diesel and gas power plant (*pembangkit listrik tenaga diesel dan gas*)

2 Electric steam power plant (*pembangkit listrik tenaga uap*)

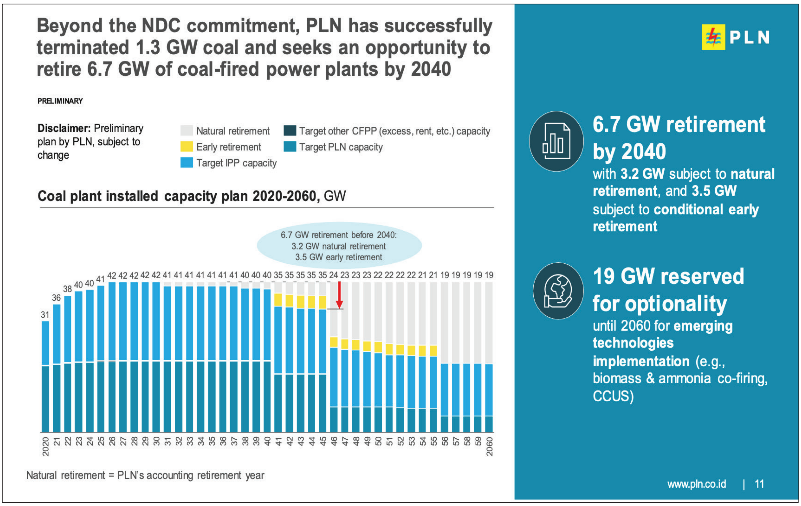


Source: PT PLN (2023)

Figure 5.1 PLN's Emission Profile 2020–2060

Figure 5.1 shows PLN's plan to achieve a 51% reduction in emissions by 2040 and aims to reach zero by 2060. The following is a graph of the emission profile between 2020 and 2060 in units of million metric tons of CO_2e. There was an increase in emissions from gas, while emissions from coal and oil decreased. Emissions from oil were initially low, followed by gas emissions, and coal emissions were highest. In units of tCO_2/MWh, the emission intensity is initially 0.89. By 2060, when the emission intensity reaches zero, there will be no more gas, oil, or coal emissions.

Third, PLN supports decarbonization in the upstream sector, such as launching a battery exchange business with BRIN, Grab, and VIAR, launched in 20 locations in 2022. PLN has also established 15 partnerships with EV4W (low speed), EV2W (high speed), and Grab to encourage the growth of the electric vehicle ecosystem. PLN successfully sold 1 TWh Renewable Energy Certificates (REC) in 2022 and established 8 MW of green energy as a service to Multi Bintang Indonesia. *Fourth*, PLN focuses on expanding interconnections and developing smart grids. Four islands have implemented smart micro grids with photovoltaic solar panels, batteries, hybrid diesel, and energy management systems in Nusa Penida, Semau, Selayar, and Bilicinge. *Fifth*, PLN has initiated efforts to reduce the use of fossil fuels through the early retirement of coal power plants and de-dieselization. The 1.3 MW coal power plant project (Jawa-3 CFPP coal-fired) has been successfully terminated. The early retirement roadmap has been arranged with the Ministry of Energy and Mineral Resources (ESDM) according to Indonesia's energy transition plan. Meanwhile, 46 MWp solar panels with the purchase of 100 MWh batteries are underway to replace diesel power plants in 36 locations.



Source: PT PLN (2023)

Figure 5.2 Coal Plant Installed Capacity Plan 2020–2060

PLN has succeeded in retiring a 1.3 GW coal power plant and is looking for opportunities to retire a 6.7 GW coal power plant by 2040. Figure 5.2 shows the planned capacity of coal power plants from

2020–2060. The number of "natural retirement" or power plants that retired in the economic year will increase from 2040–2060. PLN's capacity target will experience a significant decrease, and IPP's capacity target will slightly decrease. "Early retirement" will be implemented from 2040–2055. Coal-fired power plants will retire by 6.7 GW in 2040, with 3.2 GW for natural retirement and 3.5 GW for controlled early retirement. There is an allocation of 19 GW, which will be kept until 2060 for new technology implementation options (such as co-firing/biomass/ammonia) and CCUS. These steps demonstrate PLN's determination to become a clean company and contribute to the transition towards cleaner and more sustainable energy in Indonesia.

F. Challenges and Opportunities Ahead

Technology research and development are being carried out for power plants that use power from hydrogen, ammonia, and biomass co-firing. They are also being tested on a small scale. The Indonesian government has provided support and incentives for clean power companies investing in hydrogen, ammonia, and biomass co-firing technologies. The challenges faced include implementation costs such as infrastructure costs, initial investment, and maintenance. The infrastructure and fuel supply are only partially available in Indonesia. The availability of biomass as fuel in co-firing is also a challenge regarding a sustainable and sufficient biomass supply.

Some potential scientific gaps that may still need to be overcome on the way to a clean power company in Indonesia 2045 are the continuing research and development of clean energy technologies to increase efficiency, competitiveness, and technologies for renewable energy, such as solar, wind, hydrogen, and biomass. Then, it is necessary to develop infrastructure and an integrated grid system to overcome renewable energy production fluctuations. Policies and regulations are also needed to support and encourage clean energy development. Such policies must be consistent and sustainable to reduce barriers and encourage investment in the clean energy sector. Equally important is increasing public awareness about the importance of clean energy and changing energy consumption behavior. This target for Indonesia in 2045 has been achieved in countries implementing clean energy. Indonesia still needs time to achieve this, mainly because of its high dependence on fossil energy, such as oil and coal.

The implementation of clean energy faces several challenges that must be overcome to achieve optimal success. Some of the main challenges in implementing clean energy include limited infrastructure. Development of infrastructure that supports clean energy, such as renewable power plants and distribution networks, often requires significant investments and takes a long time. These challenges include more financial resources, complicated licensing, and technical limitations in building efficient infrastructure.

Although clean energy technologies have decreased over time, there are still significant cost differences with conventional energy sources such as coal or oil. These challenges include a more extensive return on investment and dependence on financial support and incentives from the government or other institutions. Frequent energy policy changes can create uncertainty for investors and industry players. Changes in regulations, cuts in subsidies, or inconsistent decisions can hinder clean energy development and discourage investors from making long-term investments.

More decentralized clean energy systems, such as solar panels and wind turbines spread across multiple locations, require efficient integration into the existing electricity grid. These challenges include stable power distribution management, adequate energy storage, and coordination between clean energy producers and electricity service providers. Paradigm changes and public awareness of the importance of clean energy are still a challenge. Society needs to understand better the benefits of clean energy and the negative impacts of conventional power. In addition, the community's adoption of clean energy technology also depends on economic factors, availability, and habits that have been formed. Cooperation between the government, the private sector, and the community is essential to address this challenge. Clear policy support, appropriate incentives, increased investment in technology research and development, and broader education will help accelerate clean energy implementation and achieve sustainable success.

G. Closing

In general, the progress made by clean power companies in Indonesia is developing, using clean energy technologies such as solar panels, wind turbines, and other renewable energy systems to meet the company's electricity needs. This progress has helped reduce dependence on fossil energy sources and greenhouse gas emissions. Clean power companies also encourage the use of electric vehicles or facilitate carpooling programs for employees to help reduce air pollution and the environmental impact of transportation. Some companies focus on more efficient and environmentally friendly waste management, including waste reduction, recycling, and using recycled materials. Socialization is increasingly being carried out to increase public awareness of environmental issues and the importance of adopting sustainable business practices.

The challenge that clean power companies face is limited access to clean technology, which is still expensive or challenging to implement in certain areas. Indonesia is also still dependent on fossil energy sources. Infrastructure and the costs of transitioning to renewable energy can be constraints. Another challenge is the ambiguity or changes in environmental policies and regulations in Indonesia, which can affect the company's business planning and strategy. Lastly is the lack of consumer awareness of environmentally friendly products and services.

Preparing and implementing the energy transition in Indonesia is essential for overcoming energy challenges, protecting the environment, increasing energy security, creating economic opportunities, and improving people's quality of life. This effort requires collaboration between the government, the private sector, and society to achieve a sustainable and future-oriented energy system. The energy transition in Indonesia brings long-term hopes and benefits, including energy sustainability, environmental protection, improved public health, economic opportunities, and community empowerment. With a strong awareness and commitment to adopting clean and sustainable energy sources, Indonesia can take the lead in shifting towards a more sustainable and future-looking energy system.

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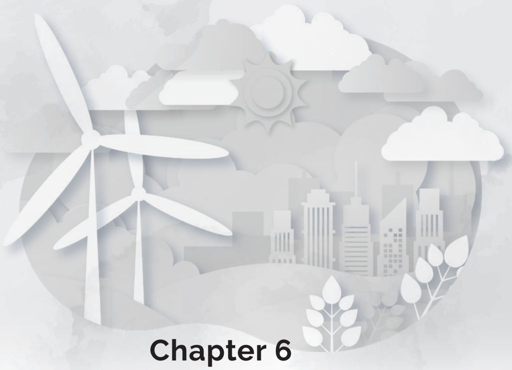

Chapter 6

Batteryless Solar Home System for Urban Area

Hasti Afianti

A. Flexy Energy for Urban Areas

The main advantages of renewable energy sources (RES) are stable energy supplies, and interruptions rarely occur. As enticing RES might be, they are still not widely accessible compared to conventional energies, especially in Indonesia. If so, what options do city residents have if they want to use RES for their homes? Fortunately, there is a well-known example of RES for urban residents. That is solar home system (SHS). Solar energy has many benefits for everyday life, one of the most profound uses is by converting sunlight into electricity.

Solar power plants (SPP) have an enormous potential in Indonesia because it is a tropical country, so that the sun always shines all year round. The main factor to support the operation of solar power plants

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is batteries. However, batteries are not cheap items so that prices and lifespan are very influential in the investment of SPP construction.

SHS is the diminutive form of SPP. SHS with an off-grid topology sometimes does not require other sources such as microgrid or wind turbin to produce electrical energy. This topology can rely on solar panels and batteries to support energy needs. Solar panels that are exposed to sunlight will produce DC electricity. This electricity will charge the battery, and then the electricity stored in the battery is then converted into AC electricity so that it can be used for household needs. On the other hand, SHS in on-grid topology can work without the use of battery. While the sun is still shining, SHS works to get electricity and if there is a shortage of electricity when the sun is not shining, electricity can be obtained from the grid, so there is no need to use batteries as a storage facility.

Therefore, this chapter proposes the use of on-grid, batteryless SHS for urban areas. One of the main reasons is due to the drawbacks from using batteries. First, hazardous materials in batteries, such as lead and magnesium, will become toxic, knows as hazardous waste (B3). This kind of waste is quite dangerous if not managed properly. Then, the lifetime of the current battery is only around 5 years, so new batteries are required for the continuity of SHS operations. Not to mention the high price of batteries, they are also quite large in dimensions so they require a large area for storage. These factors should be a concern for SHS users.

B. Electric Power System: An Overview

The electricity system is starting to change from traditional electricity to a modern one called microgrid. In traditional systems, electric power can only be distributed in one direction, starting from generation, transmission and distribution to consumers. Meanwhile, in a microgrid system, the electrical network is integrated between components connected to the system. There are distributed generators with small or large capacity renewable energy with communication devices that can regulate the flow of distributed electricity in both directions, making these systems more efficient, sustainable and highly reliable.

1. Traditional Electric Power System

In this modern era, electricity is a basic need that is essential for human life. Without electricity, humans will have difficulty carrying out their daily activities. The use of electricity in life is very broad, starting from the fields of industry, transportation, lighting, as well as a source of energy for electronic devices, such as TVs, refrigerators, air conditioners, and so on. In Indonesia, production and distribution of electrical energy is the responsibility of, State Electricity Company (PLN). The circuit of the electric power system can be seen in Figure 6.1.

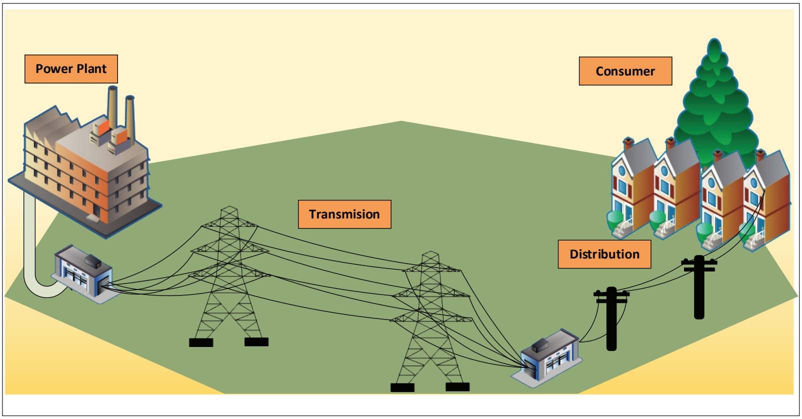
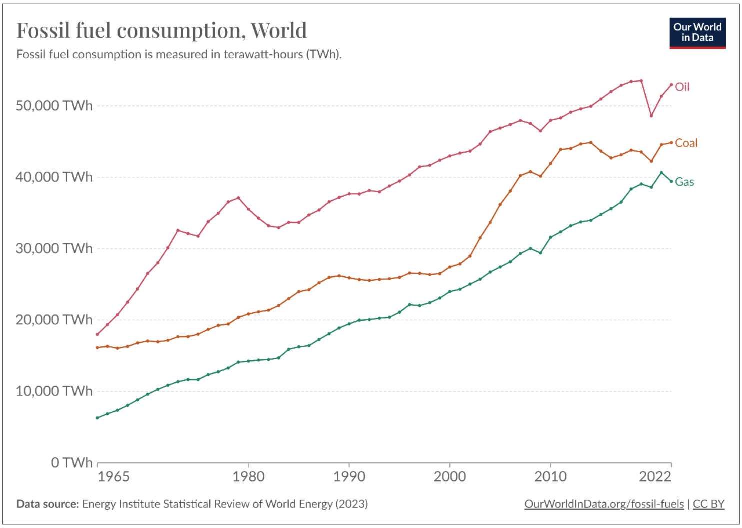


Figure 6.1 Electric Power System from the Producer (PLN) to Consumers

The following describes the main parts of the general electric power system. Electrical power system has several electrical installation circuits which are divided into four parts.

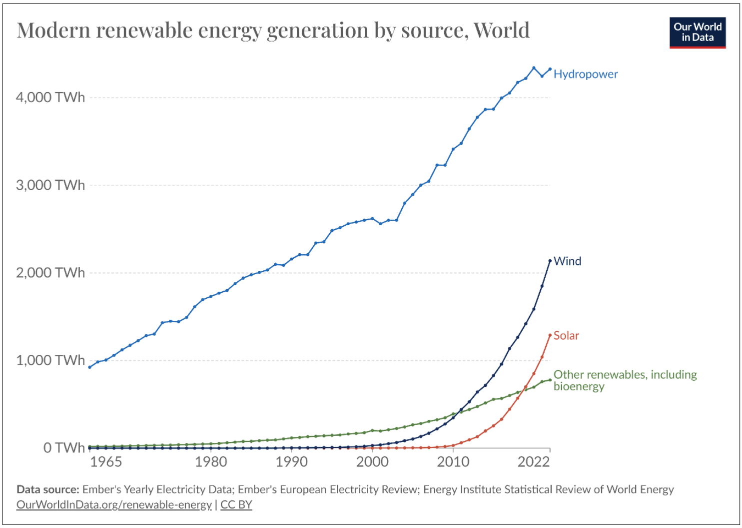
1) Power Plant

The process of converting energy into electricity occurs at the power plant. Turbines and generators are the main components in several types of power plant. A power plant (also referred to as a generating station, power station, powerhouse, or generating plant) is an industrial facility for the purpose of generating electric power. Most power plant contain one or more generators, a rotating machine that converts mechanical power into electric power. Most power plants in the world use fossil fuels, such as coal, oil, and natural gas to generate electricity as compared in in Figure 6.2 and Figure 6.3. Others use nuclear power, but there is an increasing use of cleaner renewable sources, such as solar, wind, wave, and hydro.



Source: Energy Institute Statistical Review of World Energy (2023)

Figure 6.2 Fossil Fuel Consumption



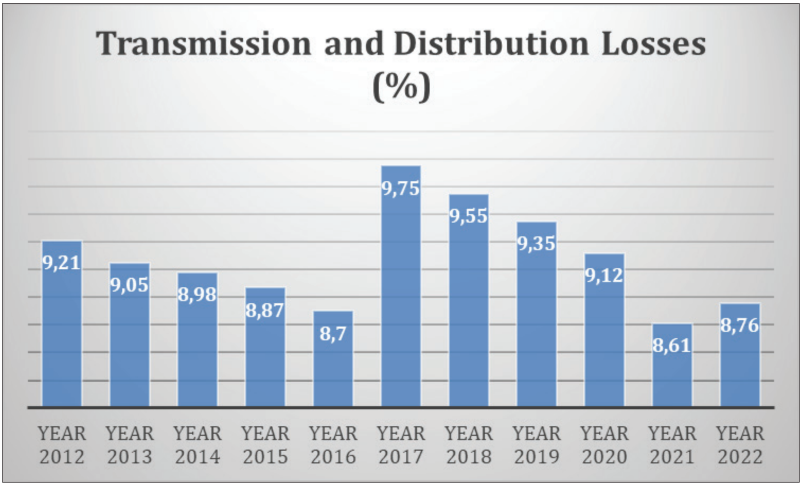
Source: Ritchie et al. (2020)

Figure 6.3 Renewable Energy Generation

2) Transmission

Transmission is a channel for distributing electrical energy, in the form of extra high voltage air duct (SUTET) and high voltage air duct (SUTT) which functions to distribute electricity from the central substation to another substation with long distances.

In high-voltage alternating-current (AC) grids, there is transmission loss of approximately 6–10% per 1,000 km. In high-voltage direct-current (DC) grids, which are subject only to ohmic losses, the loss is calculated at approximately 4% per 1,000 km. Figure 6.4 shows data from the Ministry of Energy and Mineral Resources (2022) which states the transmission and distribution of losses in Indonesian.



Source: Ministry of Energy and Mineral Resources Republic of Indonesia (2022)

Figure 6.4 Transmission and Distribution Losses in Indonesia Electricity in Percent

Power plants are usually located far from each other and connected to through a transmission system area to distribute electric power over a distributed load. This can be regarded as an interconnection system. This interconnection causes:

a) higher system reliability,
b) increment of the generating electricity efficiency,
c) simplification of generator scheduling, and
d) electrical power transmission.

Transmission of electric power is the process of distributing electricity from the generation center to the distribution channel so that later it can be distributed to consumers.

3) Distribution

This distribution system is a sub-system of electric power that deals directly with consumers. This sub-system consists of: control center or substation, substation connections, medium voltage lines or primary network (6 kilo volts and 20 kilo volts) in the form of overhead lines or underground cables, and low voltage lines or secondary network (380 volts and 220 volts). The distribution channel functions to distribute electricity from the substation to the consumer load.

4) Consumer

Consumers are users of electric power services. After going through the series of steps above, electrical energy finally reaches the house and can be used for daily needs, such as watching television, cooling the fridge, lighting the room, ironing, and so on. There are several types of consumers depending on the volt ampere (VA) used. Ordinary consumers, such as households or offices, use low voltage with power 1,300 VA, 2,200 VA, 3,500 up to. 5,500 VA, 6,600 VA and above but less than 200 kVA. Medium voltage consumers, such as malls, industries business, government with power more than 200 kVA. Meanwhile, for high voltage consumers used by industry with power more than 30,000 kVA.

2. Microgrid

It is likely that there are still many households that have difficulty obtaining electricity, especially those in remote areas, on mountain slopes, and areas that are very difficult to reach. Due to economic limitations and geographical conditions, a centralized electricity distribution system cannot cover all those areas. Economic, technological, and environmental breakthroughs have changed the pattern of electricity generation and distribution. Since the introduction of the microgrid by Lasseter (2004), the pattern of electricity generation has begun to change, from a centralized pattern to a smaller, distributed pattern. Microgrid is a distributed generation pattern that can cover a variety of energy sources, from fossil sources to renewable energy, such as wind, solar, biogas and so on (Afianti et al., 2016). Microgrid is a solution to the problem of electricity supply for remote and urban areas. This system consisting of at least one energy source connected to the load. It is capable of operating in grid-connection (on-grid) or

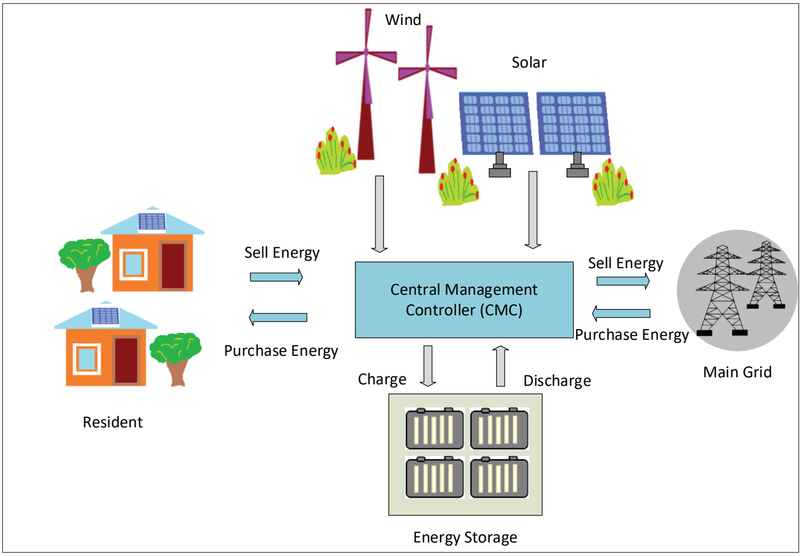


Figure 6.5 Microgrid System

stand-alone (off-grid/islanding). Based on the energy sources available from an area, microgrid can consist of several energy sources, for example solar cell with wind energy, solar cell with micro-hydro, solar cell with fuel cell, and other combinations which are formed as a distributed generator (DG). The microgrid structure consists of source, load, converter and storage system (Afianti et al., 2015). The illustration of microgrid system is illustrated in Figure 6.5.

The use of microgrids continues to grow rapidly and is an effective solution to overcome electricity shortages in various regions, especially remote areas. One of the driving factors is the decreasing investment costs for renewable energy-based generators. Solar panel and wind turbine technology have entered the mature phase this time, so it is possible to be produced in large quantities. Even though the energy source in a microgrid does not have to be renewable energy, the very rapid growth in the use of renewable energy will still be the main driving force for microgrid growth in the coming years.

C. Renewable Energy Potential in Indonesia

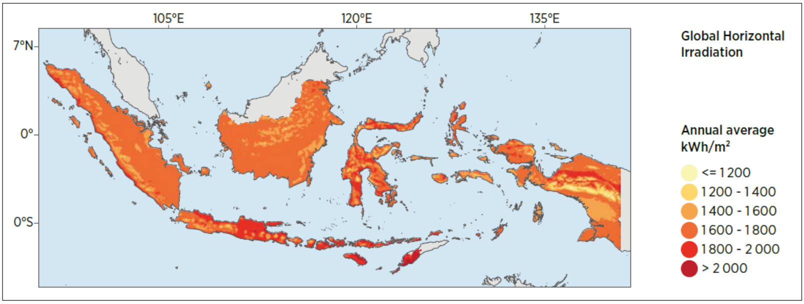
Indonesia has enormous renewable energy potential, especially in the five renewable energies: solar, water, wind, biomass, and geothermal. In 2022, International Renewable Energy Agency (IRENA) has launched a list of potential renewable energy in Indonesia in its book, Indonesia Energy Transition Outlook (IRENA, 2022). Table 6.1 shows the potential for renewable energy in Indonesia. By looking at this potential for renewable energy, the government continues to strive to accelerate the development of new renewable energy to achieve the target of 23% renewable energy in the national energy mix in 2025 as mandated by the National Energy General Plant (RUEN).

Table 6.1 Indonesia Renewable Energy Potential

No	Renewable energy	Total Potential (GW)	Total Installed Capacity 2021 (GW)
1	Biomass	43.3	19
2	Geothermal	29.5	21
3	Hydro	94.6	61
4	Ocean	17.9	0
5	Offshore Wind	589	0
6	Onshore Wind	19.6	0.2
7	Solar	2898	0.2

Source: IRENA (2022)

From Table 6.1, it is known that the largest potential for renewable energy in Indonesia is solar energy. This is understandable because Indonesia is located on the equator, which is abundant with sunlight, as evidenced in Figure 6.6. This figure shows the potential for sunlight exposure in Indonesia.



Source: IRENA (2022)

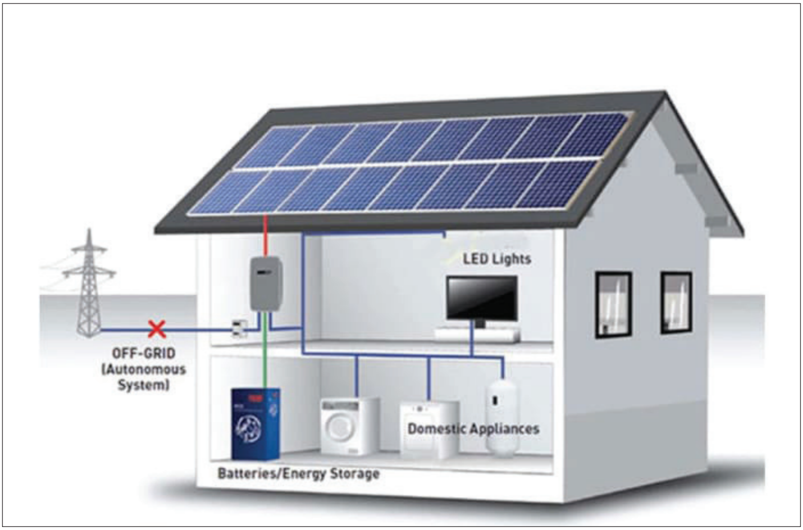
Figure 6.6 Global Horizontal Irradiation in Indonesia

With great potential in solar power, the government strongly supports the movement of people who want to use solar power as a substitute for electricity sourced from PLN electricity. This is evidenced by the issuance of Minister of Energy and Mineral Resources Regulation Number 49 of 2018 concerning use of Rooftop SHS by PLN Consumers which was revised with Minister of Energy and Mineral Resources (ESDM) Regulation Number 12 and Number 13 of 2019 concerning Power Generation Capacity for Self Interest. Substance in the latest Regulation of the Minister of Energy and Mineral Resources Number 26 of 2021 is rules for exporting and importing electricity from consumers to PLN.

From the regulations on the use and utilization of this solar energy source, of course people do not need to worry if they want to use SHS as a source of electrical energy for families at home. Besides all the regulations, the government has started using alternative energy from sunlight for public facilities. For example, using solar energy for outdoor lighting so that the budget can be more economical. Government support requires appreciation and community participation to help protect the surrounding natural environment through reducing gas emissions and global warming.

D. Solar Home System (SHS)

Referring to the microgrid concept, SHS have a topology similar to microgrid. The SHS can be connected to the grid (on-grid) or not connected to the grid (off-grid). An overview for both off-grid and on-grid SHS can be seen in Figure 6.7. SHS off grid conditions can be met if the solar panel circuit can meet all load requirements, so it does not require another electricity source, for this reason SHS does not need to be connected to the grid. If the solar panel circuit cannot meet the load requirements, it can be connected to the grid as an additional electricity source, this condition is known as the SHS on grid condition.



Source: Shopbwana (2021)

Figure 6.7 Solar Home System

1. The Main Equipment for Building SHS

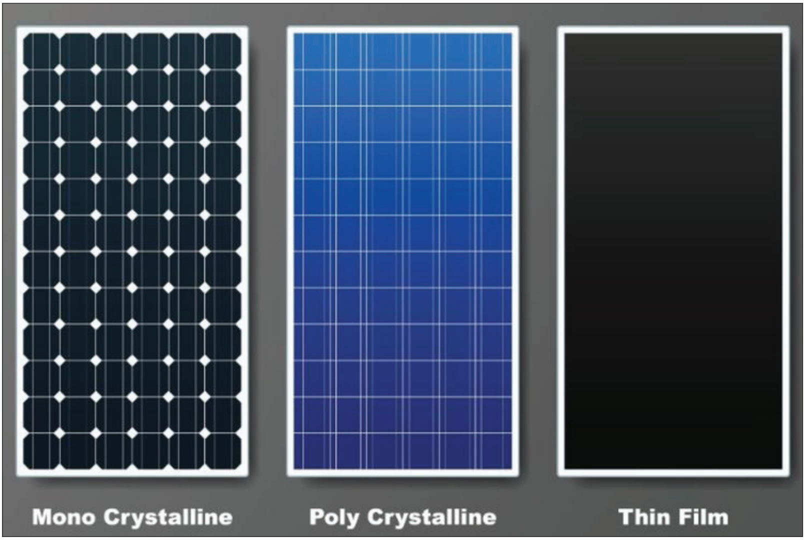
a. Photovoltaic (PV) Panel

Solar panels are devices that can convert sunlight energy into electrical energy. This equipment needs a wide place for better effect. Solar panels usually take place on the rooftop of the house or building as in Figure 6.8.

Source: Firdaus (2022)

Figure 6.8 Rooftop PV

Solar cell technology is currently very developed. Currently, there are 3 types of the most popular solar cells: monocrystalline, polycrystalline, and thin film solar cells, as show in Figure 6.9.



Source: Ruhulessin (2022)

Figure 6.9 Types of Solar Panel

1) Monocrystalline Silicon

This one is a type of solar panel that is widely used. It is made of pure silicon crystals which are thinly sliced using a machine to form a round shape. This solar cell is called "monocrystalline" because the silicon used is single crystalline silicon. The efficiency of monocrystalline silicon solar panels can reach more than 20%, much higher than other types of solar panels. This high efficiency indicates that this solar panel has the ability to convert energy from the sun into electricity so well that it only takes a smaller cross-sectional area to produce the same energy than other types of solar panels.

2) Polycrystalline Silicon

As the name implies, this type of solar panel is composed of many silicon crystal fragments, which makes the shape quite unique because there are cracks or fragments on its surface. The efficiency of polycrystalline silicon solar panels can reach 17%. Even though the efficiency is lower than monocrystalline silicon, this type of solar panel is widely used because the price is relatively more affordable.

3) Thin Film Solar Cells

This type of solar panel is called a "thin film" because it uses a fragile solar cell measuring about 10 nm, much thinner than other types of crystalline silicon which measures around 200–300 nm. A thin layer is added to glass, plastic, or metal surfaces. The advantage of this type of solar panel is that it is very light and flexible, and its performance does not decrease at high temperatures like other types. Unfortunately, energy conversion efficiency is still low, only around 10%.

Before deciding to install a solar home system, it's a good idea to know the number of solar panels needed. Larger homes require a lot of electrical energy; if a house has energy-efficient electronic equipment, it may consume significantly less power than a smaller-sized home.

Table 6.2 An Estimation of Household Electricity Needs per Day

Household Appliances	Amount	Long Usage (Hour)	Electrical Power (Watt)	Total Electricity Usage (Watt)
Lamp	10	10	10	1,000
Iron	1	1	300	300
Television	1	3	75	225
Water Pump	1	2	125	250
Rice Cooker	1	2	200	400
Refrigerator	1	24	90	2,160
Total Electricity Usage in a Day (Watt)				4,335

For example, a house uses 4,335 watts of electricity in one day, with details of usage in Table 6.2. When using solar panels, the energy produced cannot be used 100%; usually 40% of the electrical energy produced will be lost. Thus, it is necessary to add up the loss from the total power that will be used.

Total energy power = Home energy power + (40% home energy power shortage)

= 4,335 watts + (4,335 x 40%)

= 6.069 watts

The important thing to determine the amount of power of a home solar system is to know the watt peak (WP). It is the nominal value of the power in watts generated from a home solar system. Usually, the peak sun hour (PSH) in Indonesia takes 5 hours, so to calculate the amount of power from a solar home system as follows:

Power of solar home system = Total power : PSH
= 6,069 watts : 5 hours
= 1,214 WP

The house needs 1,214 WP. In the market, solar panel power variants ranging from 200 WP, 330 WP, 450 WP and 540 WP. For example, if the house owner choose 330 WP type, the number of panels needed are:

1,214 watts peak: 330 watts peak = 3,6 pieces

Hence, the number of solar panels needed is 4.

b. Inverter

The SHS system utilizes photovoltaic technology on solar panels which converts solar radiation and temperature into DC electricity. This electrical energy cannot be used directly to meet the load at home, because common electronical equipment at home, such as refrigerators, TVs, ACs, chargers, lights, water pumps, computers, and so on, use AC electricity. Thus, an inverter is needed to convert the DC from the solar panels into AC.

Source: RS Worldwide (n.d.)

Figure 6.10 Inverter

However, the are other functions of inverter on SHS except changing power flow:

1) Export Import Power

It can import excess electrical power produced by the solar panel system into the PLN network, and export electrical power from PLN to the house when the solar panels stop working at night. Additionally, some inverters will charge the batteries of on-grid solar panel systems.

2) Stabilize Voltage

The power that flows from the battery to the load must be at optimal conditions so that it can be utilized properly. The inverter has the ability to stabilize the voltage to take care of it.

The size of the solar panel is the most important factor in determining the appropriate size for the inverter. For solar inverter to convert DC electricity coming from the array, it needs to have the capacity to handle all the power that the array produces. In a 6 kilowatts system, the proposed inverter is to be around 6,000 watt, plus or minus a small percentage. Measuring the need for an inverter based on a ratio is done by comparing the inverter output, that is the

DC output power of the solar panel compared to the AC output power of the inverter. For example, if a 6 kilowatts solar panel is installed with a 6 kilowatts inverter, the ratio is 1. If the solar panel output is 6 kilowatts with a 5 kilowatts inverter, the ratio is 1,2. Selecting the best and most suitable inverter for installing solar panels has at least a ratio of 0,9 to 1,25, with the most ideal being 1. A good inverter also has a conversion efficiency rating of over 98% and has passed certification tests according to EN 50530, the European standard—the overall efficiency of grid-connected photovoltaic inverters.

c. Solar Charge Controller

The solar charge controller (SCC) is an important component in every solar panel installation. There are many variables that affect the amount of power that solar panels produce, such as sunlight levels, temperature, and the state of charge of the battery. The figure of SCC is shown in Figure 6.11.

Source: ICA Solar (2021)

Figure 6.11 Solar Charge Controller

SCC ensures the battery supplies power with a stable and optimal quality. One of the other functions of SCC is to prevent excessive battery charging by limiting the number and speed of battery charging. SCC also prevents battery to over-discharge by shutting down the system if the power stored in the battery drops below 50 percent capacity and charging the battery at the correct voltage level. This helps keep the battery life longer and healthier.

The Solar Charge Controller (SCC) also has several other important functions, such as:

1) protect the battery from overload, which can cause overheating and fire. If that happens, the SCC will break the circuit or fuse;
2) disconnect automatically the non-critical loads from the battery when the voltage drops below a predetermined threshold; and
3) backflow blocker through the battery to the solar panel.

There are two types of SCC under development today: pulse width modulation (PWM) controllers and maximum power point tracking (MPPT) controllers. PWM charge controllers are an older and cheaper technology that, unfortunately, less efficient than MPPT charge controllers (Putra et al., 2022). Both are widely used and perform similar functions to save battery life. Both PWM and MPPT have a lifespan of around 15 years, although durability varies based on use.

d. Batteries

The use of batteries is very important as solar power, which can be considered as intermittent renewable energy, is very dependable on. The function of the battery is to store solar energy captured by solar panels, then used when the solar panels cannot meet the load requirements. Solar panel battery life needs a delicate maintenance. With solar panel warranties ranging from 20–25 years, it is important to have long-lasting, reliable, and efficient batteries to match that lifespan.

There are at least three popular types of solar panel batteries available on the market:

1) **Lithium-ion battery**, which is the most common source of solar energy storage. This battery is light, compact, and have a longer life. Li-Ion battery depth of discharge (DoD), a provision that limits the maximum discharge can be applied to the battery, is also higher than others (Aji, 2021). DoD is an important parameter appearing in the context of rechargeable battery operation.
2) **Lead-acid battery**, which tends to be heavier and bulkier than Li-Ion, also with a shorter life and a lower DoD. However, lead-acid battery is some of the most affordable on the market and easy to find at any hardware store.
3) **Salt battery**, the most environmentally friendly option because it does not contain metal. It uses a saltwater electrolyte to generate charge.

The battery should be placed where the temperature is stable; not too hot or too cold. It is best to install the battery outdoors in the shade in the temperature climate. On the other hand, consider installing a solar battery in the basement or garage if the location has extreme cold or hot temperatures. Always avoid exposing the battery to extreme weather conditions.

DoD is provision that limits the maximum discharge depth can be applied to the battery. Most battery cycles are built to handle a 50% depth of discharge, but some batteries can handle up to 80% discharge. The battery cannot be continuously charged when it is less than 10% as this will prevent the battery from completing a full cycle and cause damage.

Charging the solar panel battery with a high voltage exceeding a predetermined limit can cause the battery to experience overcharging. In the long term, this can cause gas to escape from the battery and reduce the amount of battery fluid. Discharging current is a current of energy release that has quite a significant impact on the condition of the battery. If the battery is continuously supplied with high currents, it will decrease the usable capacity of the battery.

2. The Requirements Installing SHS for Housing in Indonesia

This is accordance with the requirements for installing SHS regulated in Permen ESDM No.49 of 2018 which was revised with Permen ESDM No. 12 and No. 13 of 2019.

1) **Use a postpaid meter**. For houses/buildings that will use SHS, PLN provides a condition, using a postpaid meter. Thus, customers who are currently using a prepaid meter must submit a change first, so that the electricity fee payment mechanism changes to a postpaid system.
2) **Use export-import (EXIM) kWh meter**. Apart from using a postpaid meter, the next SHS installation requirement requires customers to use an EXIM kWh meter. The function of the EXIM kWh meter is to record the amount of power used from PLN, and the amount of power exported to the PLN network.
3) **Maximum capacity of SHS that can be installed**. The next condition for installing SHS is that customers can only install SHS with a maximum power of 100% electricity connected to PLN. This means that for PLN customers who have homes with electricity needs of 1300 kWh, the maximum installed SHS capacity is 1300 kWh.

If the electricity generated during the day is greater than needed, then the electricity will automatically enter the PLN network and become "savings". Electrical power savings recorded on the EXIM meter will reduce the amount of electricity used by customers. The amount of electricity exported to PLN is multiplied by 65% of the electricity exported based on EXIM meter records. For SHS with a power of more than 500 kVA, it must be equipped with a Certificate of Operational Worthiness (SLO). The SLO is an absolute requirement for SHS installation for customers who plan to install SHS with a power of more than 500 kVA. This SLO permit and certification is only issued by the Technical Inspection Institute (LIT).

E. Batteryless Solar Home System: On-Grid SHS

On-grid SHS is the right solution for homeowners, as well as commercial and industrial buildings, who want to utilize solar energy without being dependent on battery. On-grid SHS that are supported by good grid conditions certainly make it very possible not to use batteries in this system, because if the solar panels with their intermittent nature cannot support the power requirements, they will be immediately covered by the grid.

The hassle of choosing, controlling, and maintaining battery that is a hassle in one factor why more people are adamant on using off-grid SHS. Plus, the price of batteries are not cheap, and the impact of battery waste on the environment becomes additional consideration.

SHS without battery offers a number of attractive advantages for its users. Here are some of the main advantages of this technology:

1) Environmentally Friendly and Sustainable

The use of SHS without batteries allows the conversion of solar energy into electricity without the emission of greenhouse gases or other environmental pollution. It is an environmentally friendly and sustainable solution, helping to reduce carbon footprint and supporting efforts to fight climate change.

2) Save Operational Costs

Once the solar panels are installed, the operating costs are almost zero. Solar energy as an unlimited natural resource allows the use of low-cost and stable electrical energy in the long term.

3) Energy Independence

With battery-free solar panels, homes or businesses can achieve partial or complete energy independence. They are no longer dependent on the public electricity network, especially in areas that are difficult to reach by traditional electricity infrastructure.

4) Easy Installation and Maintenance

Solar panels without batteries tend to be easier and cheaper to install than systems with batteries. Routine maintenance usually only requires cleaning the panel surface from dust and dirt so that its performance is optimal.

5) Requires No Battery Storage Space

By removing the storage battery from the system, battery-less solar panels free up significant physical space. This is particularly useful in areas where space is limited for installation.

6) Long Life and Long Lasting

Solar panels without batteries have a long service life and are durable. Usually, they come with warranties that last for decades, thus providing long-term investment security.

Before deciding to use SHS without a battery, there are several things to consider, such as:

1) Device power consumption: make sure the device to be connected has low power consumption in order to function properly.
2) Solar panel position: make sure the solar panel is placed in a position exposed to direct sunlight to produce maximum power.
3) Device protection: make sure the device connected to the solar panel is protected by a stable voltage to avoid the risk of damage to the SHS device.

1. Grid Tie Inverter (GTI)

The main component of SHS is the solar panel which is a series of photovoltaic solar modules. Solar panels must be coupled with an inverter. The inverter is essential because it converts the direct current (DC) input voltage generated by the solar module into an alternating current (AC) output voltage. It must be done because electrical energy is distributed only in the AC system. Loads such as household appliances also consume AC power. What the inverter will do is synchronize the voltage and frequency from the network with the inverter so that it can join the PLN network. Thus, an inverter is always put side-by-side with the panel.

SHS that is connected to the PLN network requires an inverter with high efficiency. The inverter must produce a current and voltage that has a frequency with a pure sinusoidal waveform to be in line with the current and voltage of the grid; for this, a GTI is needed. The GTI device contains a special circuit that can match the voltage, frequency, and phase of the grid. GTI are specifically designed for SHS that are connected to the electricity grid which do not require batteries.

Solar panels have a weakness in that their output power depends on sunlight conditions. When the sunlight is dim, the output current of the solar module can drop drastically, so that the output power of the solar panel is not optimal. If the load still requires a large amount of power while the output power from the solar panels is not sufficient, GTI will add to the shortage of power from the grid. One of the uses of GTI is to suck or draw electricity from the grid. This inverter will take electricity from PLN if the supply from the solar panels is unable to meet all load power requirements. Especially at night, the inverter will completely draw power from the PLN. An explanation of this power distribution is illustrated in Figure 6.12.

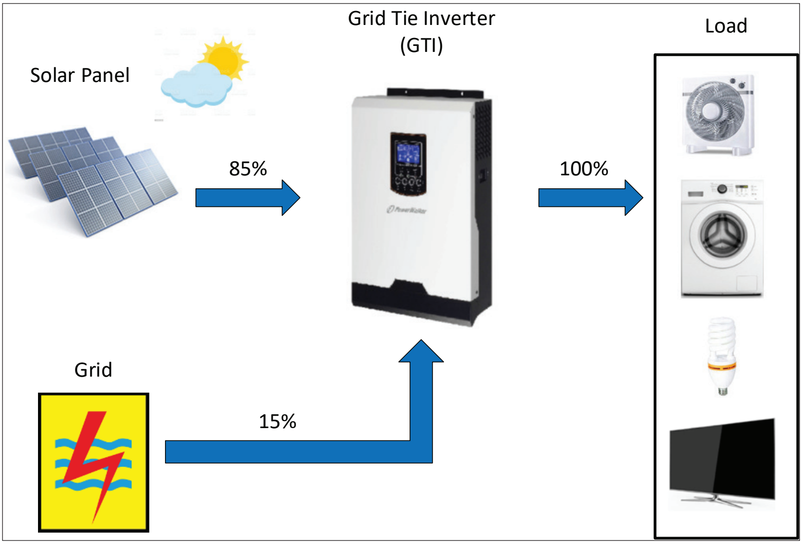


Figure 6.12 GTI drawing electricity from PLN when power is insufficient.

Meanwhile, when the sun is shining brightly, the solar panels will produce enough power to exceed the load power requirements. At this time, the GTI will feed excess power to the PLN grid, selling electricity to PLN. An explanation of this power distribution is illustrated in Figure 6.13.

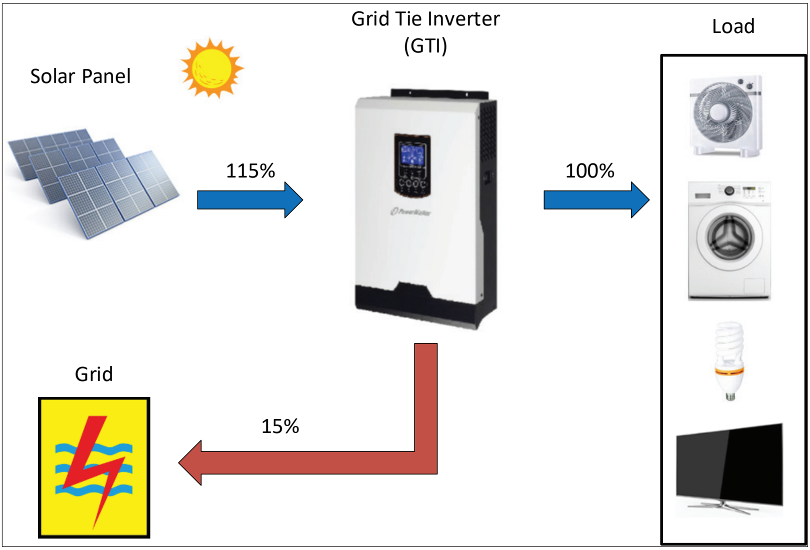
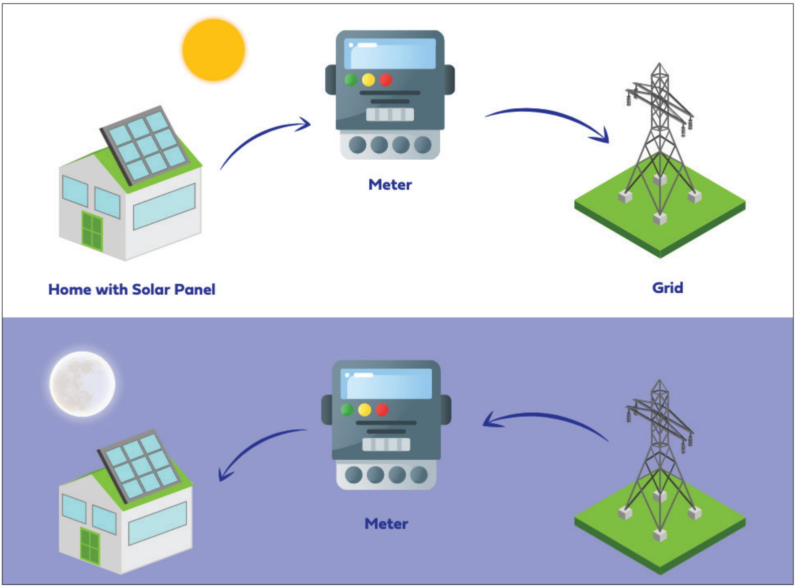


Figure 6.13 GTI selling electricity from PLN when power is excessive.

One important thing to know about the GTI is that it is designed to disconnect from the power grid if it goes down. The disconnection of the grid is done because it prevents the electricity generated by solar panels from entering the grid because it can endanger workers who carry out repairs on the grid.

2. Net Metering

Net metering is a system intended for PLN consumers who have SHS to send electricity produced by SHS to the PLN network. Net metering aims to provide opportunities for communities and companies that use solar panels to make maximum use of the electricity produced, especially when it is not in use. Net metering has the same meaning as EXIM metering, illustrated in Figure 6.14. It measures the electricity sent by SHS to PLN and the electricity taken by SHS from PLN. When monthly electricity bill is due, PLN will calculate how much electricity is sent to PLN and how much is taken from the PLN network. The results of this measurement will be used to determine the electricity bill each month. This program makes solar panel owners more economical because they are connected to the grid and do not require batteries.



Source: Solar Square (2022)

Figure 6.14 Net Metering Works

To get net metering, owners must have an SHS that has a certificate of operation. The SHS that is built must meet certain installation requirements and specified components. Considering that the electricity from SHS will be connected to the PLN network, SHS components such as inverters, SCC, solar panels, cabling, and all kinds of SHS electricity networks must really be recognized as feasible.

The usage of net metering refers to regulations:

1) PLN Board of Directors Regulation 0733.K/DIR/2013, 19 November 2013 concerning the Utilization of Electrical Energy from Photovoltaics by Customers.

2) SPLN D5.005-1:2015, 13 May 2016, Technical Requirements for Interconnection of Photovoltaic (PV) Systems on low voltage distribution networks with a capacity of up to 30 kWp.

With this reference, net metering can only be applied by customers who meet certain requirements.

F. Closing

Based on geographical conditions, which make our country get abundant sunlight throughout the year, SHS is expected to be one of the most potential alternative energies for Indonesian to participate in reducing carbon dioxide emissions and improving the environment, in addition to saving expenses for electricity needs. However, it is necessary to know and take into account the adverse effects of the B3 waste produced by off-grid SHS, so that the goal of reducing carbon dioxide emissions and maintaining a better environment can be optimally achieved. The use of batteryless SHS in an on-grid system is proven to be applicable in places where there is an electricity network. With this system, even though there is still waste produced, it can save up to 30% of the investment spent on making SHS.

Furthermore, batteryless SHS can be potentially used outside the on-grid conditions. By combining SHS with other energy such as diesel generators, it can also be applied to off-grid conditions. Research using the HOMER software has been carried out to compare the combination of batteryless SHS and diesel generators with stand-alone diesel generators. The results of this study prove that technically, the combined operation of batteryless SHS and diesel generators is cheaper than stand-alone diesel generators by up to 43% (Tsuanyo, et al., 2015). Evaluation of the environment also proves that the use of SHS is very environmentally friendly compared to diesel generators (Azoumah, 2011).

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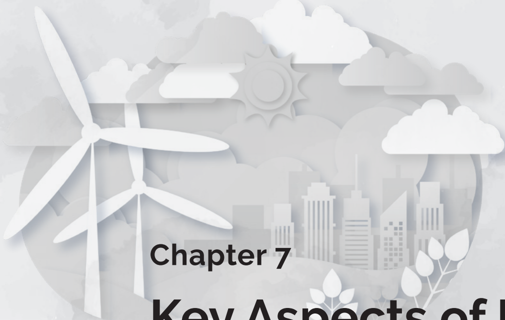
Part 3
Environmental and Green Leadership



Chapter 7

Key Aspects of Environmental Assessment for Indonesia Energy Transition

Af'ida Khofsoh, Inggit Kresna Maharsih, & Muhammad Hamzah Solim

A. Indonesia's green energy potential

Indonesia, nestled within the Pacific Ring of Fire, boasts a unique advantage for renewable energy. With over a hundred active volcanoes, the nation holds vast geothermal potential. The government is committed to harnessing this power, aiming for 10,000 MW from geothermal sources by 2030 (Nasruddin et al., 2016; Darma et al., 2021). This journey towards green energy encompasses solar panels capturing the equatorial sun, turning organic matter into bioenergy, and harnessing the power of wind and marine sources. Indonesia's dedication to clean energy doesn't just reduce emissions; it seeks to create an environmentally sustainable future. This chapter unfolds as a compelling account of environmental stewardship, from the towering volcanoes to the sun-kissed shores.

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Khofsoh, A., Maharsih, I. K., & Solim. M. H. (2023). Key aspects of environmental assessment for Indonesia energy transition. In A. Kiswantono & R. M. Shoedarto (Eds.), *Indonesia's energy transition preparedness framework towards 2045* (209–275). BRIN Publishing. DOI: 10.55981/brin.892.c817, E-ISBN: 978-623-8372-41-6

As the world's fourth most populous country, Indonesia is experiencing rapid economic growth (Hill, 2018). However, this growth has come at a cost to the environment, resulting in increasing pollution levels, deforestation, and biodiversity loss. As a signatory to the Paris Agreement (2015), Indonesia is committed to reducing greenhouse gas (GHG) emissions and transitioning to a low-carbon economy (Joung et al., 2020; Murdiyarso et al., 2010; Carlson et al., 2012). In recent years, one approach to achieving this transition has been the adoption of energy transition technologies, such as renewable energy sources like wind, solar, nuclear, hydropower, electrochemical fuel, biomass, and geothermal energy (Halkos & Gkampoura, 2020; Gallo et al., 2016; Irwandi et al., 2021; Nasruddin et al., 2016; Darma et al., 2021; Qi & Zhang, 2017; Sivalingam et al., 2022). These technologies offer a multitude of environmental benefits. By harnessing nature's power, wind and solar energy produce electricity without greenhouse gas emissions, actively contributing to the fight against climate change. Nuclear energy provides a low-GHG, dependable energy source. Meanwhile, hydropower generates electricity while maintaining water resources and facilitating irrigation. Electrochemical processes, including hydrogen fuel cells, showcase environmental friendliness and have the potential to significantly impact power generation. Biomass serves as an eco-friendly heat and electricity source. Lastly, geothermal energy taps into the Earth's heat, providing a sustainable and reliable power source. However, the adoption of new energy transition technologies can also have potential environmental impacts (Röck et al., 2020). To ensure that any proposed changes in energy sources or technologies are made in an environmentally sustainable manner that minimizes negative effects on the natural and human environment, an environmental assessment (EA) is necessary (Boehlert & Gill, 2010).

EA will evaluate the potential environmental impacts of the proposed energy transition technology in Indonesia, identify any possible adverse environmental effects, and suggest ways to mitigate those effects (Röck et al., 2020; Carlson et al., 2012). EA will also consider the potential impact on human health, cultural resources, and the economy. The goal of EA is to provide decision-makers in

Indonesia with the information they need to make informed decisions about adopting new energy transition technology and to ensure that any proposed changes are environmentally sustainable.

B. Environmental Assessment (EA)

The purpose of EA is to guarantee that any suggested modifications are ecologically sustainable and to give Indonesian decision-makers the knowledge they require to make well-informed decisions about implementing new energy transition technologies. These explanations will serve as the foundation for our explanation of the five key elements in this section, which include a description of the project, baseline environmental conditions, environmental impact analysis, mitigation measures, and alternative analysis of the environmental impacts in this section.

1. Project Description of The Proposed Energy Transition Technology

Two aspects are related to this project description, including descriptions and objectives of the proposed energy transition technology. Firstly, the proposed energy transition technology refers to the shift from traditional energy sources such as fossil fuels to renewable energy sources such as solar, wind, and hydropower (Hosseini, 2020; Gallo et al., 2016), as seen in Figure 7.1. In addition, biomass and geothermal energy also can develop significantly in Indonesia (Darma et al., 2021; Nasruddin et al., 2016). Transitioning to renewable energy sources is critical to achieve low-carbon economy and reducing GHG emissions (Joung et al., 2020; Murdiyarso et al., 2010). By using clean energy technologies like solar, wind, hydropower, biomass, and geothermal energy we can generate electricity without emitting greenhouse gases contributing to climate change. This shift away from traditional fossil fuels is necessary to mitigate the negative impacts of climate change and move towards a more sustainable energy future (Joung et al., 2020; Gallo et al., 2016). Secondly, the objectives of the proposed energy transition technology are to achieve a low-carbon economy, reduce dependency on fossil fuels, increase energy security, and improve public health, economic and environmental benefits, as illustrated in Figure 7.2.

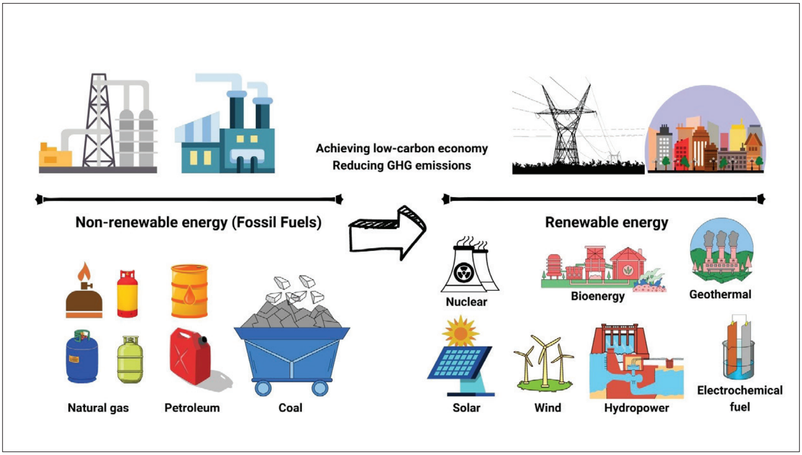
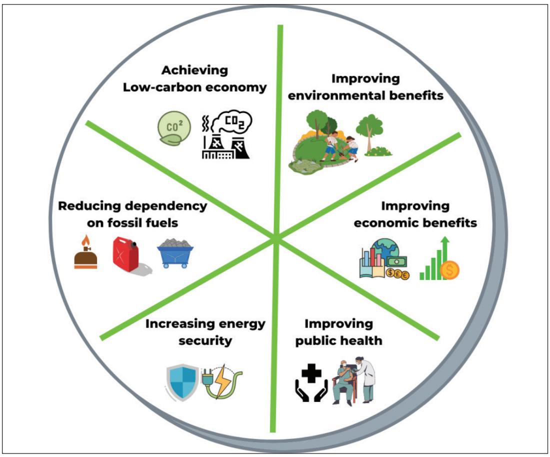


Figure 7.1 A Proposed Energy Transition Technology Shifts from Traditional (Non-Renewable) Energy Sources such as Fossil Fuels to Renewable Energy Sources



Source: adapted from Gallo et al. (2016) and Gielen et al. (2019)

Figure 7.2 Benefits Aimed by the Proposed Energy Transition Technology

a. Achieving a low-carbon economy

Transitioning to renewable energy sources is important in mitigating climate change and creating a more sustainable future. Burning fossil fuels, such as coal, petroleum or oil (Carlson et al., 2012), and natural gas, releases greenhouse gases into the atmosphere, contributing to global warming and climate change (Murdiyarso et al., 2010). On the other hand, renewable energy sources emit less greenhouse gases and can generate electricity without relying on finite resources. By shifting towards renewable energy sources like solar, wind, hydropower, biomass, and geothermal energy, we can significantly reduce our GHG emissions and move towards a low-carbon economy (Gielen et al., 2019; Joung et al., 2020). This transition also have additional benefits, such as reducing dependence on fossil fuels and improving public health (Halkos & Gkampoura, 2020). Renewable energy can be produced domestically, reducing dependence on foreign oil and gas, and mitigating geopolitical risks, as well as reducing air and water pollution, plus improving public health.

b. Reducing dependency on fossil fuels

Fossil fuels, such as coal, oil, and gas, are finite resources that are being depleted over time. These resources have become scarcer, their price has become more volatile, and even their availability has become more uncertain. In addition, the production and consumption of fossil fuels can have geopolitical risks, including conflicts over resources and potential disruptions in global energy supplies. Transitioning to renewable energy sources like solar, wind, hydropower, biomass, and geothermal energy can help reduce our reliance on finite fossil fuels and create a more stable and resilient energy system (Gallo et al., 2016). Renewable energy sources can provide a consistent and reliable source of energy that is not subject to price volatility or geopolitical risks. It can help promote energy security and stability, reducing our dependence on foreign oil and other fossil fuel resources (Hosseini, 2020). Furthermore, renewable energy sources have the potential to provide cost savings over time as the technology and infrastructure for generating renewable energy become more efficient and cost-effective (Gallo et al., 2016). This can create opportunities for economic growth and job creation, further promoting energy security and resilience.

c. Increasing energy security

When a country relies heavily on imported fossil fuels to meet its energy needs, its energy security is vulnerable to disruptions in supply. This can happen due to various factors such as price volatility, geopolitical conflicts, or natural disasters (Abdullah et al., 2020). As a result, the country's energy supply can become unstable, and the economy can suffer. By transitioning to renewable energy sources, a country can decrease its dependence on imported fossil fuels, which makes the energy system more resilient to supply disruptions. Renewable energy resources, such as solar, wind, hydropower, biomass, and geothermal energy, are domestic resources that can be harnessed within a country's borders. Thus, a country can secure its energy supply and insulate its economy from fluctuations in global energy markets and geopolitical risks.

Additionally, renewable energy systems can be more decentralized than fossil fuel-based ones. For example, a country can install solar panels on rooftops or wind turbines in remote areas, reducing the need for centralized power generation and transmission infrastructure (Gallo et al., 2016). This can further increase energy security by reducing the vulnerability of the energy system to large-scale disruptions, such as cyber-attacks or physical attacks on critical infrastructure (Abdullah et al., 2020).

Renewable energy sector also has the potential to create new jobs and stimulate economic growth. This is because renewable energy technologies often require more labor-intensive manufacturing, installation, and maintenance processes than traditional fossil fuel-based technologies (Gallo et al., 2016). Even according to the International Renewable Energy Agency (IRENA), the renewable energy sector employed around 11 million people globally in 2018, and this number is expected to continue growing in the coming years (Hosseini, 2020) (Halkos & Gkampoura, 2020).

d. Improved public health

Adopting renewable energy sources can lead to improved public health by reducing air and water pollution, which can negatively impact human health. Fossil fuel combustion is a significant source of air pollution, and the transition to renewable energy sources can reduce harmful emissions of particulate matter, nitrogen oxides (Murdiyarso et al., 2010), and sulfur dioxide, among others. In addition, producing renewable energy does not require water for cooling, which can reduce water pollution caused by thermal pollution from power plants (Gallo et al., 2016). By improving air and water quality, adopting renewable energy can help reduce the incidence of respiratory and cardiovascular diseases and improve overall public health (Halkos & Gkampoura, 2020).

e. Economic benefits

Economic benefits can appear if renewable energy technologies are conducted thoroughly (Halkos & Gkampoura, 2020). This includes creating new jobs in the renewable energy sector, such as designing, constructing, and maintaining wind turbines and solar panels (Gallo et al., 2016). In addition, as renewable energy sources become more widely used, the cost of production is expected to decrease, making it more competitive with traditional fossil fuels, and it can stimulate economic growth in related industries, such as manufacturing solar panels and wind turbines and developing energy storage systems (Gallo et al., 2016). Regarding this, deploying renewable energy technologies can lead to new investment opportunities and attract foreign investment to the country. Moreover, adopting renewable energy sources can also provide cost savings to consumers. This is because renewable energy sources have lower operating costs compared to traditional fossil fuel sources, which often require expensive fuel procurement and transportation costs (Halkos & Gkampoura, 2020).

f. Environmental benefits

Like economic benefits, if the proposed energy transition technology is successfully achieved, it can lead to several environmental benefits. These include:

1) Improved air quality (Gallo et al., 2016). Traditional fossil fuel sources such as coal and oil can produce air pollutants, negatively impacting human health and the environment. By using renewable energy sources, the amount of air pollutants can be reduced, improving air quality.
2) Reduced water usage (Gallo et al., 2016). Some traditional energy sources, such as coal and natural gas, require significant amounts of water for their production processes. By transitioning to renewable energy sources, the amount of water required for energy production can be reduced.
3) Reduced land or forest degradation (Murdiyarso et al., 2010). Renewable energy sources such as solar and wind power do not require large amounts of land for their production, unlike traditional energy sources such as coal mining or oil drilling. The amount of land degradation can be reduced by reducing the need for these practices.
4) Increased biodiversity (Murdiyarso et al., 2010). Traditional energy sources such as oil drilling or coal mining can significantly impact wildlife habitats and local ecosystems (Choi et al., 2020; Carlson et al., 2012). By using renewable energy sources, the impact on biodiversity can be reduced, allowing ecosystems to recover and thrive.
5) Reduced waste generation. Some traditional energy sources can produce significant amounts of waste, such as coal ash or nuclear waste (Denholm et al., 2012; Li et al., 2022). Using renewable energy sources can reduce the amount of waste generated, leading to less pollution and environmental degradation.

2. Baseline Environmental Conditions

Before implementing any energy transition technology, it is crucial to understand the existing environmental conditions in the project area, such as air quality, water and soil conditions, sensitive ecosystems or habitats, and potential risks to human health and safety (Kokkinos et al., 2020). In Indonesia, the use of fossil fuels for electricity generation has resulted in air pollution, posing risks to both human health and the environment (Halkos & Gkampoura, 2020). In addition, the transition to renewable energy sources can also have potential environmental impacts, and it is important to identify the potentially affected environmental resources in the project area. These may include air, water, land, and biodiversity. For instance, constructing a wind farm may impact bird populations or other wildlife habitats (Choi et al., 2020; Halkos & Gkampoura, 2020). Similarly, hydroelectric dam construction may affect fish populations and alter river ecosystems.

If the transition to renewable energy will be adopted in Indonesia, some aspects should be considered. Here are some potential environmental impacts associated with the transition to renewable energy sources.

a. Air pollution

Renewable energy sources such as wind and solar power generate electricity without emitting greenhouse gases. However, producing and disposing of the equipment and materials required to harness these energy sources can result in air pollution. For example, producing solar panels requires mining and processing raw materials such as silicon, which can generate air pollutants. The transportation and installation of solar panels also require energy and may result in emissions from vehicles and machinery (Gallo et al., 2016; Li et al., 2022). Similarly, producing wind turbines requires mining and processing metals and other materials, which can generate air pollutants. Yet, it is important to note that the amount of pollution generated during the production and disposal of renewable energy technologies is generally much lower than that associated with traditional fossil fuels. Additionally, measures can be taken to minimize the environmental impact of clean energy technologies, such as using renewable energy sources to produce equipment and improve manufacturing process efficiency.

b. Water resources

Deploying hydroelectric dams (Gallo et al., 2016) can positively and negatively impact water resources and river ecosystems, as shown in Figure 7.3. While hydropower is a renewable energy source that does not emit greenhouse gases, constructing large dams can alter river flows, sediment transport, and fish populations. These alterations can have significant ecological impacts, such as changes in the water temperature, dissolved oxygen levels, and nutrient concentrations in downstream water bodies. Dams can also create barriers that prevent fish from reaching their natural spawning grounds, affecting both the fish population and the ecosystems that rely on them (Boehlert & Gill, 2010).

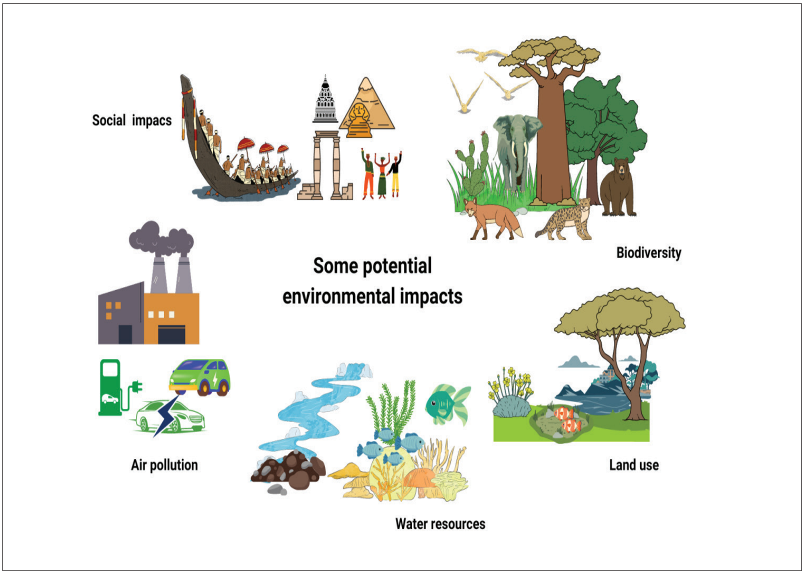


Figure 7.3 Some Potential Environmental Impacts Associated with the Transition to Renewable Energy Sources

In addition to ecological impacts, the construction of hydroelectric dams can have social and economic impacts on local communities that rely on rivers for their livelihoods. The construction of large dams can lead to the displacement of local communities, loss of cultural heritage, and changes in traditional practices and livelihoods. Therefore, it is essential to carefully assess and evaluate the potential impacts associated with hydroelectric dams and implement appropriate mitigation measures to reduce negative impacts on water resources and river ecosystems (Gallo et al., 2016). One illustration is a hydropower plant in Asahan River near Toba Lake. It has substantial adverse effects on the river and its nearby environment. The reduced water flow—a consequence of hydropower operations—not only hampers aluminum production at PT Inalum but also threatens the overall production levels. This decline in water flow can disrupt the river's natural habitat and biodiversity, leading to ecological imbalances. Furthermore, the control of water discharge for hydropower can disrupt downstream communities and ecosystems by altering water levels and flow patterns (Irwandi et al., 2021).

c. Land use

The deployment of renewable energy technologies may require significant amounts of land, which can impact wildlife habitats and sensitive ecosystems (Boehlert & Gill, 2010; Choi et al., 2020). For example, the construction of large solar arrays or wind farms may require the clearing of land, which can lead to habitat loss and fragmentation for wildlife. Similarly, the construction of hydroelectric dams can alter river ecosystems and affect fish populations. To mitigate these impacts, it is crucial to consider the siting of renewable energy projects carefully and to conduct thorough environmental assessments to identify potential impacts on wildlife and ecosystems. Additionally, measures such as habitat restoration and wildlife corridors can be implemented to minimize the impact on local ecosystems (Boehlert & Gill, 2010; Choi et al., 2020). Indonesia, for example, has experienced significant land-use changes, including deforestation and habitat loss in Sumatra and Java islands as caused by installation of renewable energy (Farobie & Hartulistiyoso, 2022).

d. Biodiversity

Renewable energy technologies are generally less harmful to the environment than traditional fossil fuel sources, but they still impact biodiversity in some cases. For example, constructing wind turbines or solar panel installations may require clearing large areas of land, which can significantly impact local ecosystems. In addition, the noise generated by wind turbines may also affect the behavior and communication of certain wildlife species (Choi et al., 2020); for example, it can influence fish populations and other aquatic species (Boehlert & Gill, 2010). Therefore, it is essential to carefully assess and manage the potential impacts of renewable energy projects on biodiversity, particularly in areas with sensitive ecosystems or endangered species.

According to Farobie and Hartulistiyoso (2022), deforestation caused by installation of renewable energy plants in Indonesia has led to significant biodiversity loss, particularly in relation to its rainforests and wildlife. Furthermore, the expansion of palm oil plantations, concentrated in Sumatra and Java Islands, has resulted in habitat destruction and the displacement of indigenous species, contributing to biodiversity loss. The conversion of natural ecosystems to palm oil plantations has also led to the loss of critical habitats for endangered species such as orangutans, tigers, and elephants.

e. Social impacts

Deploying renewable energy sources may also have social impacts, including effects on local communities and cultural heritage. For example, building large-scale solar or wind farms may require land acquisition, displacing local communities or impacting traditional land use practices (Gallo et al., 2016). The construction of renewable energy infrastructure may also impact cultural heritage (Frantál & Kunc, 2011) sites or other areas of cultural significance to local communities. It is important to consider and address these potential social impacts in EA process and involve local communities in decision-making

(Boehlert & Gill, 2010). It is also important to identify and address potential environmental issues or concerns through a comprehensive EA process. By doing so, we can ensure that the transition to renewable energy sources is sustainable and beneficial for the environment and society.

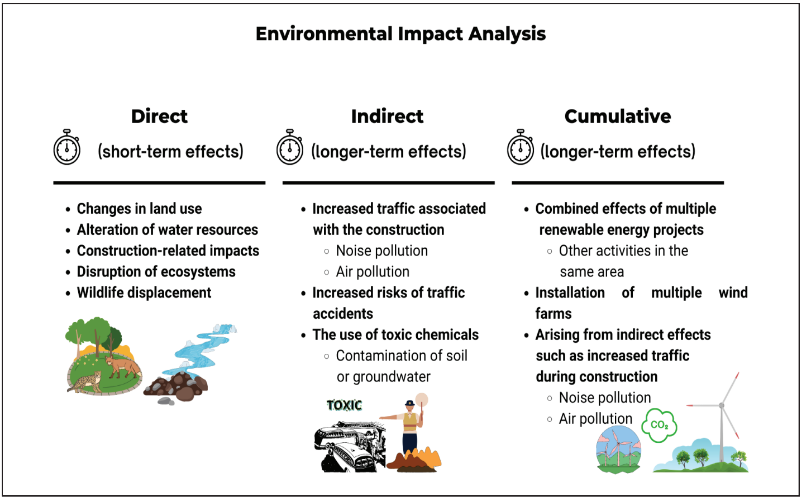
Although Indonesia has a significant potential for renewable energy sources, there is still a significant challenge—the lack of openness in coordinating a just energy transition. Future policies and plans must be centered on the needs of the community, especially the marginalized, to guarantee that they gain from a just energy transition. Stakeholder involvement in policy discussions is essential to developing comprehensive, inclusive solutions and ensuring universal participation (Alam et al., in press).

3. Environmental Impact Analysis

Figure 7.4 gives a brief summary of the identification and evaluation of potential environmental impacts associated with the proposed energy transition technology. We know that assessing the potential environmental impacts associated with Indonesia's proposed energy transition technology is helpful. It is crucial to identify and evaluate the potential environmental impacts. It includes thoroughly analyzing the potential effects on air quality, water quality, land use, biodiversity, and social impacts. This assessment should consider both renewable energy technology's construction and operation phases. Thus, the potential impacts associated with the technology can be divided into direct, indirect, and cumulative effects (Boehlert & Gill, 2010; Hosseini, 2020; Halkos & Gkampoura, 2020).

a. Direct impacts

Direct impacts are the immediate and observable effects of the proposed energy transition technology. These impacts can occur during the project's construction, operation, and decommissioning phases. These are some examples of direct impacts associated with the deployment of renewable energy technologies.



Source: Adapted **from Boehlert dan Gill (2010) Hosseini (2020); Halkos dan Gkampoura (2020)**

Figure 7.4 The environmental impacts analysis associated with the proposed energy transition technology can be divided into direct, indirect, and cumulative effects.

1) **Changes in land use**. Deploying renewable energy technologies, such as solar panels and wind turbines, may require large land areas for installation. This can result in the displacement of wildlife habitats (Choi et al., 2020), the loss of agricultural land, and changes in the natural landscape (Carlson et al., 2012).
2) **Alteration of water resources**. Hydropower plants may alter river flows, which can impact fish populations, and change water quality, resulting in the loss of aquatic habitats (Gallo et al., 2016; Boehlert & Gill, 2010).
3) **Construction-related impacts**. The construction of renewable energy facilities can result in soil erosion, noise pollution, and the destruction of vegetation (Murdiyarso et al., 2010).
4) **Disruption of ecosystems**. Construction activities related to renewable energy projects can lead to the fragmentation of

ecosystems, reducing their resilience and causing a decline in biodiversity (Boehlert & Gill, 2010).

5) **Wildlife displacement** (Halkos & Gkampoura, 2020). The installation of wind turbines or solar panels can cause the displacement of wildlife, particularly birds and bats, which can collide with these structures (Choi et al., 2020).

b. Indirect impacts

Indirect impacts are often more challenging to identify and quantify than direct impacts (Boehlert & Gill, 2010). They may arise from secondary or tertiary effects of the proposed energy transition technology and may also be cumulative in nature. For example, the increased traffic associated with constructing a wind farm may cause indirect impacts such as noise and air pollution from vehicle emissions. It may also lead to increased risks of traffic accidents. The use of toxic chemicals in the production of renewable energy technologies may lead to indirect impacts such as contamination of soil or groundwater (Boehlert & Gill, 2010)

Indirect impacts can also have longer-term effects, such as changes in land use patterns or alterations to local economies. For example, constructing a large wind farm in a rural area may lead to indirect impacts, such as changes in land use from agricultural to energy production, which may have long-term economic impacts on the local community.

c. Cumulative impacts

Cumulative impacts refer to the combined effect of multiple activities or stressors over time, which may have an effect greater than the sum of individual impacts (Boehlert & Gill, 2010). In the case of energy transition technology, the cumulative impacts may arise from the combined effects of multiple renewable energy projects and other activities in the same area. For instance, installing multiple wind farms in a particular region may impact local wildlife habitats, biodiversity, and the visual landscape. Over time, the cumulative effects of multiple wind farms may lead to significant changes in the local ecosystem.

Similarly, the cumulative impact of various renewable energy projects, along with other land use activities such as urban development, agriculture, and forestry, can have cumulative impacts on local water resources, including rivers and groundwater (Carlson et al., 2012). Cumulative impacts may also arise from indirect effects such as increased traffic during the construction phase of renewable energy projects. The increased traffic may cause air and noise pollution and damage to local infrastructure, leading to additional environmental impacts (Röck et al., 2020).

Nowadays, these impacts (direct, indirect, and cumulative) can influence human health, cultural resources, and economy. The proposed energy transition technology may impact human health, particularly during the construction and operation phases. For example, the production of renewable energy technologies may involve the use of hazardous chemical compounds (Gallo et al., 2016) that can have negative impacts on human health (Kokkinos et al., 2020) (Halkos & Gkampoura, 2020). Additionally, noise pollution and other disruptions during the construction and operation of renewable energy facilities may impact nearby communities. For cultural resources, the deployment of renewable energy technologies may impact cultural resources, including historic or culturally significant sites. For example, constructing a wind farm in an area with significant cultural heritage may impact traditional practices or sacred sites (Frantál & Kunc, 2011). An EA should evaluate the potential impacts on human health and cultural resources, including both direct and indirect impacts, and develop strategies to mitigate any potential negative effects (Boehlert & Gill, 2010).

Furthermore, the transition to renewable energy sources may have significant economic impacts, both positive and negative. On one hand, developing a domestic renewable energy industry can create new jobs and stimulate economic growth. On the other hand, shifting away from traditional energy sources may impact existing industries, such as coal mining. Therefore, an EA should evaluate the potential economic impacts of the proposed energy transition technology, including both direct and indirect effects, and develop strategies to maximize positive economic outcomes while minimizing negative impacts (Boehlert & Gill, 2010).

Overall, a comprehensive EA should evaluate the potential impacts of the proposed energy transition technology on human health, cultural resources, and the economy and develop strategies to mitigate any potential negative effects while maximizing positive outcomes. Regarding this, we can ensure that Indonesia's transition to renewable energy sources is sustainable and beneficial for all. Measuring these impacts typically involves a combination of quantitative and qualitative methods.

For direct environmental impacts, quantitative data collection is crucial. This entails gathering data on parameters such as pollutant levels (e.g., greenhouse gas emissions), resource consumption (e.g., water usage), or changes in specific environmental indicators (e.g., deforestation rates). Additionally, direct emissions of pollutants can be measured through air quality monitoring stations, and site-specific studies, including surveys and sampling, can evaluate the immediate effects of a project on the environment. Such assessments may encompass changes in local biodiversity or alterations in soil quality resulting from construction activities (Boehlert & Gill, 2010; Choi et al., 2020; Carlson et al., 2012).

When it comes to indirect environmental impacts, the life cycle assessment (LCA) methodology stands out as an effective approach. LCA evaluates the environmental impact of a product or process throughout its entire life cycle, encompassing stages from raw material extraction to production, use, and disposal. Furthermore, input-output analysis proves valuable in assessing the indirect effects of changes within one sector of the economy on other sectors. This method estimates how alterations in production, such as increased demand for specific resources, indirectly influence environmental pressures (Boehlert & Gill, 2010). Regarding cumulative environmental impacts, these arise from the combined effects of multiple projects, activities, or stressors on the environment. Assessing cumulative impacts typically involves gathering data on both direct and indirect impacts while considering temporal and spatial factors. Geographic Information Systems (GIS) and spatial analysis techniques are employed to map and analyze the spatial distribution of various environmental stressors, aiding in the identification of areas where cumulative impacts are most pronounced. Additionally, long-term monitoring is crucial since cumulative impacts often develop over extended periods. Regular and ongoing monitoring of environmental parameters is essential for identifying trends and accurately assessing cumulative effects (Boehlert & Gill, 2010; Gallo et al., 2016; Kokkinos et al., 2020; Halkos & Gkampoura, 2020).

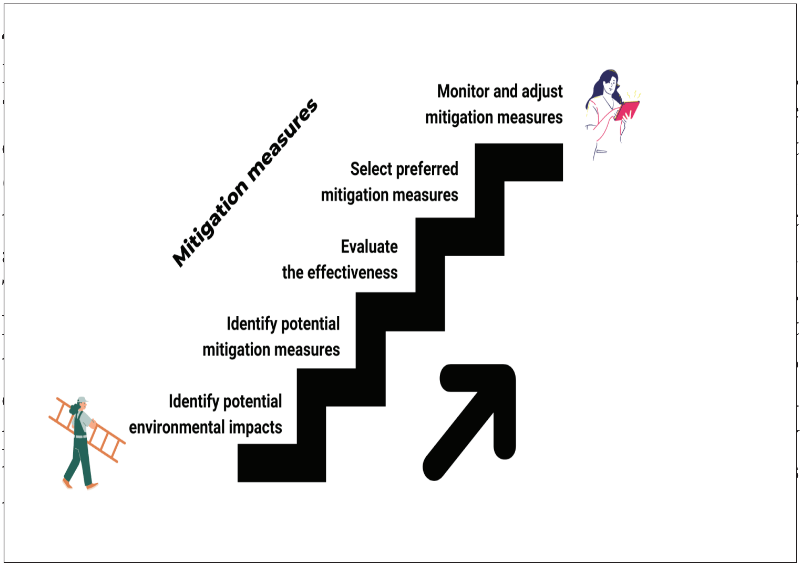


Figure 7.5 Five Steps to Identify and Assess How to Reduce or Avoid Potential Environmental Impacts Associated with the Proposed Energy Transition Technology

a. Identify potential environmental impacts

EA should consider the potential environmental impacts associated with the proposed energy transition technology (Boehlert & Gill, 2010; Gallo et al., 2016). The assessment should identify the likely sources of impact, the nature and extent of the impacts, and the likelihood and severity of each impact. This can be done through various methods, such as data collection (e.q. air quality assessment take several months to a year; biodiversity monitoring for several years or even decades related to the populations and ecosystem dinamics), modeling (e.q. use of Gaussian dispersion models to estimate the ground-level concentrations of pollutants; LCA to assesses a product or process throughout its entire life cycle, from raw material extraction to production; hydrological models to predict changes in water flow and quality in response to various factors, such as land use changes or the construction of dams), and stakeholder consultation (e.q. involvement, purposes, timing and feedback incorporations) (Boehlert & Gill, 2010; Gallo et al., 2016; Gielen et al. 2019; Kokkinos et al., 2020; Halkos & Gkampoura, 2020).). The assessment should also identify any uncertainties or data gaps that may exist and include a plan for addressing these uncertainties through further data collection or analysis. By identifying potential environmental impacts and uncertainties early in the planning process, decision makers can better understand the trade-offs associated with different energy transition technology options and make informed decisions that balance environmental, social, and economic considerations.

b. Identify potential mitigation measures

Mitigation measures are actions or strategies taken to reduce or avoid the potential environmental impacts of a proposed energy transition technology. These measures should be designed to minimize the negative effects of the technology while maximizing its benefits. There are several types of mitigation measures, including engineering controls, management practices (Carlson et al., 2012), and monitoring programs. Engineering controls involve implementing pollution control technologies, such as air filters or wastewater treatment systems, to minimize the release of pollutants into the environment. For example, a wind farm may use advanced turbine technology to reduce bird and bat mortality (Choi et al., 2020; Halkos & Gkampoura, 2020).

Management practices may include construction phasing plans, habitat restoration programs, or waste reduction strategies. For example, a solar energy project may implement a waste reduction program to reduce the environmental impact of the manufacturing process for solar panels (Denholm et al., 2012; Li et al., 2022). In addition, monitoring programs involve ongoing observation and evaluation of the potential environmental impacts of the proposed energy transition technology (Gallo et al., 2016). This may include monitoring wildlife populations, air and water quality, and other environmental indicators to ensure that mitigation measures are effective and can identify any new impacts that may arise.

c. Evaluate the effectiveness of mitigation measures

When evaluating potential mitigation measures, it is important to consider their effectiveness in reducing or avoiding environmental impacts and their feasibility and practicality. Factors such as cost, technical feasibility, and public acceptance should also be taken into account (Kokkinos et al., 2018). The most effective mitigation measures are those that can be implemented in a timely and cost-effective manner, with minimal disruption to the project schedule and surrounding communities (Murdiyarso et al., 2010; Gallo et al., 2016).

Additionally, it is important to consider the potential unintended consequences of mitigation measures. For example, a mitigation measure aimed at reducing noise pollution from wind turbines may inadvertently harm local bird populations (Boehlert & Gill, 2010; Choi et al., 2020). Thus, it is important to carefully evaluate potential trade-offs and unintended consequences to ensure that they do not result in additional negative impacts.

d. Select preferred mitigation measures

Once the potential mitigation measures have been evaluated, the most effective and feasible measures should be selected for implementation. The selection of the best mitigation measures should be based on a careful evaluation of the potential impacts, the effectiveness of each measure, and the feasibility of implementing the measure, using impact and/or cost-effectiveness, and environmental standards and regulations (Murdiyarso et al., 2010; Carlson et al., 2012; Gallo et al., 2016).

For instance, a company may use cost-effectiveness standards to expand an existing solar power plant to meet increased electricity demand. During the environmental impact assessment, it is identified that the expansion will result in a small but measurable increase in water usage, primarily for cleaning the solar panels. Consideration of mitigation measures is the implementation of conventional water sources and rainwater harvesting, then evaluation for cost (installation, maintenance, and water usage fees), environmental impact, and long-term viability. Thus, based on the evaluation, the company decided to implement rainwater harvesting for the solar panel cleaning process. While it involves higher initial costs, it is more cost-effective and environmentally sustainable in the long run (Desideri et al., 2013; Tasnim et al., 2022; Li et al., 2022; Whitehead et al., 2013; Valatin et al., 2022).

However, complete elimination of impacts may not be feasible, in which case the best mitigation measure is one that minimizes the potential environmental impact to the greatest extent possible. In some cases, multiple mitigation measures may need to be implemented to achieve the desired level of impact reduction. The feasibility of implementing a mitigation measure should also be considered (Murdiyarso et al., 2010). Factors that may affect feasibility include technical constraints, such as the availability of pollution control technologies or the practicality of implementing a particular construction phasing plan, and economic constraints, such as the cost of implementing a particular mitigation measure (Röck et al., 2020).

e. Monitor and adjust mitigation measures

Monitoring and evaluation are crucial steps to ensure that the mitigation measures implemented effectively reduce or avoid potential environmental impacts (Boehlert & Gill, 2010; Murdiyarso et al., 2010). The monitoring process should be designed to detect environmental changes that may be related to the proposed energy transition technology (Gallo et al., 2016). It should also be able to identify any unintended consequences of mitigation measures and provide feedback on the effectiveness of these measures. Based on the monitoring results, necessary adjustments or modifications to the mitigation measures should be made (Boehlert & Gill, 2010). These adjustments may include changes to the design or implementation of the measures or additional measures to address any unanticipated impacts. This iterative process of monitoring and adjusting mitigation measures is important to ensure that the proposed energy transition technology is environmentally responsible (Murdiyarso et al., 2010; Gallo et al., 2016).

Then, the effectiveness of a mitigation measure refers to its ability to reduce or avoid potential environmental impacts. The effectiveness of a measure may depend on a range of factors, including the nature and severity of the effects, the scale of the project, and the available technology or management practices (Murdiyarso et al., 2010; Boehlert & Gill, 2010). The effectiveness of each mitigation measure should be evaluated based on these factors to determine whether the measure is likely to be effective in reducing or avoiding potential environmental impacts. In addition, the measure refers to its practicality or likelihood of implementation (Boehlert & Gill, 2010) that may depend on factors such as the availability of technology or equipment, the availability of skilled labour, and the regulatory or legal framework (Boehlert & Gill, 2010). The feasibility of each mitigation measure should be evaluated based on these factors to determine whether the measure is feasible to implement (Murdiyarso et al., 2010). Even, the potential costs of a mitigation measure refer to the financial or economic costs associated with implementing the measure. The costs of a mitigation measure may include capital costs (equipment or infrastructure), operating costs (maintenance or personnel), and compliance costs (regulatory or legal requirements) (Murdiyarso et al., 2010; Boehlert & Gill, 2010; Gallo et al., 2016). The potential costs of each mitigation measure should be evaluated to determine whether the measure is likely to be cost-effective and whether the benefits of the measure outweigh its costs.

Thus, a follow-up environmental monitoring and assessment program should be established to evaluate potential residual impacts after implementing mitigation measures in Indonesia. The program should aim to exercise these points.

1) **Monitor the effectiveness of the implemented mitigation measures**. Environmental monitoring, such as pollution levels, resource consumption, biodiversity, soil and water quality, should ensure that the implemented mitigation measures work as intended and effectively reduce or avoid potential environmental impacts (Boehlert & Gill, 2010; Gallo et al., 2016). The monitoring program should identify gaps or deficiencies in the mitigation measures and recommend corrective actions where necessary.
2) **Identify any residual impacts that cannot be fully mitigated**. Despite the implementation of mitigation measures, residual impacts may still remain, including habitat fragmentation, noise pollution, air and water quality, land use changes, and visual impact (Gielen et al., 2019; Boehlert & Gill, 2010). The environmental monitoring program should identify residual impacts and assess their significance and likelihood. This assessment can be used to inform further mitigation measures or management strategies to address the residual impacts (Murdiyarso et al., 2010).
3) **Evaluate the effectiveness of the environmental assessment process** (Boehlert & Gill, 2010). The environmental monitoring program should also evaluate the effectiveness of the environmental assessment process itself. This evaluation can be used to identify any improvements or modifications that could be made to the assessment process to address potential impacts better and improve the overall environmental sustainability of the energy transition technology (Gallo et al., 2016; Carlson et al., 2012).

Additionally, mitigation measures will be considered to minimize the environmental impacts. The following are some measures for the renewable and non-renewable energy.

a. Fossil fuel

Until 2030, fossil energy will continue to dominate primary energy used for power plants in Indonesia, with an expected share of about 78.32% (Nasruddin et al., 2016). However, coal, gas, and oil reserves are expected to run out in 75 years, 33 years, and 12 years, respectively, based on the ratio of production reserves. Moreover, fossil-based energy resources have polluted the environment badly. Continuing to rely on those traditional fossil fuel sources would negatively impact the environment, including air pollution, water pollution, and GHG emissions contributing to climate change (Murdiyarso et al., 2010).

Thus, while fossil fuels have been the primary energy source for many years, their use has come at a significant cost to the environment. Burning fossil fuels, such as coal and oil, releases large amounts of carbon dioxide and other greenhouse gases into the atmosphere, contributing to global climate change (Murdiyarso et al., 2010). In addition, the extraction and transportation of fossil fuels can have negative impacts on local ecosystems, including air and water pollution, habitat destruction, and the release of toxic substances into the environment. These negative impacts can severely affect human health, wildlife, and the environment (Boehlert & Gill, 2010; Kokkinos et al., 2020).

There have been reported cases that fossil fuels lead to negative impacts in some areas of Indonesia, including in East Kalimantan, Mahakam Delta, and Jakarta. Coal mining in East Kalimantan is known for its extensive coal mining activities (Dama et al., 2021). The province has experienced significant environmental degradation due to open-pit mining practices, deforestation, and habitat destruction. These activities have led to soil erosion, water pollution, and air quality deterioration. The Tenggarong District in East Kalimantan, for instance, has faced severe land subsidence due to mining, affecting local communities and ecosystems (Zulkarnain, 2014). Then, some areas of Mahakam River's delta are used for oil and gas extraction (Vo et al., 2000; Chaineau et al., 2010). This has resulted in land subsidence and coastal erosion, endangering local communities. Additionally, the disposal of waste materials from these activities into rivers has led to water pollution and damaged aquatic ecosystems. Meanwhile, air pollution in Jakarta is not directly related to fossil fuel extraction; this city struggles with severe air pollution largely driven by vehicle emissions. The high dependence on fossil fuel-powered vehicles, particularly in traffic-congested areas, has led to poor air quality and public health concerns (Santosa et al., 2008; Lestari et al., 2022).

Cannon and Kiang, (2022) suggests that the private sector, particularly coal mining companies, should be willing to overcome the negative impacts of their activities. This includes reducing environmental damage and addressing issues such as heavy metal pollution and soil and water quality degradation. Additionally, mining companies are urged to create "green" areas or rehabilitate the environment after coal mining activities. Moreover, the regional government is encouraged to listen to various aspirations and demands from civil society related to environmental sustainability. This implies that the private sector should take into account the concerns and feedback of local communities and environmental organizations (Cannon & Kiang, 2022).

In other study, Denholm et al. (2012) discusses the need for mitigations in the context of radiation exposure on wildlife. For example, radon gas, which is a naturally occurring radioactive gas, might leak during the extraction of fossil fuels, particularly natural gas that found in geological formations. Radon, along with other naturally occurring radioactive materials (NORM), can migrate with natural gas to the surface (Nabhani et al. 2016; Rozell et al. 2012). That is why it is important to study the long-term effects of radiation and the presence of adaptation in wildlife populations. The authors suggest that further funding is required to advance our understanding of radiation responses at the systemic, organismic, cellular, and molecular levels.

They also highlight the need for experimental models that closely mimic the natural environment to elucidate the molecular mechanisms of radiation responses and establish biomarkers of ecosystems impacted by radiation.

b. Nuclear Energy

While nuclear energy produces low-to-none GHG emissions, it does generate radioactive waste, which poses risks to human health and the environment (Fragkos et al., 2021). Additionally, nuclear power plants can significantly impact local ecosystems, particularly during construction, such as destroying habitats and displacing wildlife (Choi et al., 2020; Denholm et al., 2012). In the event of a nuclear accident, such as the tragedy of Chernobyl in Ukraine and Fukushima in Japan, the environmental impacts can be devastating and long-lasting (Fragkos et al., 2021; Cannon & Kiang, 2022). The Chernobyl nuclear disaster in 1986 is one of the most infamous examples of the environmental impact of a nuclear power plant. The explosion and subsequent release of radioactive materials had devastating effects on the surrounding ecosystem, leading to the evacuation of nearby towns, long-term health issues, and the establishment of an exclusion zone due to high radiation levels (Cannon & Kiang, 2022). Similarly, The Fukushima Daiichi nuclear disaster in 2011 was caused by a massive earthquake and tsunami that led to the release of radioactive materials from the Fukushima Daiichi Nuclear Power Plant. The disaster resulted in the evacuation of residents, contaminated soil and water, and significant health and environmental concerns (Cannon & Kiang, 2022).

In addition, the disposal of 1.3 million tonnes of radioactively polluted water from the Fukushima nuclear plant has been started in 2023, according to the announcement made by the Japanese Prime Minister Fumio Kishida. Japan asserts that the water's radioactive level is much lower than the limit established by numerous international organisations (Mada, 2023). However, it is important to note that it has already contaminated water in the sea. Therefore, nuclear energy must be carefully evaluated and regulated to minimize environmental impacts and protect public health and safety.

Furthermore, in Indonesia the potential location for conducting a nuclear energy program in Indonesia is the Bangka-Belitung Province. A feasibility study program was conducted by Batan in Bangka-Belitung from 2011 to 2013, and a local survey was carried out in parallel to compare the perceptions of the local community with the national perception of the nuclear power plant (NPP) program. However, the support for nuclear power plants in Bangka-Belitung was lower compared to the national level, possibly due to concerns related to the Fukushima accident and political campaigns during the governor election. The not-in-my-back-yard (NIMBY) phenomenon was observed in Bangka-Belitung, where the perception of the NPP program was seen as solely a Batan program rather than a government decision based on public needs (Wisnubroto et al., 2019).

Denholm et al. (2012) suggests that one possible solution to mitigate the challenges of deploying conventional nuclear power in a grid with large amounts of wind and solar energy is to couple thermal energy storage to nuclear power plants. This would enable the reactor to remain at nearly constant output, while cycling the electrical generator in response to the variability of the net load. By doing so, the nuclear power plant can provide load following and cycling duty while operating at a constant reactor power output. However, Denholm notes that these reactor designs are in the early stages of development, and new work will need to be developed to analyze one or more possible coupled nuclear/thermal energy storage (TES) systems, in order to validate the potential of this concept and to concretely identify the key challenges and future research needs for such a system.

In Indonesia, Wisnubroto et al. (2019) presents the results of a public opinion survey on nuclear energy in Indonesia conducted from 2010 to 2016, showing that the level of public support for the nuclear power plant program is above 70% nationally in the last three years. The survey also highlights the importance of government transparency in explaining the benefits and risks of the program. Mitigation measures for nuclear energy in Indonesia include the integration of NPP promotion activities between the central and regional governments, incentives for infrastructure development at prospective NPP sites to minimize the NIMBY phenomenon, and providing explanations to the public about the benefits and risks of the nuclear power plant program. Additionally, targeting women in promotional activities is expected to have a significant impact on the high level of public support for the NPP program. Then, concerns about the potential for accidents due to earthquakes and tsunamis, as well as the low safety culture and readiness of Indonesian human resources, suggest that strict safety measures and improvements in safety culture and human resources are necessary. The cost of building nuclear power plants and the possibility of corruption are also factors to consider, suggesting the need for cost-effective alternatives and measures to prevent corruption in mega nuclear power plant projects. The use of TV for socialization and radio for promotion is effective in disseminating information about nuclear energy to the public.

c. Hydropower

Hydropower is a renewable energy source that can provide clean electricity without producing GHG emissions. However, constructing large dams for hydropower generation can significantly impact local ecosystems. Dams can alter river flow, affecting water quality and availability for downstream communities and ecosystems. Dams can also significantly impact fish populations, blocking migratory routes and disrupting spawning habitats. In addition, the construction of large dams can lead to the displacement of communities and the destruction of cultural resources. Therefore, the environmental impacts of hydropower must be carefully evaluated, and measures must be taken to minimize these impacts (Halkos & Gkampoura, 2020; Boehlert & Gill, 2010; Gallo et al., 2016).

As an illustration, the operation of hydropower plant in Asahan River, near Toba Lake, has a significant negative impact on the river and its surrounding ecosystem. The decrease in water flow caused by hydropower operations affects the rate of aluminum production at PT Inalum, leading to a reduction in overall production. This decrease in water flow can also have adverse effects on the natural habitat and biodiversity of the river, disrupting the ecosystem balance. Additionally, the regulation of water discharge for hydropower generation can further impact the water levels and flow patterns in the river, potentially affecting downstream communities and ecosystems (Irwandi et al., 2021).

Irwandi et al. (2021) mentions that excessive use of water for hydropower and deforestation have contributed to the decrease in Lake Toba's water level. However, it does not provide specific information on how to mitigate the impact of hydropower on the lake's water level. It suggests that a more comprehensive and in-depth study is needed to confirm the causes of the decline and fluctuation of the lake's water level. Therefore, it does not provide any specific mitigation measures for hydropower.

d. Wind Energy

Wind energy is a renewable source that generates electricity without producing GHG emissions (Gallo et al., 2016). However, the construction and operation of wind turbines can have negative impacts on local wildlife populations, particularly birds and bats (Choi et al., 2020; Halkos & Gkampoura, 2020). Wind turbines can pose a collision risk for birds and bats, and studies have shown that some species are more vulnerable than others (Boehlert & Gill, 2010). In addition, constructing wind turbines may lead to habitat loss or fragmentation, indirectly impacting wildlife populations. Wind turbines can also generate noise pollution, negatively impacting wildlife and humans. For instance, the Altamont Pass Wind Farm in California, USA, has been known for its significant impact on bat, birds, and raptors populations (Kuvlesky et al., 2007). Particularly for species that are rare or endangered, collision mortality, displacement, and habitat loss have the potential to have an impact at the population level. Bird and bat mortality due to wind turbines is an ongoing concern, and researchers are actively studying the issue to better understand the scale of the problem and implement mitigation measures. Bird mortality rates at wind farms can vary from almost negligible to substantial, depending on factors like location, bird species, and turbine design, with some studies reporting rates ranging from 1 to 10 birds per turbine per year. Similarly, bat mortality varies significantly, with reports of fatalities ranging from a few to over 40 bats per turbine per year (Kuvlesky et al., 2007). These numbers are averages and can vary widely among different wind farms, influenced by factors such as local ecology and conservation efforts. Mitigation efforts include technologies like avian radar and acoustic deterrents, strategic wind farm placement away from critical habitats, and ongoing research to refine our understanding of and solutions for this issue. Therefore, the environmental impacts of wind energy must be carefully evaluated, and measures must be taken to minimize these impacts. This can include sitting wind turbines away from sensitive wildlife areas, using technology to minimize collision risks, and reducing noise pollution through sound barriers or quieter turbines (Boehlert & Gill, 2010; Gallo et al., 2016).

Choi et al. (2020) discusses several mitigations related to bird and bat mortality at wind turbines in the Northeastern United States. Here are the key mitigations mentioned in the document.

1) **Curtailment Regimes**. The paper mentions the use of curtailment regimes, which involve purposeful reduction in turbine operation and electricity generation. These regimes can help mitigate bird and bat mortality by reducing the risk of collisions with wind turbines.
2) **Turbine Design and Size**. The study found that bird and bat fall distances increase with turbine size. This suggests that larger turbines may pose a greater collision risk. Therefore, considering turbine design and size can be a mitigation strategy to minimize bird and bat mortality.
3) **Species-specific Considerations**. The document highlights the importance of considering species-specific characteristics when assessing bird mortality at wind turbines. Different bird species

may exhibit varying collision risks, and understanding these differences can inform mitigation efforts.

4) **Improved Monitoring and Reporting**. The authors emphasize the need for improved monitoring and reporting of bird and bat mortality at wind facilities. This can provide valuable data for assessing the effectiveness of mitigation measures and identifying areas for improvement.

However, it is important to note that the document does not provide an exhaustive list of all possible mitigations, but rather focuses on specific findings and considerations related to bird and bat mortality at wind turbines in the Northeastern United States.

e. Solar Energy

The production of solar panels or photovoltaic can create some waste and pollution. Still, the overall environmental impacts are generally lower than those associated with traditional fossil fuel sources. The main environmental impacts of solar energy are associated with producing the solar panels themselves. This can include using hazardous materials in manufacturing, such as lead and lead and cadmium, and the generation of waste and pollution. Tasnim et al. (2022) studied the current state and subsequent management of solar photovoltaic (PV) modules in Bangladesh. About 15–25 years after installation, the solar PV cells have a lifetime of proper service. Both the opportunity for recycling and the danger of manufacturing hazardous waste exists with solar PV cells. The solar panel would eventually decompose into waste, notably electronic waste, which could eventually cause environmental issues.

However, many manufacturers have implemented measures to reduce these impacts, such as using less hazardous materials and implementing recycling programs for end-of-life solar panels (Gallo et al., 2016). In addition, the placement and construction of solar panel installations can have some environmental impacts, such as land use changes and impacts on local wildlife populations. However, these impacts are generally considered much lower than those associated with traditional energy sources, such as coal mining or oil drilling. Overall, the environmental impacts of solar energy are relatively low compared to conventional energy sources, and using solar energy can help reduce GHG emissions and mitigate the impacts of climate change (Halkos & Gkampoura, 2020; Gallo et al., 2016; Li et al., 2022).

Desideri et al. (2013) explains the environmental impact of two power generation technologies: Concentrated Solar Power (CSP) and Photovoltaic (PV) systems. While the explanation does not explicitly mention specific mitigations, it focuses on evaluating and comparing the environmental impacts of these technologies throughout their life cycles. The goal is to identify areas of higher impact and potential improvements to reduce the environmental footprint of the systems. The study uses LCA methodology to analyze the impacts and provides results in terms of CO2 emissions, global warming potential (GWP), and other indicators.

Managing waste associated with solar energy systems involves addressing various stages of their lifecycle, from manufacturing to disposal, including manufacturing and energy storage waste, end-of-life management, electronic and packaging waste. The production of solar panels involves the use of various materials, including metals, semiconductors, and glass. Manufacturing processes may generate waste, such as off-cuts and defective panels. To address this, manufacturers often recycle materials when possible and implement waste reduction strategies. Solar energy systems sometimes incorporate energy storage solutions like batteries. Batteries have a limited lifespan, and their disposal at the end of life can pose environmental challenges due to the presence of hazardous materials. Proper recycling and disposal procedures are essential to minimize these impacts.

For end-of-life management, solar panels have a long lifespan, often exceeding 25 years (Chowdhury et al. 2020). However, at the end of their useful life, they must be disposed of or recycled. The disposal of solar panels in landfills can lead to environmental concerns because they contain materials like cadmium and lead. Many countries are now developing recycling programs for solar panels to recover valuable materials and reduce waste. For electronic waste (e-waste), solar inverters, controllers, and monitoring equipment can contribute to electronic waste when they reach the end of their life cycle. E-waste management involves proper recycling and disposal methods to prevent the release of harmful substances into the environment. Furthermore, in packaging waste, solar equipment is often shipped with packaging materials that can contribute to waste. Manufacturers are encouraged to use eco-friendly packaging materials and recycling options (Shah et al. 2023; Chowdhury et al. 2020; Oteng et al. 2021).

f. Electrochemical Fuel

Electrochemical processes consist of oxidation and reduction reactions. These methods have been applied widely to synthesize materials and generate power. Electrochemical reactions can be optimized by choosing various electrodes, solvents, electrolytes, and cell designs. A fuel cell is an electrochemical cell in which fuel and oxygen are persistently supplied from the exterior of the cell to generate electricity, as shown in Figure 7.6.

Hydrogen can be used as a fuel due to its cleanliness, abundance on earth, versatility, and efficiency. The absence of a combustion process in producing hydrogen-based fuel for hydrogen fuel cells lead to this technology more environmentally friendly. In addition, the hydrogen fuel cell produces neither GHG nor toxic and hazardous side products.

However, providing suitable infrastructure to apply hydrogen fuel cells on a large scale is essential. Hence, a high capital cost is needed to set up this type of fuel cell. Besides, electrochemical reactions of corrosion can have several negative impacts, particularly in terms of economic losses and infrastructure failures. Akpoborie et al. (2021) stated that corrosion caused by hazardous chemicals and hydrocarbons can lead to the deterioration and breakdown of infrastructure in industries such as marine, oil and gas, petroleum distillation, and chemical processing. This unstoppable catastrophe results in high costs for repairs, replacements, and maintenance. Thus, optimization of hydrogen fuel cells is required for renewable energy sources by making significant investments, collaboration, and innovations. Additionally, each alternative has its own set of environmental impacts and trade-offs. A comprehensive EA would evaluate the specific alternatives being considered to determine the most environmentally sustainable and socially responsible approach to the energy transition.

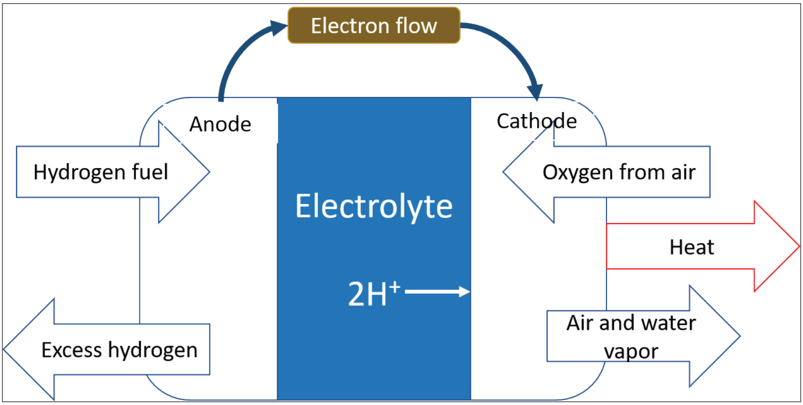


Figure 7.6 Reaction Mechanism in Hydrogen Fuel Cell

One of mitigation measures is optimizing cathode voltage. Sivalingam et al. (2022) suggests that fine-tuning the cathode voltage can enhance acetate synthesis and H_2 gas-liquid mass transfer in the homoacetogenic fermentation process. By carefully adjusting the voltage, it is possible to achieve more efficient production of acetic acid. In addition, understanding electron transfer mechanism is needed. The study highlights the need for a detailed metabolic study to investigate the electron transfer mechanism and the impact of reducing power on the electrode and the culture media. Understanding these mechanisms can help optimize the bioelectrochemical synthesis process and improve overall efficiency. Besides, managing acetic acid oxidation to reduces product synthesis and releases CO_2, negatively impacting carbon capture efficiency. Mitigation measures could involve finding ways to prevent or minimize acetic acid oxidation, such as optimizing the anode potential or exploring alternative electrode materials. Then, enhancing H_2 gas consumption, such as applying reducing power to the cathode, reduced the demand for H_2 gas in the fermentation medium. To enhance H_2 gas consumption, strategies could be explored to improve the efficiency of H_2 utilization or to optimize the conditions for H_2 availability in the system (Sivalingam et al., 2022).

Furthermore, Akpoborie et al. (2021) suggests for mitigation measures to improve the overall efficiency of homoacetogenic fermentation. In electrochemical, one of the most common methods to mitigate the negative impact of corrosion is through careful material selection. Choosing materials that are resistant to corrosion can significantly reduce the likelihood of structural failure and economic losses. Then, altering certain factors in the environment can also slow down the corrosion process. For example, removing oxygen from the solution can help mitigate corrosion. This method aims to create an environment that is less conducive to corrosion. Further, using inhibitors which can be added in low concentrations might reduce or eliminate the corrosive effects of the environment on materials. They work by forming a protective layer on the surface of the material, preventing corrosion from occurring (Akpoborie et al., 2021).

g. Biomass energy

Biomass energy refers to the energy derived from organic matter, such as plants, agricultural residues, and wood. It is a renewable energy source that can be used for various purposes, including heat generation, electricity production, and transportation fuel. Biomass energy is obtained through processes like combustion, gasification, torrefaction, pyrolysis, liquefaction, and fermentation, which convert the organic matter into usable forms of energy (Buffi et al., 2022; Foong et al., 2023; Ubando et al., 2019). Additionally, solid biomass, biodiesel, bioethanol, and biogas are all energy sources that are derived from biomass (Huang & Wu, 2008; Proskurina et al., 2019). Biomass serves as the feedstock for producing these types of renewable fuels.

1) **Solid biomass.** One of them is wood pellets, a type of solid biofuel made from compressed sawdust and wood shavings. They are a form of biomass, which refers to organic matter that can be used as a source of energy. Some advantages of this type are as renewable energy source, made from wood waste and byproducts, it has a high energy density, which means it can produce a lot of heat with a small amount of fuel. Additionally, these pellets are easy to transport and store, as they are uniform in size and shape, as well as it produces less ash and emissions than traditional wood burning. However, the disadvantages of the pellets are they require energy and resources, such as electricity and water, which can have environmental impacts; the transportation of wood pellets over long distances can increase their carbon footprint; and it can compete with other uses of wood, such as for furniture or construction (Proskurina et al., 2019).
2) **Biodiesel.** This is a renewable fuel made from vegetable oils or animal fats through a process called transesterification. It is used as an alternative to traditional diesel fuel and can be used in diesel engines without modification. According to Huang and Wu, (2008), the advantages of biodiesel are it is a biodegradable fuel that can reduce air emissions, increase the domestic energy supply, and create new markets for farmers. Additonaly, generating biodiesel from energy crops cultivated on polluted farmlands can provide a solution for re-using polluted farmlands. In study of Ashnani et al. (2014), Malaysia is among the largest producers of palm oil, which is the main raw material for producing biodiesel, and developing biodiesel production in Malaysia can meet the country's energy needs and make it a leading producer of biodiesel. However, there are also some disadvantages or barrier to the adoption of biodiesel, including the necessary stable supply of raw materials. In this case, the high cost of biodiesel is a major problem in Taiwan. The relatively cheap fossil diesel price in Taiwan makes it difficult to promote biodiesel without governmental support. Then, establishing a recycling system,

defining economic and legal measures, and improving public acceptance and inter-ministry coordination mechanisms are some of the issues that must be addressed to actively promote biodiesel utilization (Huang & Wu, 2008).

3) **Bioethanol.** It is an alcohol fuel made from fermenting the sugars found in crops like sugarcane, corn, or wheat. It is commonly blended with gasoline to create a biofuel that can be used in gasoline engines. As it is made from plant materials such as corn, sugarcane, or switchgrass, it can be blended with gasoline to reduce emissions and increase octane levels, it can be produced domestically, reducing dependence on foreign oil. In addition, it can be used in existing vehicles with little or no modification. On the other hand, the disadvantages are the production of bioethanol requires energy and resources, such as water and fertilizer, and then the use of food crops for bioethanol production can compete with food production and raise food prices, as well as the transportation of bioethanol over long distances can increase its carbon footprint (Proskurina et al., 2019).

4) **Biogas.** It is produced through the anaerobic digestion of organic materials, such as agricultural waste, food scraps, and sewage. It mainly consists of methane and carbon dioxide and can be used for heating, electricity generation, and as a vehicle fuel. Based on Khalil et al. (2019), the advantages of biogas production in Indonesia, which come from animal waste, can help in waste management by reducing the amount of waste in landfills. It can also be used for power generation, heating, and cooking, which can help meet Indonesia's energy needs. In addition, biogas production can also lead to the production of organic fertilizers, which can be used in agriculture. On the other hand, the disadvantages are the deployment of biogas technology remains low in Indonesia due to several barriers, such as economic, technical, political, institutional, and social barriers. Furthermore, the quality and volume of biogas production can be affected by several parameters, such as the design of the biodigester reactor, type of raw material,

temperature, pH, and presence of other nutrients or substances. If not properly managed, biogas production can also lead to the emission of greenhouse gases, such as methane. Overall, biogas production can be a sustainable and viable alternative source of energy in Indonesia, but it requires careful planning and management to ensure its effectiveness and minimize its negative impacts.

Saharudin et al. (2023) evaluates the environmental and economic sustainability of bioenergy with carbon capture and storage (BECSS) for electricity generation using palm oil wastes in Malaysia. The study finds that BECSS can generate electricity and remove CO_2, contributing to negative GHG emissions in a developing country. The LCA shows that the environmental impacts of BECSS vary depending on the feedstock used, with fibers having the lowest and palm fronds the highest impacts for most of the categories considered. Based on the current availability of palm oil wastes in Malaysia, the system could generate 7730 GWh/yr, boosting the national share of bioenergy by 7.6 times, while removing Mt CO_2/yr, equivalent to 10% of annual emissions from the electricity sector. For Indonesia, the environmental monitoring and assessment program should follow relevant regulations and guidelines and involve consultation with local communities and stakeholders to ensure that the monitoring and assessment activities are relevant and appropriate to local conditions and concerns. The program should also be adequately resourced and staffed with qualified personnel to ensure that it is carried out effectively.

h. Geothermal energy

Geothermal energy harnesses the Earth's core heat to generate electricity, making it a sustainable and environmentally friendly energy source. Unlike fossil fuels, it remains unaffected by resource scarcity and rising oil prices. However, not all countries possess the potential for geothermal energy; it is primarily available in regions traversed by the 'Ring of Fire.' Fortunately, Indonesia is one such country located along this geological marvel, making it rich in geothermal potential (Khalil et al., 2019).

Indonesia's unique geography, marked by 117 active volcanoes, underscores its vast geothermal energy potential. The government has recognized this opportunity and is actively working to expand its geothermal power generation capacity (Nasruddin et al., 2016). Geothermal energy offers several advantages in Indonesia, including its eco-friendliness and independence from fossil fuel availability and pricing fluctuations. In fact, Indonesia's geothermal potential accounts for approximately 40% of the world's total, estimated at around 28,617 MW (Nasruddin et al., 2016; Yudha et al., 2022). This substantial geothermal capacity has the potential to drive economic growth, particularly in the eastern regions of Indonesia where electricity demand is high (Suharmanto et al., 2015). Despite the challenges posed by the Covid-19 pandemic, the global geothermal power generation capacity has seen modest growth. Over the past year, only eight countries increased their geothermal capacity, resulting in the installation of 16 additional plants. Notably, Kenya led this growth with an addition of 83 MW, followed closely by Indonesia with 80 MW, and the United States with 72 MW. Nicaragua also contributed by adding 10.4 MW towards the end of the year. Additional capacity expansions were reported in China, the Philippines, and Japan. It is worth highlighting that Indonesia entered the ranks of the top 10 geothermal energy-producing countries by the end of 2021, with a potential resource capacity reaching 2,356 MW (Richter, 2023). This achievement is attributed to recent developments at Sorik Marapi, Sokoria, and a small binary plant at Lahendong.

The Indonesian government, recognizing the significance of geothermal energy, has enacted Regulation No. 21/2014 to bolster its development. With a strong commitment to expanding its geothermal power generation capacity, Indonesia has set ambitious targets. By 2025, the country aims to reach a capacity of 9,500 MW (Nasruddin et al., 2016), and it envisions generating 10,000 MW from geothermal sources by 2030 (Darma et al., 2021). That study from Darma et al. sheds light on the immense potential of geothermal energy in Indonesia. It identifies 312 locations abundant in geothermal resources, with reserves totaling a staggering 29 GW. The predominant use of geothermal energy in Indonesia presently revolves around electricity generation, primarily through indirect methods. However, there are ongoing efforts to optimize its application for heat pumps. Additionally, the paper delves into the financing schemes designed to bolster geothermal field exploration and development within the country (Darma et al., 2021).

Dhar et al. (2020) examine the potential environmental impacts associated with geothermal energy production and propose mitigation strategies. Some of the recommended measures include favoring closed-loop systems over open-loop systems to minimize groundwater impact, designing plants to prevent steam releases into the atmosphere, and implementing reclamation efforts to restore areas disturbed during plant construction, focusing on reducing soil compaction and controlling chemical releases. Furthermore, it is crucial to proactively identify potential environmental effects and their corresponding mitigation measures before initiating geothermal energy production. This process involves categorizing environmental impacts based on safeguard subjects such as air quality, water resources, biodiversity, and human health. It also considers the nature of impacts, whether they are direct, indirect, short-term, or long-term. Understanding the pathways of stresses and emissions, including greenhouse gas emissions and geothermal fluid discharges, is essential for crafting effective mitigation strategies that ensure the sustainability of geothermal energy operations.

In a separate study, Omodeo-salé et al. (2020) introduced a basin thermal modeling approach aimed at risk mitigation in geothermal energy exploration. This innovative approach involves a comprehensive characterization of the petroleum system within the study area. It accomplishes this by reconstructing the thermal history of the basin and quantifying the key variables that influence temperature dynamics. The primary objective is to trace the origin of hydrocarbons and assess the processes driving the petroleum system in the region.

The incorporation of this approach into the feasibility and planning stages of future geothermal exploration endeavors holds immense value. Project developers can leverage this data-driven approach to make well-informed decisions and effectively manage the risks inherent in geo-energy projects. Such proactive measures can help avert unforeseen occurrences related to hydrocarbon presence and mitigate potential negative societal perceptions. Ultimately, this can garner increased support for the transition to geothermal energy utilization.

On the other hand, geothermal energy in Indonesia is predominantly regarded as a conventional system, rather than a basin system. Indonesia's location along the Pacific Ring of Fire provides abundant high-temperature geothermal resources, making individual high-temperature reservoirs a practical choice for power generation. The conventional system is a proven and reliable technology for converting high-temperature steam into electricity, aligning well with Indonesia's energy goals. Moreover, it allows flexibility to tailor each geothermal project to its unique conditions. Conventional systems are often preferred for project financing due to their perceived lower risk. Indonesia has established regulations that support this approach (Sharmin et al., 2023; Fan & Nam, 2018; Nasruddin et al., 2016).

Tabel 7.1 The Environmental Impacts of Non-renewable and Renewable Energies and Mitigation Measures

No.	Energy types	Environmental Impacts	Mitigation measures	References
1.	Fossil fuel (Coal, petroleum, natural gas) **Type:** Non-renewable energy **Potential Energy:** - GW **Risk:** Moderate to high	**Biotic factors** Biodiversity, including local species or population: Plants: meadow, pasture, woodland, and mangrove Animals: fish, shrimp, Humans: children, adults **Abiotic factors** Deforestation, habitat destruction, soil erosion and low fertility; poor vegetation cover; and ecosystem, air and water pollution; acid rain	Pre-mitigation: Conducting proper assessments prior to implementing new development projects to select the most environmentally acceptable alternatives and minimize land clearing. Using horizontal drilling techniques to lay down pipelines and avoid vegetation removal. Implement measures to reduce lead (Pb) emissions from gasoline, such as phasing out leaded gasoline and promoting the use of unleaded gasoline. Post-mitigation: Implementing offset policies and associated actions such as replanting programs, mangrove rehabilitation, and sustainable programs for shrimp pond farming. Regularly conducting biodiversity surveys to update knowledge of local biodiversity and identify sensitive areas that need protection. Develop and enforce regulations for industries to treat their gas exhausts and reduce their contribution to air pollution. Planting legume cover crops, which can help improve the soil condition of post-mining sites and prevent erosion.	(Dama et al., 2021) (Chaîneau et al., 2010) (Santosa et al., 2008) (Zulkarnain, 2014) (Lestari et al., 2022)

No.	Energy types	Environmental Impacts	Mitigation measures	References
2.	**Nuclear Energy** **Type:** Renewable energy **Potential Energy:** 35 GW* **Risk:** high	**Biotic factors** Biodiversity, including local species, population or communities: Plants: meadow, pasture, and woodland Animals: insects (eggs and larvae), birds, fish, mammals Humans: children and adults (cyto- and histology - molecular level) **Abiotic factors** Contamination of nuclear waste in air, soil, and water in the surrounding areas, plant and animal habitat or ecosystems.	Pre-mitigation: Conducting studies and developing strategies to understand the long-term effects of radiation on the ecosystem, including wildlife populations and their adaptation mechanisms, Integration of NPP promotion activities between the central and regional governments, incentives for infrastructure development at prospective NPP sites to minimize the NIMBY phenomenon and providing explanations to the public (via TV or social media) about the benefits and risks of the nuclear power plant program. Concerns about the potential for accidents due to earthquakes and tsunamis, as well as the low safety culture and readiness of Indonesian human resources, suggest that strict safety measures and improvements in safety culture and human resources are necessary. Post-mitigation: Monitoring and assessment of the extent of contamination in the air, soil, and water to determine the areas that require immediate attention, and Evacuation of humans from the affected areas to minimize radiation exposure. Encouraging laboratory experiments with low dose radiation and implementing measures to prevent further release of radioactive materials.	(Wisnubroto et al., 2019) (Fragkos et al., 2021) (Cannon & Kiang, 2022) (Denholm et al., 2012)

No.	Energy types	Environmental Impacts	Mitigation measures	References
3.	**Hydropower** **Specification:** **Type:** Renewable energy **Potential Energy:** 83 GW* **Risk:** Moderate to high	**Biotic factors** Biodiversity, including local species, population, or communities: Plants: crops (agriculture) Animals: benthic community, fish, aquatic and/or marine mammals Humans: adults (farmers, sailors) **Abiotic factors** Deforestation; disruption of natural river ecosystems and biodiversity loss; catastrophic flooding, displacement of local communities and loss of cultural heritage because of reservoir inundation and land acquisition; increased sedimentation in downstream areas; noise generated during the construction and operational phases.	Pre-mitigation: Developing and enforcing regulations to control water discharge from hydropower plants and ensure sustainable water management. Conducting comprehensive studies to understand the specific effects of industrial and household activities on the decline and fluctuation of the water level. Mitigation measures for the environmental and ecological effects of ocean renewable energy development include addressing concerns such as noise pollution, pile driving, and electromagnetic fields (EMFs) emitted by the energy harnessing process. Post-mitigation: Implementing sustainable practices in industrial activities to reduce water usage and minimize environmental damage. Promoting reforestation efforts to counteract deforestation and its negative effects on the water level. Collaborating with the government and stakeholders to obtain detailed climate projection information and use it for mitigation, adaptation, and anticipation activities against future drought. Prioritizing the identification of the most dominant factor causing the decrease in the water level through systematic studies.	(Irwandi et al., 2021) (Halkos & Gkampoura, 2020) (Boehlert & Gill, 2010)

No.	Energy types	Environmental Impacts	Mitigation measures	References
4.	**Wind Energy** **Specification:** **Type:** Renewable energy **Potential Energy:** 39 GW* **Risk:** Moderate to high	**Biotic factors** Biodiversity, including specific or certain species, population or communities: Plants: crops (agriculture), meadow, pasture, woodland Animals: migratory birds, bats, raptor populations, predator (Golden Eagles and Griffon Vultures) Humans: adults **Abiotic factors** Disruption of natural environment; noise interference; collisions and fatalities - direct mortality of wildlife; habitat alteration and loss.	Pre-mitigation: Pre-construction assessment to inform mitigation measures during planning, and post-construction mortality surveys coupled with measures like turbine curtailment. Developing guidelines to assist wind developers in sitting their projects, including standard pre- and post-construction survey methodology to compile data over time. Engaging with stakeholders, including government agencies, non-governmental organizations, power companies, and development agencies, to ensure responsible wind-power development. Proper sitting of wind farms to avoid frequent flight paths of soaring birds and areas of high prey density. Developing visual modifications such as painting rotor blades and turbine bases black to increase visibility to birds. Post-mitigation: Post-construction mitigation strategies such as shutting down turbines when raptors approach, which has been effective in reducing mortality, Reducing other unrelated human-caused mortality agents, such as electrocution, lead exposure, poisoning, and trade, this can benefit the survival of large raptor species.	(Choi et al., 2020) (Gallo et al., 2016) (Halkos & Gkampoura, 2020) (Boehlert & Gill, 2010) (Kuvlesky et al., 2007) (Watson et al., 2018)

No.	Energy types	Environmental Impacts	Mitigation measures	References
5.	**Solar Energy** **Specification:** **Type:** Renewable energy **Potential Energy:** 361 GW* **Risk:** Moderate to high	**Biotic factors** Biodiversity, including local species, populations or communities: Plants: crops (agriculture), meadow, pasture, woodland Animals: birds, fish, and mammals Humans: adults **Abiotic factors** Potentially harmful materials from disposable; the generation of electronic waste, soil and water pollution; carbon emissions; land use conflicts, damaged ecosystems; and release of hazardous materials such as lead, tin, cadmium, selenium, and tellurium, and cadmium,	Pre-mitigation: Encouraging the adoption of solar energy systems at both large-scale utility projects and small-scale residential installations to diversify the energy mix and promote energy independence. Investing in research and development to improve the efficiency and performance of solar panels. Promoting demand-side flexibility through demand-side management and demand response, which can enhance the flexibility and reliability of solar energy systems. Post-mitigation: Encouraging the expansion of solar energy systems for heating, cooling, and transportation. Implementing a comprehensive collection and management system for PV waste, involving primary and regional collector delegate bodies, and recycling delegate bodies. Encouraging the recovery and recycling of materials from waste PV panels, such as glass, aluminum, silicon, and copper, to minimize environmental impact and promote resource recovery. Ensuring safe and complete management of PV module waste through a well-organized collection system and raising awareness among stakeholders about the positive impact of recycling PV.	(Desideri et al., 2013) (Li et al., 2022) (Qi & Zhang, 2017) (Tasnim et al., 2022) (Gallo et al., 2016) (Halkos & Gkampoura, 2020)

No.	Energy types	Environmental Impacts	Mitigation measures	References
6.	**Electrochemical fuel** **Specification:** **Type:** Renewable energy **Potential Energy:** 52 GW* **Risk:** Low to Moderate	**Biotic factors** Biodiversity, including local species, populations or communities: Plants: - Animals: fish, and mammals Humans: children and adults **Abiotic factors** Corrosion, including appearance devaluation of buildings, structures, and antiques; contamination of products when corroded pipelines carry liquids; decrease in acetic acid production rates and release of CO2, which negatively impacts net carbon capture efficiency	Pre-mitigation: Developing advanced electrode designs and materials that enhance electron transfer efficiency and minimize side reactions, such as the use of catalysts or modified electrode surfaces, can mitigate the negative impacts of electrochemical reducing power. Optimizing the reactor configuration and operation mode, such as using continuous flow systems or flow cell reactors, can help minimize the effects of biofilm formation and improve the overall performance of the electrochemical system. Post-mitigation: The use of eco-friendly organic inhibitors as an alternative to toxic and non-environmentally friendly inorganic inhibitors. Balancing the reduction potential at the cathode with the oxidation potential at the anode is crucial to mitigate the negative impacts of electrochemical reducing power in homoacetogenesis and optimizing the operating conditions and electrode materials to minimize acetic acid oxidation and maximize acetate synthesis. Implementing control strategies to maintain the appropriate reducing power level, such as using potentiostatic control or feedback control systems, can help prevent acetic acid oxidation and ensure efficient acetate production.	(Akpoborie et al., 2021) (Sivalingam et al., 2022)

No.	Energy types	Environmental Impacts	Mitigation measures	References
7.	**Biomass energy** **Specification:** **Type:** Renewable energy **Potential Energy:** 37 GW* **Risk:** Moderate to high	**Biotic factors** Biodiversity, including local species, populations or communities: Plants: crops, meadow, pasture, and woodland Animals: fish, birds, and mammals Humans: children and adults **Abiotic factors** Land use, soil erosion or land degradation; potential deforestation; competition with food production, habitat and biodiversity loss; carbon emissions and air pollution, such as particulate matter and nitrogen oxides, which can have negative impacts on air quality and human health.	Pre-mitigation: Implementation of policies and regulations that incentivize the use of biomass energy and ensure compliance with sustainability criteria and greenhouse gas emission reduction targets Ensuring the use of sustainable biomass feedstocks and promoting crop diversification to avoid competition with food production Implementing sustainable farming practices and land management techniques to minimize deforestation and habitat loss, and promoting the use of agricultural and forestry residues as feedstock for biomass energy production Investing in research and development to improve biomass energy conversion technologies, such as gasification and pyrolysis, to minimize air pollutant emissions. Post-mitigation: Implementation of life cycle assessment studies, continued research and development to improve the technology readiness level of biomass-to-hydrogen conversion processes The implementation of waste to energy technology, specifically the production of biogas from animal waste, and the design of the biodigester reactor, type of raw material, temperature, pH, and presence of other nutrients or substances	(Buffi et al., 2022) (Proskurina et al., 2019) (Huang & Wu, 2008) (Ubando et al., 2019) (Ashnani et al., 2014) (Khalil et al., 2019) (Foong et al., 2023)

No.	Energy types	Environmental Impacts	Mitigation measures	References
8.	**Geothermal** **Specification:** **Type:** Renewable energy **Potential Energy:** 18 GW* **Risk:** Moderate to high	**Biotic factors** Biodiversity, including indigenous populations or local species: Plants: crops, meadow, pasture, woodland, national park, and forest Animals: fish, birds, and mammals Humans: children and adults **Abiotic factors** Deforestation, land degradation, habitat disruption and potential seismic activity, land subsidence and fluid disposal	Pre-mitigation: Conducting thorough environmental impact assessments prior to the construction of geothermal power plants to identify and mitigate potential risks to air quality, human health, and local ecosystems. Engaging with local people or communities and indigenous populations to ensure their participation and consent in geothermal energy projects, and providing appropriate compensation or alternative livelihood options if displacement is necessary Conducting thorough environmental impact assessments and implementing mitigation measures to minimize the impact on conservation forests and national parks. Post-mitigation: Implementing proper monitoring and management strategies to ensure the sustainable use of geothermal reservoirs and prevent depletion or contamination of the resource. Implementing best practices for drilling and extraction processes to minimize environmental impacts, such as land subsidence and fluid disposal.	(Darma et al., 2021) (Suharmanto et al., 2015) (Nasruddin et al., 2016)

*Source: Sikumbangg (2022)

5. Alternative Analysis and Assessment Criteria of Renewable Energy

To effectively identify and evaluate viable alternatives for the proposed energy transition technology, a systematic approach is essential. This involves screening and assessing various alternatives, selecting the most suitable option, and conducting a comprehensive analysis of its environmental impact. Furthermore, it is crucial to understand and implement the Analytical Hierarchy Process (AHP) for creating and evaluating alternatives. This process should be seamlessly integrated into a decision support system for robust environmental assessment.

a. Alternative Analysis

As alternative analysis, identifying and evaluating reasonable alternatives to the proposed energy transition technology is crucial to the EA, as summarized in Figure 7.7. This analysis aims to compare the proposed technology with other options that could achieve the same objectives with fewer environmental impacts or at lower costs (Boehlert & Gill, 2010; Gallo et al., 2016). Therefore, we need to identify and evaluate reasonable alternatives, including screening and evaluation of alternatives, selection of preferred alternative, and analysis of environmental impact.

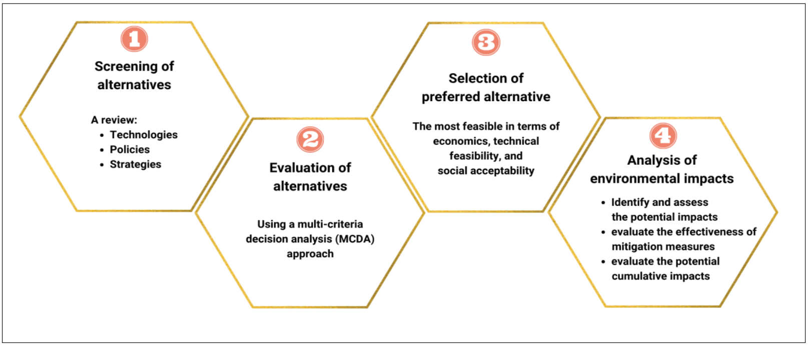


Figure 7.7 Identifying and evaluating reasonable alternatives to the proposed energy transition technology is crucial to the environmental assessment (EA).

1) Screening of alternatives

A preliminary screening of alternatives can be conducted to identify potential options that may be viable for achieving the desired objectives. This screening process can include a review of available technologies, policies, and strategies that could be used to achieve the objectives of the proposed energy transition technology (Kokkinos et al., 2020; Gallo et al., 2016). When conducting a preliminary screening of alternatives for achieving the desired objectives of an energy transition technology, there are several steps that can be taken.

a) **Identify the objectives**. The first step is clearly defining the energy transition technology's objectives. For example, the objectives may be to reduce GHG emissions, improve energy security, or enhance economic development (Carlson et al., 2012; Murdiyarso et al., 2010; Gallo et al., 2016).
b) **Review available options**. Once the objectives have been identified, a review of available options can be conducted. This may involve researching and analyzing various technologies, policies, and strategies that could be used to achieve the objectives (Boehlert & Gill, 2010; Carlson et al., 2012; Murdiyarso et al., 2010; Gallo et al., 2016) .
c) **Evaluate feasibility**. After reviewing the available options, the next step is to evaluate the feasibility of each alternative. This may include assessing factors such as cost, technical feasibility, and regulatory requirements (Gallo et al., 2016).
d) **Prioritize options**. Based on the evaluation of feasibility, options can be prioritized. This may involve selecting the most promising alternatives based on their potential to achieve the desired objectives while also considering factors such as cost and potential impacts on the environment and local communities (Boehlert & Gill, 2010).
e) **Conduct a detailed assessment**. Once the most promising alternatives have been identified, a detailed assessment can be conducted to evaluate further each option's feasibility, effective-

ness, and potential impacts (Boehlert & Gill, 2010; Carlson et al., 2012).

2) Evaluation of alternatives

After identifying potential alternatives through screening, it is important to evaluate them against a set of criteria that are relevant to the project objectives. This evaluation can be conducted using a Analytical Hierarchy Process (AHP) approach (Budak et al., 2019), which involves weighing the importance of different criteria and comparing the alternatives based on their performance against each criterion.

The criteria used to evaluate alternatives will vary depending on the project objectives and context. However, standard criteria for evaluating renewable energy alternatives may include environmental impacts (e.g. GHG emissions, impacts on wildlife and habitats) (Murdiyarso et al., 2010; Gallo et al., 2016), economic feasibility (e.g. cost-effectiveness, potential revenue streams), technical feasibility (e.g. reliability, scalability, available technology), and social acceptability (e.g. public perception, impacts on local communities and cultures; Kokkinos et al., 2020; Gallo et al., 2016; Frantál & Kunc, 2011).

Once the alternatives have been evaluated against the criteria, a comparative analysis can be conducted to determine the most suitable alternative for the project. This analysis may involve a trade-off between different criteria, such as balancing higher environmental impacts against lower costs (Gallo et al., 2016; Kokkinos et al., 2020). Ultimately, the chosen alternative should be the one that best meets the project objectives while minimizing negative impacts and maximizing positive benefits.

3) Selection of preferred alternative

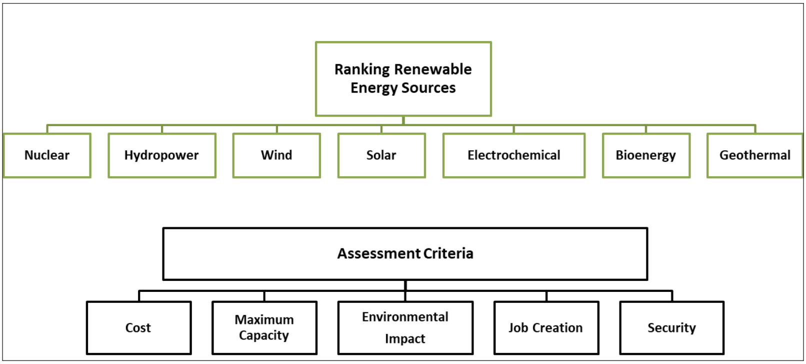
A preferred alternative can be selected once the comparative analysis is conducted and the various alternatives are evaluated based on the established criteria. The preferred alternative should have the most negligible environmental impact, meet the project objectives, and be the most cost-effective (Gallo et al., 2016). The preferred alternative may have a lower environmental impact but may be the most feasible in terms of economics, technical feasibility, and social acceptability. Trade-offs between environmental impacts and other factors may sometimes be required. In such cases, it is necessary to ensure that the identified impacts are mitigated effectively and that the benefits of the proposed energy transition technology outweigh any potential negative impacts (Gallo et al., 2016; Kokkinos et al., 2020).

4) Analysis of environmental impacts

Once the preferred alternative is selected, a more detailed analysis of its potential environmental impacts should be conducted. This analysis should identify and assess the potential impacts of the preferred alternative on the environment and evaluate the effectiveness of mitigation measures to minimize or avoid those impacts (Murdiyarso et al., 2010). The analysis should also evaluate the potential cumulative impacts of the preferred alternative, including its interaction with other existing or proposed activities in the same area. The results of the environmental impact analysis should be used to inform decision-making and identify any necessary modifications to the preferred alternative to minimize or avoid significant environmental impacts (Kokkinos et al., 2020).

b. Assessment Criteria of Renewable Energy

The assessment criteria of the energy alternatives is a methodology integrated into a decision support system that use the analytical hierarchy process (AHP), illustrated in Figure 7.8. Its aim is to rank various energy alternatives in accordance with a number of criteria and identify the most suitable energy options for a certain city (Budak et al., 2019). The results of the decision support system created in this study may be used by decision-makers and stakeholders to make educated judgements about the financing and adoption of energy alternatives for a city or region. The four categories of economy, technology, environment, and society that were used to evaluate renewable energy in multi-criteria decision-making in the literature correspond to these five criteria, including cost, maximum capacity, environmental impact, job creation, and security (Table 7.2).



Source: adapted from Budak et al. (2019)

Figure 7.8 Hierarchical Structure of Ranking and Selection of Renewable Energy Sources

Table 7.2 Five assessment criteria of energy alternatives

Criteria	Description	Categories
Cost (C)	Investment, maintenance and operating cost, and other life cycle costs	Economy
Maximum capacity (MC)	Installed capacity, reliability, and service life	Technology
Environmental impact (EI)	Pollution, emission, noise, land use, and consumer acceptance	Environment
Job creation (JC)	Job opportunities, economic impact, and regional development	Socio-economy
Security (S)	Risks, disruptions, and disasters	Socio-Technology

Source: Budak et al. (2019)

Following the identification of the five criteria for the evaluation of energy alternatives based on a literature review, the AHP is used to calculate the weights for each criterion. Through pairwise comparisons of criteria, the AHP solicits expert input and assesses each expert's comparisons for consistency. The weights of the criterion are computed using consistent input from numerous experts. Additionally, cost and maximum capacity are two criteria that can be measured and have units; however, environmental impact, job creation, and security are a combination of concrete and intangible variables that are challenging to quantify (Budak et al., 2019).

Table 7.3 Performance scores of criteria

Criteria	Scores	
	0	**10**
Cost (C)	Most expensive	Least expensive
Maximum capacity (MC)	Extremely low	Extremely high
Environmental impact (EI)	Most harmful to the environment	Small or negligible impact on the environment
Job creation (JC)	Net gain of job opportunities is small or negligible, or net loss of job opportunities	Substantial net gain of job opportunities
Security (S)	Vulnerable to incidents and/or catastrophic consequence if incidents occur	Resilient to incidents and the impact of an incident is minimum

Source: Budak et al. (2019)

Table 7.4 Assessment of energy alternatives

Renewable energies	Criteria					Total	Recommendation
	C	MC	EI	JC	S		
Nuclear							
Hydropower							
Wind							
Solar							
Electrochemical							
Biomass							
Geothermal							

Source: Budak et al. (2019)

The AHP asks experts to rate the effectiveness of alternative energy sources for each criterion on a scale of 0 to 10 (Table 7.3). Then, the energy alternatives for a certain city are evaluated using these criteria. An expert is given a variety of energy options for each criterion, and the expert rates the performance of each alternative for the criterion. The seven energy alternatives assessed in this study are nuclear, hydropower, wind, solar, electrochemical, bioenergy, and geothermal (Table 7.4). The expert's assessment of an alternative for a criterion is a performance score to be recorded in the cell at the intersection of the criterion and alternative in Table 7.3. After assessment of energy alternatives has already finished, then it will continue to assess the environment using the Analytical Hierarchy Process (AHP) involves a structured approach to evaluating various environmental criteria and sub-criteria to make informed decisions (for further overlook of various environmental impacts, please see the Table 7.1).

To begin with, the initial step involves identifying criteria and sub-criteria that define the scope of environmental aspects for assessment. These encompass a range of factors such as air quality, water pollution, land use, and biodiversity. Moreover, each criterion can be further segmented into sub-criteria, facilitating a comprehensive analysis of the environmental components under consideration. Subsequently, the process entails conducting pairwise comparisons to establish the relative significance of these criteria and sub-criteria. This involves assigning numerical values to depict the degree of importance of one criterion in relation to another. The assigned values are assigned on a scale ranging from 1 (indicating equal importance) to 10 (representing significantly greater importance) (Budak et al., 2019). Through these comparisons, a hierarchical structure is formed, reflecting the priority of each criterion within the realm of environmental assessment. Moving forward, the procedure includes constructing matrices for each criterion and corresponding sub-criterion. These matrices facilitate the side-by-side comparison of these elements, utilizing the previously assigned numerical values. To ensure coherence, the matrices are normalized, culminating in the derivation of priority weights for both criteria and sub-criteria. This is achieved by calculating the geometric mean for each row, thereby establishing the proportional importance of each component within the entire assessment framework.

To ensure the consistency of our comparisons, it is important to calculate the consistency ratio for each matrix. This step helps validate the reliability of the judgments made during the process. A consistency ratio of approximately 0.1 or lower is generally considered acceptable as it indicates a well-balanced assessment. Moving forward, the calculation of overall priority weights is paramount. This involves multiplying the priority weights derived from each matrix with the priority weights of their respective parent criteria. Summing up these values for each criterion yields the comprehensive overall priority weights. Following this, it is crucial to conduct a sensitivity analysis to gauge the stability of your results. By making slight adjustments to the pairwise comparison values, you can observe the extent of change in the overall priorities. This step contributes to the robustness of the assessment, ensuring the reliability of the outcomes. Subsequently, the interpretation of the results is pivotal. These results yield a clear hierarchy of environmental criteria and sub-criteria based on their relative significance. Such prioritization plays a vital role in the decision-making process. It effectively highlights which aspects of the environment necessitate greater attention within the assessment. This structured approach empowers stakeholders to make well-informed decisions that align with the overall goals of environmental preservation and sustainability (Budak et al., 2019).

After employing the AHP method to assess renewable energy options, a comprehensive understanding of their environmental impacts can be gained. AHP provides a structured approach to evaluating and comparing various criteria and sub-criteria, aiding in decision-making for selecting the most suitable renewable energy sources. In terms of environmental impact, AHP can help in quantifying factors such as greenhouse gas emissions, land use, water consumption, and other ecological considerations associated with each renewable energy option. This enables a more accurate and holistic assessment of the sustainability of different sources. Based on the AHP analysis, recommendations can be derived to optimize the selection of renewable energy sources with minimal negative environmental impacts. For instance, if solar and wind energy receive higher scores due to their lower emissions and land use compared to bioenergy, the recommendation might prioritize these sources for implementation.

C. Closing

In conclusion, Indonesia's transition to renewable energy sources offers a substantial opportunity to mitigate climate change and reduce the adverse environmental impacts linked to traditional fossil fuels. However, conducting a comprehensive environmental assessment (EA) is imperative to identify and assess the potential environmental implications of the proposed energy transition technology, alongside the consideration of viable alternatives. The EA should also pinpoint and evaluate mitigation measures to minimize or circumvent potential environmental impacts, taking into account the effectiveness, feasibility, and associated costs of each measure. Furthermore, it is crucial to evaluate potential residual impacts that might persist even after the implementation of mitigation measures and to scrutinize their potential effects on human health, cultural resources, and the economy. If Indonesia commits to pursuing and developing renewable energy, the nation stands to benefit significantly. This shift would substantially reduce greenhouse gas emissions, aligning with climate commitments. Improved energy security would result as the country diversifies its energy mix, reducing dependence on imported fuels. This transition would also foster economic growth, generate employment opportunities, and advance rural electrification. Technological innovation and improved air quality would follow suit, promoting public health and environmental conservation. Additionally, Indonesia could emerge as a global leader in sustainable energy practices, while local communities would benefit economically and participate in cleaner energy solutions.

One suitable method for assessing energy alternatives is the Analytical Hierarchy Process (AHP). This methodology integrates expert knowledge and data analytics, providing scores and rankings for various energy technologies. These rankings enable decision-makers to formulate long-term energy investment strategies for municipalities. Furthermore, decision-makers can make informed choices about transitioning to renewable energy sources, aiming to minimize adverse environmental impacts. Public engagement and consultation should be integral to the EA process, ensuring that all stakeholders have the opportunity to offer input, voice concerns, and seek clarifications.

Overall, the EA process is indispensable to guarantee the sustainable and environmentally responsible implementation of Indonesia's transition to renewable energy sources. While Indonesia boasts significant potential for various renewable energies, including solar, wind, hydropower, biomass, and geothermal energy, enticing private power investments in the sector remains challenging. To address this challenge, the government must provide unequivocal support for private power investments, reducing uncertainties in project development and enhancing economic viability. Additionally, education initiatives targeting developers and lenders on ensuring project viability are essential, and international support in terms of finance, technology, human resources, and technical assistance is vital to achieving the set targets.

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Chapter 8

Energy Transition at the Sub-national Level through Green Leadership

Beny Harjadi

A. Green leadership for sustainability

Transition in local levels through green leadership refers to the effort of leaders in managing their area with principles of sustainability and environment protection. This effort was made due to the increasing number of environmental problems faced by regions around the world, such as climate change, decreasing water and air quality, and destruction of natural habitats. All of this requires real action from the local government in protecting the environment so that it remains sustainable.

Green leadership is also considered as one of the solutions to achieve UN's sustainable development targets. This is because green leadership considers the balance of all factors in an integrated manner,

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namely social justice, economic growth, and environmental preservation. Conservation of water resistance and water in a watershed also considers the condition of urban slum settlements as a basis for economic growth (Surya et al., 2020). At the local level, green leadership can be done in various ways, such as reducing greenhouse gas emissions, developing renewable energy, implementing environmentally friendly waste management system, replanting forests, and so on.

Additionally, greens leadership can also be implemented through government policies and programs that support the use of renewable energy and environmentally friendly technologies. For example, technology such as remote sensing can monitor landscapes, land use, and land cover to monitor natural damage (Abdi, 2020). It can also estimate biomass and renewable energy (Kumar et al., 2015).

Green leadership may also encourage community participation in environmental conservation efforts. It refers to the collaborative effort between government, region, community, and private sector in creating sustainable environment. In regards to this, Grothmann et al. (2013) has analyzed the capacity of institutions to adapt to climate by integrating psychological dimensions.

Transition to a sustainable and environment-friendly energy system is an important step in overcoming climate change and ensuring the future with cleaner and safer energy. Indonesia needs to effectively handle climate change with adaptation programs at the local level (Rahayu, 2013). An example of region that can obtain huge benefit from green leadership is Central Java. Implementing green leadership in Central Java's energy transition projects involves a holistic approach that includes policy, infrastructure, education, and stakeholder engagement. By prioritizing sustainability and collaboration, Central Java paves way for a cleaner, more resilient, and prosperous energy future.

Developing green leadership in the region is not a simple task. There are many fundamental problems that must be resolved first before a region can implement green leadership strategies, strengthening the energy transition process. The issues could be illustrated through these questions.

1) What are the principles of green leadership, and how can they be applied at the local level?
2) What is the role of local government in leading the transition towards sustainability at the local level?
3) What are the programs and implementation of local government policies in the framework that supports the energy transition to sustainability?
4) How can public and private institution can participate in supporting green leadership at the local level?
5) What are the obstacles and challenges that will be faced in implementing green leadership at the local level, and how to overcome it?

The principle of green leadership refers to an approach that focuses on environmental sustainability and social responsibility. The main objective is to integrate environmentally friendly and sustainable practices into the decision-making and actions of leadership. The application of the principles of green leadership at the local level involves taking steps to generate positive impacts on the environment and society, while achieving social and economic goals.

These are some of the key principles in green leadership.

1) **Environmental Considerations**. Green leaders consider the environmental impact of their decisions and actions. They prioritize the maintenance of natural resources, reduce waste, and limit harmful emissions.
2) **Sustainable Innovation**. Green leaders drive innovation in renewable energy, green technology, and other sustainable solutions to reduce dependence on finite resources.
3) **Community Involvement**. Green leaders seek to involve the community in the decision-making process related to the en-

vironment. Community participation can help generate more inclusive and sustainable solutions.

4) **Education and Awareness**. Green leaders play a role in educating society about environmental issues and developing awareness of the importance of sustainable actions.
5) **Social Justice**. Green leaders recognize the link between environmental sustainability and social justice. They work to reduce social inequalities and ensure that environmental benefits are enjoyed by all levels of society.

The application of these principles at the local level can be done in various ways.

1) **Environmental Policies and Regulations**. Local leaders can encourage the adoption of policies and regulations that support sustainable practices, such as proper waste management, protection of green areas, and use of renewable energy.
2) **Green Infrastructure Projects**. The construction of environmentally friendly infrastructure projects, such as bicycle paths, city parks and energy-efficient buildings, can be real examples of the application of green leadership principles.
3) **Partnerships and Collaboration**. Local leaders can work with private institutions, NGOs and communities to develop sustainable solutions, such as recycling programs, tree planting and eco-conscious campaigns.
4) **Environmental Education**. Integrating education on environmental issues into the school curriculum and organizing environmental education campaigns can increase public awareness.
5) **Use of Local Resources**. Leaders can encourage sustainable use of local resources, such as local organic farming or the development of ecotourism-based industries.

The application of green leadership principles at the local level is an important step in creating an environmentally and socially sustainable society. One way this can be done is by establishing green leadership standardization certification. It is a process by which an organization, project, or individual follows certain established standards to measure and ensure sustainable and environmentally friendly practices in their operations. So far, the government has yet to announce the plan to implement this certification to energy sources in Indonesia, such as solar power plants (PLTS), national power plants (PLN), or micro-hydro power plants in Central Java, Indonesia. However, there is general information regarding certification and standardization in the context of green energy. These are some of the standards frequently used in the green energy industry.

1) **ISO 14001**. This is an international standard for environmental management. By adopting this standard, organizations can identify and manage the environmental impacts of their operations and improve their overall environmental performance.
2) **Leadership in Energy and Environmental Design (LEED)**. This is a certification system used to measure the sustainable performance of buildings and their associated environment. Although more focused on buildings, LEED principles can also be applied to renewable energy projects.
3) **Green Energy Certification Schemes**. There are various green energy certification schemes that focus on energy production from renewable sources such as solar and micro-hydro. These examples may vary by country and region, and they assess the quality and sustainability of renewable energy projects.
4) **Renewable Energy Standards**. Many countries have specific standards to ensure that energy produced from renewable sources meets certain requirements. These standards can relate to electricity quality, conversion efficiency, and environmental impact.
5) **Local Regulations and Incentives**. Sometimes, local or national governments have regulations and incentives that support the development of renewable energy. This could include requirements for obtaining permits, tax incentives and other support programs.

Based on the principles, we should make a positive contribution to the development and implementation of green leadership policies and programs at the local level and help create a society that is more aware of the importance of protecting the environment and contributing to its conservation efforts. Furthermore, to support the development and implementation of green leadership policies and programs at the local level, the following are some concrete steps that can be taken.

1) **Education and Awareness Enhancement**. As individuals, we can continue to learn about environmental issues and share this knowledge with others. Educating ourselves and others about the impact our actions have on the environment is an important first step.
2) **Increasing the Level of Participation in Decision-Making Processes**. Getting involved in community discussions and forums regarding local environmental policies can contribute to sustainable decision-making.
3) **Intensify Collaboration and Partnership**. Working with local governments, non-profit organizations, local businesses, and communities can create synergies to develop and implement sustainable solutions.
4) **Adopt Sustainable Practices**. At the individual level, we can adopt sustainable practices such as recycling, energy saving and selection of eco-friendly products.
5) **Drive Sustainable Policy**. Provide support to local leaders who are committed to sustainable policies and programs through participating in elections, providing input, or organizing campaigns.
6) **Empower Community**. Encouraging communities to participate in environmental activities, such as environmental clean-ups or tree planting, can build collective awareness and a spirit of contribution.

7) **Share Knowledge and Resources**. Sharing information about sustainable practices, green technologies and successful initiatives can help inspire others to do more for the environment.
8) **Have a Sustainable Lifestyle**. An environmentally conscious lifestyle, such as reducing excessive consumption of goods, avoiding waste, and choosing public transportation or cycling, can set a real example for the surrounding community.

By taking these steps, we can have a significant positive impact on the development and implementation of green leadership policies and programs at the local level. This joint effort will help create a society that is more aware of the importance of protecting the environment and contributes to efforts to preserve it, so that we can leave a better planet to future generations.

B. Roles of local government

Green leadership is a leadership concept that aims to create positive changes in the environment and promote sustainable economic growth. Green leadership promotes the values of sustainability, innovation, collaboration, and public participation. For example, green leadership has been implemented around the affected areas of Mount Merapi after the 2010 eruption (Lestari et al., 2012). Green leadership pushes transition as the process of change towards a more sustainable society by reducing negative impacts on the environment, increasing resource efficiency, strengthening social welfare, and integrating the process into policy of climate change impact mitigation. Local government should be one of the green leaderships at a local level as the government agency responsible for the management and development of resources in its territory. Local governments have an important role in creating policies and programs that support the transition towards sustainability.

Local government must be able to drive society. As a group consisting of individuals who live and interact with each other in a social environment, communities have an important role to play in supporting the transition to sustainability through participation in the implementation of local government policies and programs. Local and sectoral coordination is an important effort to increase climate change adaptation in Indonesia (Yoseph-Paulus & Hindmarsh, 2018).

In addition, local government must cooperate with private sector in their region. This sector has an important role to play in supporting the transition towards sustainability through sustainable business practices and collaboration with local governments and communities. An example to this is how private sector often implement digitalization analysis as a tool to achieve adaptation to climate change conditions and sustainable development growth (Balogun et al., 2020). The same tool can be utilized by local governments in the transition process, thus warranting a collaboration with private sector.

Within this theoretical framework, green leadership is considered as an effective approach to lead the transition towards sustainability at the local level. Local governments are considered to have a major role in leading the transition towards sustainability by developing sustainability-oriented policies and programs. Communities and the private sector are also considered to have an important role in supporting the transition towards sustainability through participation and sustainable business practices.

C. Applying Green Leadership in Energy Transition at the Local Level

The implementation of green leadership in the energy transition at the local level is critical to accelerate change towards a more sustainable society as a whole and reduce negative impacts on the environment. Related to that, there are several steps that can be taken in implementing green leadership in the energy transition at the regional level.

1) **Promote the Use of Renewable Energy**. Local governments can formulate policies and programs to encourage the use of renewable energy, such as wind, solar and biomass. In this regard,

green leadership can promote the development and investment of renewable energy and reduce dependence on unsustainable fossil fuels. The availability of water as a source of renewable energy can also be utilized for industry and agriculture (Singh et al., 2020).

2) **Develop Renewable Energy Infrastructure**. Local governments can build infrastructure that supports the use of renewable energy, such as grid electricity and electric vehicle charging. In this regard, green leadership can encourage collaboration between local governments, communities, and the private sector to build effective and efficient renewable energy infrastructure. Estimation of various economic impacts is a difficulty in measuring the benefits of mitigation (Piontek et al., 2021).
3) **Promoting Energy Efficiency**. Local governments can develop policies and programs to promote energy efficiency in the household, industrial and transportation sectors. In this regard, green leadership can encourage increased public awareness of the importance of efficient energy use and develop training and education programs. Modern healthcare facilities are capable of creating energy and technological solutions for more efficient cooling (Das & J., 2023).
4) **Fostering Collaboration between Local Government, Communities, and the Private Sector**. Green leadership can promote collaboration between local government, communities, and the private sector to build effective partnerships in developing policies and programs that support the energy transition. Such collaborations can involve developing new technologies, investing in renewable energy, and improving energy efficiency. An integrated approach to natural management is often out of sync with weak governance (Riggs et al., 2018).
5) **Increase Citizen Participation**. Green leadership can encourage citizen participation in the development of policies and programs that support the energy transition. In this regard, local governments can develop effective mechanisms for community participation, such as public forums, consultations, and surveys.

Integrating people's climate change adaptation with a holistic approach can reduce the impact of climate change and increase urban resilience (Wijaya et al., 2020).

In order to apply green leadership in the energy transition at the local level, it is important to develop policy and program frameworks that are sustainability oriented and based on green leadership principles. Furthermore, collaboration between local government, communities, and the private sector, as well as community involvement, is important in achieving the best results for the energy transition at the local level. This collaboration plays a role in:

1) strategies determination for implementing green leadership in the energy transition;
2) encouraging the role of regional heads in supporting green energy and leadership transitions; and
3) managing impacts of the energy transition resulting from green leadership at the local level.

D. Moving Towards Net Zero Waste: The Case of Central Java

Central Java is a province with an area of around 32,548.20 km^2, consisting of 35 regencies/cities. Besides its capital city of Semarang, it has several other important cities, such as Solo. Some of these areas have considerable natural resource potential, including mineral, forests and timber, ground water, as well as renewable energy sources such as geothermal energy and hydropower.

Central Java also has various tourism potentials, including historical and cultural sites, national parks, and beautiful beaches. Some popular tourist objects in Central Java include Borobudur Temple, Prambanan Temple, Merapi National Park, Merbabu National Park, and Parangtritis Beach (although administratively, this beach is part of Special Region of Yogyakarta). As an area that has a lot of potential, energy use is of particular concern to support all socio-economic activities in Central Java. As a province that is committed to implementing green leadership in the energy transition at the regional level, Central Java has carried out various programs and projects to develop renewable energy and improve environmental quality. Several case studies reflecting green implementation leadership in Central Java has been described in the previous question. A number of laws regulate the green leadership in Central Java: Law No. 14 of 2018 concerning public openness, Government Regulation No. 41 of 1999 concerning air pollution control, Minister of Environment Decree No. 45 of 1997 concerning standard index of air pollution, and Minister of Environment Decree No. 115 of 2003 concerning guidelines for determination of water quality status. Ministry of Environment and Forestry (Kementerian Lingkungan Hidup dan Kehutanan [KLHK], 2019) inform that Central Java has Index Quality of Life = 60.97; Index Quality of Water = 51.64; Index Quality of Air = 84.81; and Index Quality of Land Cover = 50.08.

Central Java has become one of the provinces that is committed to implementing green leadership in the energy transition at the local level. Figure 8.1 shows a flow chart of energy production, from raw material until it reaches consumers, for PLTS, Microhydro, and PLN.

PLTS	MICROHYDRO	PLN
Raw Materials (Solar Panel) ↓ Solar Panel Manufacturing ↓ PLTS Installation and Construction ↓ Connection with the Power Grid ↓ Converting Sunlight Into Electricity ↓ Energy Storage (Optional, Battery) ↓ Use of Electrical Energy by Consumers	Water Source (River Flow) ↓ intakes (Water Collection Point) ↓ Water Flow Pipe to the Powerhouse House ↓ Powerhouse House (Turbine and Generator) ↓ Hydro Energy Transformation into Electrical Energy ↓ Voltage Regulation and Transformation ↓ Connection to the Power Grid ↓ Use of Electrical Energy by	Reservoir ↓ Regulation of Water Flow by Dams ↓ Water Intake Channel to Hydropower Turbine ↓ Potential Energy Conversion Into Mechanical ↓ Mechanical Conversion into Electrical Energy ↓ Voltage Regulation and Transformation ↓ Connection to the Power Grid ↓ Use of Electrical Energy by

Figure 8.1 Renewable Energy Flow Chart from Raw Materials to Its Use

1. Implementation of green leadership in transition energy at Central Java

The implementation of green leadership in Central Java looks quite advanced in the energy transition. Several strategies have been carried out local government to develop renewable energy and improve environmental quality in the province. These are some examples.

1) In 2016, Central Java launched a Biomass Energy program to promote the development of renewable energy and reduce carbon emissions in the province. The program includes the development of solar power plants, biomass energy, and the use of biofuels. One plant that is promoted for bioenergy is *nyamplung* (*Calophyllum inophyllum* L.). It is a type of coastal plant which can be extracted as an alternative source of bioenergy (Hani & Rachman, 2016). The local government is also trying to promote the use of environmentally friendly transportation, such as bicycles and public transportation.
2) In 2019, PT PLN (State Electricity Company) implemented a solar power plant (PLTS) construction project in Demak with a capacity of 10 MWp. This project is expected to increase clean energy production in Central Java and help reduce greenhouse gas emissions.
3) Regional Government of Banyumas, in cooperation with PT PLN, has built several micro-hydro power generating units in the area. This program is expected to utilize the potential of water energy to produce clean electricity and strengthen energy security in rural areas.
4) The Government of Central Java is collaborating with the private sector and non-governmental organizations (NGOs) to improve energy efficiency in small and medium industries (IKM). One example is in Dieng, which is a highland area with abundant water sources that are used for irrigation water needs (Hadi et al., 2013). The project includes installing energy-saving equipment, training workers, and developing an energy management system.

The examples above show Central Java's success in implementing green leadership in the energy transition at the regional level. Local governments and related parties work together to develop renewable energy, improve energy efficiency, and promote environmentally friendly transportation. This is a positive effort in overcoming environmental problems and improving the quality of life of the community.

The following are several case studies that further illustrate the application of green leadership in the energy transition in Central Java.

a. Construction of PLTS in Kandri Village, Kebumen

The Kebumen Regency Government, Central Java, has a solar power plant (PLTS) in Kandri Village with a capacity of 600 kWp. The PLTS provides a stable supply of electricity for around 3,000 households in the village. The project is the result of cooperation between the local government, village-owned enterprises (BUMDes), and the private sector. In addition, this project has also provided economic and social benefits for the local community, such as increased access to clean energy and business opportunities for BUMDes.

This PLTS is an outstanding example of sustainable development and collaboration. The project's multifaceted benefits extend beyond its capacity to supply stable electricity to local communities. Here are some notable results.

1) **Community Empowerment**. This project has empowered the local community by giving them access to a reliable and clean source of electricity. This not only improves their quality of life, but also allows them to carry out activities that were previously hindered by a lack of electricity.
2) **Economic Growth**. By collaborating with BUMDes and the private sector, this project has contributed to the local economy. The establishment and operation of the solar power plant has created jobs and stimulated economic activity in the village.
3) **Business Opportunities for BUMDes**. The partnership between BUMDes and the private sector highlights the potential for local businesses to actively participate in renewable energy initiatives. This collaboration not only generates revenue for BUMDes but also demonstrates the feasibility of the partnership for future sustainable projects.
4) **Reduced Environmental Impact**. Utilization of solar energy significantly reduces dependence on fossil fuels, thereby reducing greenhouse gas emissions and promoting a cleaner environment.

This is in line with global efforts to mitigate climate change and promote sustainable development.

5) **Community Resilience**. With a steady supply of electricity from solar power plants, communities are more resilient to power outages and interruptions, especially during adverse weather conditions or grid failures.
6) **Educational Opportunities**. Solar power plants serve as educational tools for communities, enabling them to learn about renewable energy, energy conservation and the importance of sustainability.
7) **Demonstration of Effect**. The successful implementation of the project can serve as a model for other areas in Central Java and its surroundings. It demonstrates the benefits of collaboration and adoption of renewable energy, inspiring similar initiatives in neighboring areas.
8) **Local Ownership and Pride**. The involvement of local government, BUMDes, and the private sector fosters a sense of ownership and pride among community members. They saw a direct impact from their collaboration in improving village infrastructure and overall well-being.
9) **Alignment with National Goals**. This project is in line with Indonesia's national goals to increase renewable energy capacity and reduce dependence on fossil fuels. This contributes to the country's efforts to transition towards a more sustainable energy landscape.
10) **Enhanced Social Structure**. Collaboration between various stakeholders strengthens social bonds within the community. Growing a sense of unity and shared responsibility for the progress of the village.

In conclusion, the PLTS in Kandri Village exemplifies the positive results that can emerge from collaboration between the local government, the private sector, and village-owned enterprises. By providing clean energy, economic growth and multiple benefits to society, this project is a shining example of sustainable development and green leadership in Central Java.

b. "PLN Cares for the Environment" Program

PT PLN Main Unit as a distributor of electricity in Central Java and Special Region of Yogyakarta has launched the "PLN Cares for the Environment" program, which aims to encourage the use of efficient and renewable energy in Central Java. This program includes the construction of PLTS, the construction of a more efficient electricity grid, and energy saving education for PLN customers. In addition, this program also involves collaboration with the public and the private sector in developing sustainable solutions. Prevention of sedimentation in the Mrica Reservoir cooperate with the community so that the sedimentation rate is reduced, so that the function of the reservoir as a provider of water and electricity can last longer (Wulandari, 2007).

The program shows PLN's commitment to encourage the sustainability and adoption of renewable energy in the region. The program's multifaceted approach not only addresses energy efficiency but also emphasizes collaboration with various stakeholders for sustainable solutions. The main components of the program are outlined as follows.

1) **Promotion of Efficient and Renewable Energy**. This program aims to raise awareness about the importance of efficient and renewable energy sources. This could lead to reduced carbon emissions, less reliance on fossil fuels, and a more sustainable energy future for Central Java and DIY.
2) **Development of Solar Power Plants (PLTS)**. Establishment of PLTS contributes to the expansion of clean energy capacity. Solar energy is abundant and environmentally friendly, in line with the goal of reducing greenhouse gas emissions and promoting sustainability.
3) **Development of an Efficient Grid**. Building a more efficient grid will increase the reliability and resilience of the energy supply.

This can minimize energy loss during transmission and distribution, resulting in a more cost-effective and environmentally friendly system.

4) **Energy Saving Education for Customers**. Educating PLN customers about energy efficient practices empowers them to reduce energy consumption and contribute to a more sustainable energy ecosystem. This education is in line with the broader objective of achieving efficient use of resources.
5) **Community Collaboration: Prevention of Sedimentation in the Mrica Reservoir**. Collaborating with the community for the prevention of sedimentation in the Mrica Reservoir is a prime example of involving local stakeholders in environmental protection efforts. By decreasing the sedimentation rate, the life of the reservoir and its function as a provider of water and electricity will be longer.
6) **Private Sector Partnership**. Private sector involvement in the program demonstrates a multi-stakeholder approach to sustainability. Collaboration with private entities can facilitate expertise, resources, and innovation to drive sustainable solutions.
7) **Development of Sustainable Solutions**. Collaborating with communities and the private sector emphasizes the program's dedication to finding long-term solutions that benefit the environment and local communities.
8) **Preserving Water and Power Resources**. Sedimentation prevention efforts directly contribute to ensuring the continued function of the Mrica Reservoir as a reliable source of water and electricity. This is in line with the principle of responsible resource management.
9) **Positive Social Impact**. The program's community engagement increases social cohesion and engagement, as local residents participate in efforts to protect their environment and secure vital resources.

10) **Synergy with National Goals**. The program's focus on efficient and renewable energy aligns with Indonesia's broader goals of reducing carbon emissions and advancing sustainable development.

By combining these initiatives, the "PLN Cares for the Environment" program contributes to creating a more sustainable, efficient, and environmentally sound energy landscape in Central Java and Yogyakarta. Collaboration with various stakeholders underscores the importance of joint efforts in achieving long-term sustainability.

c. Development of electricity-based transportation in the city of Semarang

The Municipal Government of Semarang, Central Java, is developing a program to encourage the use of electricity-based transportation. This program includes developing electric vehicle charging infrastructure, procuring electric vehicles for bus fleets, and developing application-based transportation systems. This program also involves community participation in the development of sustainable transportation solutions. The program initiated by the Municipal Government of Semarang in Central Java to encourage the adoption of electricity-based transportation is a commendable step towards sustainable urban mobility. By addressing various aspects of the transportation system, the program presents a comprehensive approach to reducing carbon emissions and improving the quality of urban life. The main components of this program are as follows.

1) **Development of Electric Vehicle Charging Infrastructure**. Establishing a network of electric vehicle (EV) charging stations is essential to support the growth of electric transportation. By offering convenient charging options, the city is encouraging more individuals and businesses to adopt EVs, reducing dependence on fossil fuel-powered vehicles.
2) **Procurement of EVs for the Bus Fleet**. Introducing electric buses into the city's public transport system not only reduces air and noise pollution but also serves as a model of sustainable

urban mobility. Electric buses offer a cleaner and energy efficient alternative to traditional diesel-powered buses.

3) **Application-based Transportation Systems**. The development of application-based transportation systems, such as ride-sharing or ride-hailing platforms for electric vehicles, provides residents with comfortable and environmentally friendly transportation options. It promotes the use of EVs for everyday commuting.
4) **Community Involvement in Sustainable Transport**. Encouraging community participation in the development of sustainable transport solutions creates a sense of ownership and responsibility among citizens. Community input can help adapt the program to local needs and preferences.
5) **Reducing Carbon Emissions**. The program's focus on electric transport contributes to reducing a city's carbon footprint, which is critical to fighting air pollution and tackling climate change.
6) **Improving Air Quality**. Electric vehicles generate zero exhaust emissions, leading to improved air quality in cities. This has direct benefits for public health by reducing respiratory and cardiovascular problems related to air pollution.
7) **Noise Reduction**. Electric vehicles are quieter than vehicles with internal combustion engines, which leads to reduced noise pollution in urban areas and improves the overall quality of life of residents.
8) **Demonstration of Effect**. By introducing EV and charging infrastructure, the city is setting an example for other regions and cities to follow. This is driving a wider transition to electric transport.
9) **Economic Opportunities**. Developing charging infrastructure and embracing electric transportation can drive economic growth by attracting investment, creating jobs in related industries and supporting local businesses.

10) **Better Energy Security**. By reducing dependence on imported fossil fuels, the city increases its energy security and resilience against external energy supply disruptions.
11) **Technological Advances**. Embracing electric transport promotes the adoption of advanced technologies, contributing to innovation and technological progress in the transport sector.
12) **Urban Livability**. The shift towards electric transport increases the livability of cities by reducing traffic congestion, promoting active modes of transport, and creating cleaner and more pleasant urban environments.

The Semarang City Government's program to encourage electrified transportation reflects a forward-thinking approach to urban mobility and sustainability. By integrating charging infrastructure, electric buses, application-based systems and citizen participation, this program has the potential to change transportation patterns, reduce environmental impact and improve the city's overall quality of life.

In an effort to optimize the electric vehicle program in Central Java, an electric vehicle battery factory has been built in the Integrated Industrial Area (KIT) Batang Regency with an integrated concept between nickel mining, smelter construction, precursor cathode factory. Electric vehicles are one of the potential sources to rely on in an environmentally friendly energy transition amidst the ongoing climate crisis. Batteries, which are energy storage systems, are essential for electric vehicles, plug-in hybrid electric vehicles (PHEV), and hybrid electric vehicles (HEV).

There are important things that must be considered in implementing the battery usage policy for electric vehicles, namely battery life. This is important, because when the battery runs out, it will become waste that requires special handling, so it needs to be supported by policies and a monitoring system regulated by the local government. Battery life for electric vehicles, including electric bicycles, electric motorcycles and electric cars, may vary depending on several factors, including the type of battery used, how it is used, its operating environment, and the charging technology.

The reuse or recycling of electric batteries waste is very important as they reduce the negative environmental impact and minimize the accumulation of hazardous waste. Electric batteries contain chemicals that can pollute the environment if not managed properly. There are several actions that the Central Java Regional Government and other regions must take as part of battery waste management: collection and sorting, safe transport, processing, components recycling, processing of toxic materials, reuse or rehabilitation, energy recycling, and safe disposal.

It is important to note that electric battery recycling can be a complex process as it involves different types of batteries with different components and chemicals. Therefore, local governments need to maintain effective and safe recycling systems by developing adequate infrastructure and an understanding of the proper treatment of various types of batteries.

2. The results of the energy transition in Central Java

Through those case studies, it can be seen that Central Java has taken concrete steps in implementing green leadership in the energy transition at the regional level. Collaboration between local government, communities, and the private sector as well as community participation is a major factor in achieving optimal results. It is hoped that with the application of this green leadership, Central Java can reduce negative impacts on the environment and improve people's welfare in a sustainable manner. Although several efforts have been made in implementing green leadership and energy transition in Central Java, an in-depth evaluation of the results achieved still needs to be carried out in more depth.

The following are some things that need to be evaluated regarding the results of the energy transition in the Central Java region.

1) **The Contribution of Renewable Energy to Energy Supply in Central Java**. In recent years, the government of Central Java has

developed several renewable energy projects such as solar and micro-hydro power plants. However, how much the contribution of renewable energy to energy supply in Central Java needs to be evaluated in more detail.

2) **Reducing Greenhouse Gas Emissions**. It is hoped that the application of green leadership in Central Java can help reduce greenhouse gas emissions and have a positive impact on the environment. Evaluation of reducing greenhouse gas emissions in needs to be done to find out whether the set targets can be achieved.
3) **The Implementation of Green Leadership**. The effectiveness of the system must also be evaluated for social and economic impacts. Several things that need to be evaluated include whether there is a positive impact on people's welfare, how many jobs are created, and how big the economic impact is.
4) **Project Sustainability**. An evaluation of the sustainability of a renewable energy project in Central Java also needs to be carried out to find out whether the project can run sustainably and provide long-term benefits for the community.

By evaluating the progress of energy transition in Central Java, it can be identified how far the effort has gone, whether it has been successfully deliver benefits to society or not. It can also become a base development to improve existing programs, as well as developing new ones that are more effective in addressing environmental problems, thus improving the quality of life for people in Central Java.

Ultimately, evaluating the results of Central Java's energy transition efforts is critical to determining the effectiveness and impact of green leadership initiatives. These assessments provide valuable insights that can guide future decision-making, improve ongoing programs, and inform the development of new strategies. Here's how evaluating results can contribute to the overall success of the energy transition and green leadership in Central Java.

1) **Effectiveness Assessment**. Evaluation helps determine whether the implemented program is achieving its intended goals, such as increasing the adoption of renewable energy, reducing carbon emissions, improving air quality, and increasing energy security. It highlights which aspects of the green leadership approach are working well and which may need adjustments.
2) **Benefit Analysis**. By assessing the benefits that people experience—such as increased access to clean energy, job creation, economic growth, and improved quality of life—local governments can communicate the real impact of the energy transition to their constituents.
3) **Lessons Learned**. The evaluation identifies challenges, barriers, and lessons learned during the implementation of green leadership initiatives. This knowledge helps avoid repeating mistakes and provides insight into potential solutions.
4) **Program Improvement**. Identifying areas where the current program may be lacking or needs improvement allows local government to make necessary adjustments. This ensures that the programs are adaptive and responsive to changing circumstances.
5) **Expansion and Scaling**. Successful results can form the basis for upgrading or expanding existing programs to cover a wider area or cover more communities. Successful model replication can generate a greater impact across the region.
6) **Development of New Programs**. Evaluation results can guide the development of new and innovative programs that address emerging environmental challenges and align with changing societal needs. This promotes continuous progress and adaptation.
7) **Resource Allocation**. Evaluation helps the local government to allocate resources more efficiently by focusing on initiatives that have the highest impact. This allows them to prioritize investment in areas that bring significant positive change.

8) **Evidence-Based Decision Making**. Data and insights from evaluations provide a sound basis for evidence-based decision-making, ensuring that future actions are based on empirical evidence rather than assumptions.
9) **Stakeholder Engagement**. Sharing evaluation results with stakeholders, including communities, the private sector, and non-governmental organizations, promotes transparency and inclusiveness in decision-making processes.
10) **Sustainability and Accountability**. Regular evaluations ensure that energy transition efforts are sustainable over time and local governments remain accountable for the commitments made to promote green leadership.
11) **Policy Alignment**. Evaluation results can be used to adjust policies and regulations to better support the energy transition, ensuring alignment between green leadership initiatives and broader sustainability goals.
12) **Global Reporting and Recognition**. Positive evaluation results can be shared at regional, national, and international levels, demonstrating Central Java's commitment to sustainable development and contributing to its reputation as a leader in green initiatives.

Evaluating the results of energy transition efforts in Central Java provides a holistic understanding of the impact and effectiveness of green leadership initiatives. This empowers local governments to make informed decisions, optimize resources, and forge ahead towards a more sustainable and prosperous future for their region and people.

There are several factors supporting and inhibiting the implementation of green leadership in the energy transition at the regional level in Central Java. These are the supporting factors.

1) **Renewable Energy Resource Potential**. In Central Java, solar, wind, and biomass power is large enough to make it easier for the government to develop renewable energy in the region.

2) **National Policy**. The central government has set national targets to increase the use of renewable energy, thereby encouraging local governments to implement green energy policies.
3) **Availability of Funds**. The local government has provided substantial funds to support the development of renewable energy projects.
4) **Increasingly Advanced Technology**. Technology for the development of renewable energy is increasingly advanced and affordable, thus encouraging people and entrepreneurs to switch to renewable energy.

Meanwhile, these are the inhibiting factors.

1) **Limited Human Resources**. The limited number of experts and skilled workers in the field of renewable energy in Central Java is an obstacle in the development of renewable energy.
2) **Regulatory and Bureaucratic Issues**. The complicated and time-consuming process of permits and regulations in Indonesia is an obstacle in the development of renewable energy.
3) **Dependence on Fossil Energy**. The dependence of society and industry on fossil energy is still very high, making it difficult to switch to renewable energy.
4) **Lack of Public Awareness**. People are still not aware of the importance of renewable energy and the need to switch to energy that is more environmentally friendly.
5) **Funding Problems**. Renewable energy development requires a lot of money, making it difficult for those who are less financially able to do it.

To overcome those inhibitors in the implementation of green leadership for energy transition in Central Java, there are several coping strategies that can be taken by the local government.

1) **Training Experts and Skilled Workers**. To create more experts and skilled workers, local government may conduct training programs, courses, and certifications in the field renewable energy
2) **Simplification of Licensing and Regulatory Processes**. The process of licensing and regulation in the field of renewable energy must be eased to help the development of renewable energy projects in Central Java.
3) **Diversification of Energy**. This is important to reduce dependency on energy fossil. It can be done through campaign and social in a continuous manner. The campaign should be about the benefits of renewable energy and the dangers of fossil energy for the environment.
4) **Society Awareness Enhancement**. The people need to know about the importance of renewable energy and the benefits it brings for the environment and economy. This can be done through mass media, seminars, and activities that include society participation.
5) **More Funding Scheme**. Affordable loans, incentives, and development programs for projects in renewable energy renewable can push society and entrepreneurs to support and, ultimately, switch to renewable energy in Central Java.

E. Closing

From the analysis performed, it can be concluded that implementation of green leadership in transition energy in Central Java has brought a number of positive results. Several projects in renewable energy such as solar and micro-hydro power has been successfully developed and contributing in provision of energy in the Central Java region. Additionally, some policies and programs that have carried out also gives impact positive for environment and welfare of society. Nevertheless, there are still some obstacles in the implementation of green leadership in Central Java. These obstacles include limited funds, lack of infrastructure, and low public awareness of the importance of using renewable energy.

For this reason, several recommendations are needed so that green leadership in Central Java can run more effectively and sustainably. Some of the recommendations that can be given are:

1) development of programs and policies that are more comprehensive and sustainable to increase the use of renewable energy in Central Java;
2) improved coordination between the government, the private sector and the community is needed in developing renewable energy projects;
3) increased public awareness through campaigns and socialization of the importance of using renewable energy;
4) increased investment in renewable energy infrastructure such as the construction of electricity networks that can support the development of renewable energy projects; and
5) development of cooperation with other regions to obtain technical and financial support in the development of renewable energy.

Thus, the application of green leadership in Central Java can be continuously improved and have a greater positive impact on the environment and people's welfare. As future suggestions, there are several steps that can be taken to develop transition at the local level through green leadership, especially in Central Java, such as:

1) further identifyy what factors influence the successful implementation of green leadership in the energy transition in other regions in Indonesia;
2) conduct more in-depth activities on the impact of energy transition on the environment and people's welfare in Central Java;
3) conduct comparative studies between regions that have successfully implemented green energy policies and regions that have

not been successful in order to find out what factors differentiate the two;

4) carry out further activities regarding the effect of changes in national policies on the implementation of green energy policies in the regions, especially in Central Java; and
5) conduct more specific activities on the role of local government in supporting the development of renewable energy projects in Central Java.

The steps mentioned above might provide more comprehensive and in-depth information as well as insights on the implementation of green leadership in the energy transition at the regional level, especially in Central Java. This is expected to assist the government and society in increasing the development of renewable energy and improving environmental quality and welfare of society as a whole.

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Chapter 9

Indonesia's Real Steps Towards 2045

Riostantieka Mayandari Shoedarto

A. The Changes That Keep Rolling

Can you recall the last time you went a whole day without electricity? Without the soft glow of your laptop screen and the quiet hum of the gadgets that have become an extension of you? Let's take a trip down memory lane to the 18th century, when our energy scene was all about muscles and biomass ruling the roost. And then, bam! The Industrial Revolution hit in the mid-19th century, bringing coal to the party as the ultimate energy superstar. It powered steam engines and kept the world moving along. As the 20th century unfurled its chapters, coal maintained its dominance, but it was an era of subtle transition towards higher-energy-content sources, a journey that led us towards the beckoning horizon of oil. In the second half of the

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1900s, petroleum became a big deal, stealing the show and creating a tangled mess of reliance in the global economy. It was an era of advanced technology that enabled us to produce nuclear electricity and find more gas. Back then, renewable sources like hydroelectric, wind, and solar energy were just starting to make their debut in the energy world. They were like quiet little whispers in the momentous symphony of energy.

In the 21st century, energy runs our lives like an unseen hand. It shines light on this text you are reading, facilitating the flow of information. Yet, it is not merely about lighting up rooms or charging devices, it is about thriving us in the whirlwind of the interconnected world, effortlessly engaging in social activities. Energy, harnessed through the combustion of fuels in engines, propels us forward, amplifying our capacities and supercharging human mobility. It is impossible to imagine a world without easy access to energy sources. The energy revolution keeps brewing for a sea change, until the advent of Covid-19 and the ongoing Russia-Ukraine War. While it is true that the pandemic and political turmoil have significantly hampered the growth of renewable energy and created an unclear trajectory for the energy transition overall, it became clear that our approach to energy must change to meet the needs of the present and ensure a sustainable future. As the world endured with the implications of the crisis, the journey of transition must go on.

This book is the real work of writers, researchers, and thinkers who accepted BRIN's invitation to be involved in collective thinking about the dynamics surrounding the energy transition that has been taking place in Indonesia since we resumed our daily lives after the pandemic. Within the pages of this book, you have found seven ideas that start the inception of the seven chapters in this book, covering the ins and outs of the multidimensional energy transition journey: from the depths of the ocean to the heights of urban landscapes; from preparation evaluations to appeals for equitable action; and from technical innovation to economic strategies and environmental management to navigating the uncharted waters of *Indonesia's Energy*

Transition Preparedness Framework Towards 2045. The seven chapters in this book are a legacy for future writers, potentially including you, to continue what has been written so as not to repeat from the beginning and avoid overlapping ideas.

B. Indonesia ‘s Ocean Energy Overlook

“*Nenek moyangku seorang pelaut* …”[1] is lyric from a song well-known to almost all of Indonesian children. Our seafaring ancestors were skilled mariners, finding immense joy in traversing the vast expanse of the world’s oceans. The song from our early childhood is an ancestral hint that the ocean has enormous potential to be a source of energy in addition to having the ability to support marine life. Thus, Part 1 of the book, which also contains only one chapter, welcomes you into the vast blue space surrounding our world, the sea domain, with its unique possibilities. WIth all your dive gear, we dived in an exciting journey through the Indonesian islands, exploring the deepest parts where the promise of clean energy lies.

Although it is commonly recognized that the Earth’s natural gas and oil reserves are located beneath the seafloor, the ocean itself has potential for energy production. The huge maritime region encircling the Indonesian archipelago plays an integral part in connecting the Asian and Australasian continents. Positioned within this unique web of water are the Sunda and Sahul tectonic plates, nestled amidst a predominantly shallow underwater landscape, with an average sea depth of 200 meters, or less (Ministry of Marine Affairs and Fisheries & USAID, 2018; Simanjuntak, 2006). A hidden universe appears throughout this expanse, complete with subaquatic passageways, deep sea basins, and hidden volcanoes. Notable among these geological features is the Banda region, boasting a profound underwater trench plunging to depths of 7,440 meters, while the Celebes Basin in Sulawesi claims the title of being the deepest at 6,220 meters (Asian Development Bank, 2014). Sill depths, where shallow areas border

1 Roughly translated to "My ancestor was a sailor..."

deep depressions, are key ocean circulation channels. Geographical characteristics help cold water rise from the depths.

Indonesia, where the Pacific and Indian Oceans meet, has a diverse underwater terrain vital to global ocean circulation (Qu et al., 2005). The Indonesian Throughflow (ITF) is a central low-latitude corridor that transports warm, fresh Pacific Ocean water to the Indian Ocean. The upper cell's global overturning circulation, as highlighted by Feng et al. (2018), relies on this crucial component. The significant temperature contrast between warm surface water and cold deep-sea water holds the potential to serve as a renewable energy source known as Ocean Thermal Energy Conversion (OTEC), which is an emerging technology designed to generate electricity by harnessing this temperature difference.

Our journey begins with exploring OTEC into the theoretical potential of up to 30 terawatts on a global scale (Rajagopalan & Nihous, 2013). OTEC has tremendous potential in Indonesia, though its development is being prioritized over other renewable energy sources such as hydropower, solar cells, and geothermal energy. Writing about OTEC presents an opportunity for authors to explore techniques to increase OTEC knowledge and acceptance across various social segments and stakeholders, ensuring its high demand and redirecting developers' focus away from the financial barriers it currently implies. Despite its high development costs, OTEC has captured the interest of Indonesian renewable energy enthusiasts for years like Ristiyanto.

Together with his team, Ristiyanto investigated a range of offshore OTEC plant models, from resilient tension-based systems to robust tanker-based designs. They offer an insightful overview of Indonesia's oceanic energy landscape, where technological advancements intersect with system optimization. Here, we explore each of the three primary varieties of OTEC—closed cycle, open cycle, and hybrid cycle—functions as the central component of OTEC systems, facilitating thermal energy conversion into mechanical and electrical power. We also look into the inner workings of radial flow turbines and the spine of the OTEC platform system, the unsung heroes of this green energy revolution.

Beyond the machinery, there is more to our dive into the ocean. We venture into the potential co-products of OTEC, shedding light on water desalination, hydrogen production, and the utilization of nutrient-rich, low-pollution deep-sea water for aquaculture, food production, cosmetics, and lithium extraction. By building connections with other local renewable energy sources, OTEC's ability to attract investment interest in Indonesia can be considerably increased. Collaboration with local economic and renewable energy opportunities in Indonesia also helps to explore the potential byproducts of OTEC further. However, our voyage also underscores the need to consider the possible environmental effects and ensure that our search for green energy does not adversely affect the health of our valuable ecosystem. The chapter has unequivocally demonstrated that OTEC is crucial to achieving Indonesia's goals for renewable energy, allowing the country to look forward to benefiting from OTEC's clean baseload electricity. Although the road ahead may be challenging, the promise of realizing commercial-scale OTEC power plants is within reach, offering a sustainable energy future while acknowledging the ocean's abundant resources as a divine blessing.

C. The Efforts for Successful Energy Transition

As previously told in Part 1, Indonesian ancestors fearlessly confronted the turbulent currents and were intimately familiar with the unpredictable storms that frequented the seas. Their experiences symbolize our journey to the unpredictable storm of changes and our approach to successfully navigate it. This inspires the conception of Part 2.

Energy transition involves more than just fuel mix changes or manufacturing technology changes. Social, economic, and technological systems must co-evolve to shape the shift (Cherp et al., 2018; WEF, 2021). Indonesia ranks 71st with a 2012–2021 Energy Transition Index (ETI) score of 56 out of 100 which is below the global average of 59.3. The total ETI score includes energy system performance and transition preparedness subindices. As an emerging and rising Asian nation, Indonesia has a system Performance Index of 67.8 above the global's score; and Transition Readiness of 44.8, below the global average of 54.8 (World Economic Forum, 2021). Over the past decade, 70% of ETI-tracked countries have improved their energy system performance scores, indicating a growing capacity to deliver on economic development, energy access and security, and environmental sustainability.

Our journey arrives at a point where an important question arises that resonates and reverberates throughout institutions, governmental corridors, business sectors, and the public domain. To what extent is Indonesia prepared for the forthcoming decades? The inclusion of the article by Nugroho et al. is justified as it can provide a basis for future monitoring of the Energy Transition Readiness Index in the country. The authors embark on a comprehensive examination of Indonesia's readiness from multiple critical perspectives, encompassing the policy framework, charting our progress while identifying avenues for improvement. additionally, they explore the fertile ground of investment opportunities, realizing the potential to stimulate economic growth and create employment opportunities. In tandem, infrastructure development emerges as a pivotal puzzle piece, underscoring the necessity of robust foundations to integrate renewable energy sources into our infrastructure seamlessly. Ultimately, these insights lead to recommendations that outline our way to a more sustainable and secure energy future through dedication and strong collaborations.

The stakeholder analysis of collaborators in the renewable and sustainable energy sector in Indonesia often involves the utilization of the Political, Economic, Social, Technological, Legal, and Environmental (PESTLE) methodology, serving as a foundational tool for strategic decision-making (Yudha & Tjahjono, 2019). In Chapter Four, Majesty and Purnamasari's work focuses on breaking down the PESTLE framework into actionable strategies. They emphasize the necessity of ongoing interactions between governments, international standard-setting bodies, and the private sector. More frequent experience sharing and exhibiting of successful energy transition initiatives in Indonesia and other relevant countries is also crucial.

As a member of the Association of Southeast Asian Nations (ASEAN), Indonesia finds itself at a critical juncture due to the increasing domestic energy demand. This growth poses significant challenges in ensuring the provision of sustainable and cost-effective energy. Despite the renewable energy target established by the ASEAN to achieve 23.2% by 2025, the existing policies in several ASEAN countries only facilitate the implementation of renewable energy sources to a limited extent, accounting for less than 16.9% of the total. This indicates a significant gap of approximately 6.3% between the current progress and the desired target. In order to address this disparity, it is mandatory that each ASEAN nation, including Indonesia, assumes the responsibility of improving the proportion of renewable energy sources. The level of contribution is directly related to the country's size, the total energy demand within the country, and the presence of local renewable energy sources (ACE, 2023).

Majesty and Purnamasari also emphasize the importance of promoting electric vehicle stakeholders in the pursuit of decarbonization and a seamless energy transition. Additionally, they advocate for the establishment of a pool of energy transition specialists to safeguard against local and national brain drain. Their proposal encourages the collaboration of diverse sectors and media outlets to engage in public education campaigns, thus fostering capacity building and instigating behavioral change. Furthermore, the authors discuss innovative financial strategies aimed at expediting the diversification of funding sources for energy transition projects. Among the key stakeholders highlighted are the Coordinating Ministry for Maritime Affairs and Investment Affairs, the Chambers of Commerce, and the Ministry of National Development Planning, each holding significant importance and offering convenient accessibility. Nevertheless, the assessment underscores the importance of considering the relevance of other entities within this framework.

As the energy transition continues to evolve, stakeholder mapping must be refreshed to adapt to changing dynamics, make informed decisions, and enable a successful and inclusive energy transition to cleaner and more sustainable sources (Yudha & Tjahjono, 2019). Stakeholder mapping in energy transition involves identifying, categorizing, and analyzing the diverse entities and individuals with a stake in the transition from fossil-fuel-based energy systems to cleaner, more sustainable ones.

In this part, we are given the opportunity to gain an all-encompassing comprehension of the interests and motives of various stakeholders, evaluate their level of influence, and determine their relationships and interactions within the transition process. By categorizing stakeholders based on their influence and interest, this approach provides a nuanced understanding of who stands to gain or lose from the energy transition and helps decision-makers tailor engagement and communication strategies accordingly. As a fundamental tool, stakeholder mapping goes beyond identification to mitigate possible conflicts and build critical collaborations. It effectively amplifies voices, ensures accountability, and builds trust, proactively addressing issues and objections while advocating the transparency needed to negotiate the complex electricity industry. The power industry drives worldwide economic and social progress. Transitioning to renewable energy sources reduces carbon emissions, promoting environmental stewardship and sustainable progress.

The enhancements made by clean-energy businesses will play a significant role in mitigating the effects of global climate change. In this context, the chapter, "Clean Power for Indonesia: Leading the Way in the Energy Transition," underscores the efforts made by Indonesian clean energy companies. Hapsari discusses strategic ways to become a clean power company, emphasizing energy diversification with nuclear power, battery storage, carbon capture and storage (CCS), hydrogen, ammonia, and biomass. This strategic alignment between stakeholder mapping and clean energy developments ensures that Indonesia is well-prepared for a sustainable energy future and actively contributes to mitigating the impacts of climate change through cleaner and more efficient energy solutions.

The author's primary focus is on developing the growth of renewable energy technologies and enhancing skills and knowledge in research, development, and implementation. Renewable technologies have environmental benefits and may provide jobs, economic possibilities, and sustainable energy availability for society. Also important is improving energy efficiency through regulations, including energy efficiency standards and incentive schemes. This unit is critical for decreasing energy use, operating costs, and greenhouse gas emissions. Infrastructure development, particularly sustainable transportation systems, electrified rail networks, and efficient mass transit networks, is also vital to the approach. This infrastructure is essential to minimize air pollution, greenhouse gas emissions, and fossil fuel use. Energy research and innovation require advancing energy technology, efficiency, and worker skills through collaboration worldwide.

Prioritizing sustainability and energy security is imperative to guarantee a reliable energy source while mitigating environmental impact. This overarching objective encompasses several key facets, including the advancement of renewable energy, the promotion of energy sustainability, and the strategic management of energy supply fluctuations. The integration of digital technologies, such as sensors, monitoring systems, data processing, and artificial intelligence, serves as a catalyst for enhancing energy management and monitoring capabilities. Through optimization, energy efficiency is improved, and the seamless integration of renewable energy sources is facilitated.

The localized and intermittent nature of renewable energy, coupled with its limited integration into the national power grid, presents a significant challenge. This chapter reminds us again that, being an archipelagic nation, Indonesia faces the predicament of a disparity between the geographical placement of its renewable energy sources and the centers of electricity demand. In response to this challenge, the State Power Company (PT Perusahaan Listrik Negara, PLN), has developed a comprehensive smart grid system, called the Green

Enabling Super Grid. This system includes various components such as the smart power plant, smart transmission, smart control center, smart distribution, and smart metering. The proposed implementation in Indonesia aims to establish interconnections among previously isolated electricity systems across various islands. Therefore, as per the author's viewpoint, the creation of inter-island transmission networks is crucial for expanding energy sources, decreasing environmental pollutants, and promoting economic growth and technological progress.

Hapsari recognizes that several Indonesian businesses have been developing and implementing clean energy technologies including solar panels, wind turbines, and other renewable energy systems, as well as promoting electric vehicles and employee carpooling, reducing air pollution and transportation's environmental impact. Waste reduction, recycling, and recycled materials are also priorities for certain companies. Public awareness campaigns concerning environmental challenges and sustainable business practices are growing. However, as the author reveals, clean power companies in Indonesia have their share of challenges. These challenges include the persistent barrier of limited access to cost-effective clean technology, a lingering dependence on fossil fuels, hurdles related to infrastructure development, and the ever-present ambiguity of environmental policies. Yet, amidst these formidable challenges lies an unparalleled opportunity for Indonesia's leaders to demonstrate their unwavering commitment to adopting clean and sustainable energy sources. The nation stands poised at a crossroads, with the potential to lead the way toward a more sustainable and progressive energy paradigm.

The concluding chapter within the comprehensive exploration of Part 2 "The Efforts for Successful Energy Transition" spotlights a particularly promising avenue: the advent of batteryless Roof-Top Solar Home Systems (SHS). This innovative approach holds the potential to revolutionize energy consumption while yielding substantial cost savings of up to 30% on electricity bills. Afianti propose the environmental promise that is equally compelling, focusing on reducing carbon emissions and nurturing a healthier environment.

Batteryless SHS, a beacon of sustainable energy, finds its applicability in areas already connected to the electricity grid. This versatile system can seamlessly function on-grid and off-grid by integrating with complementary energy sources like diesel generators.

The study further employed cutting-edge software to scrutinize the synergy of batteryless SHS and diesel generators against standalone diesel generators. The findings unveil a compelling advantage, showcasing that the combined operation of batteryless SHS and diesel generators could yield cost reductions of up to 43% compared to standalone diesel generators. This economic appeal is underscored by a conscientious examination of its environmental impact, revealing that SHS represents a far more environmentally benign choice than traditional diesel generators. However, the allure of significant cost savings—potentially reducing investment requirements by up to 35%—should not overshadow the essential caveat. It is paramount to recognize that the adoption of SHS may entail the production of waste materials. Therefore, it is critical to comprehensively understand these potential waste by-products and proactively address the associated challenges.

D. Environmental and Green Leadership

The last part, Part 3, highlights the fact that Indonesia's economy will continue to expand as energy demands increase. Indonesia possesses the potential to confront the energy trilemmas—energy affordability, security, and sustainability—within the context of energy challenges (World Energy Council, 2021). Nonetheless, this necessity has incurred environmental repercussions in the form of escalating pollution levels, deforestation, and the decline of biodiversity. Chapter 7, "Environmental and Green Leadership," highlights five fundamental facets of the Environmental Assessment (EA) for energy transition technology and green leadership in Indonesia. It is within this chapter that the crucial interplay between Indonesia's transition to renewable energy sources to address environmental challenges comes into focus. Khofsoh et al. assess the potential environmental implications of the proposed energy transition technology in Indonesia, identify any negative environmental effects, and provide solutions to reduce those effects.

At the heart of this chapter lies the indispensable role of a comprehensive Environmental Assessment (EA) which comprehensively evaluates the potential environmental impacts of adopting energy transition technology in Indonesia. It assesses the effectiveness, feasibility, and costs of mitigation strategies to mitigate these effects while also considering the potential residual impacts on human health, cultural heritage, and economic dynamics. The EA also considers the potential for Indonesia to become a global leader in sustainable energy, with local communities benefiting economically and actively participating in cleaner energy resources.

In this complicated setting, the authors employ the Analytical Hierarchy Process (AHP) to aid in informed decision-making. This strategy combines expert insights with data analytics, allowing decision-makers to develop long-term energy investment policies specific to their communities. This knowledge enables them to make well-considered decisions on the best paths for switching to renewable energy sources while reducing negative environmental impacts. Furthermore, the EA process emphasizes the importance of public engagement and consultation. This ensures that all stakeholders, from communities to experts, have a platform to voice their concerns, provide input, and seek clarification on important matters. The EA process serves as a keystone, ensuring that Indonesia's transition to renewable energy sources unfolds sustainably and with a steadfast commitment to environmental responsibility.

Despite Indonesia's potential in various renewable energy sectors, challenges persist in attracting private power investment. Critical to overcoming these challenges is the unwavering support of the government. Such support is essential to mitigate uncertainties in project development and enhance the economic viability of renewable energy initiatives. The chapter also emphasizes the necessity of educating developers and lenders to foster an environment in which project viability is safeguarded. International support in the form of finance, technology, human resources, and technical assistance remains indispensable for achieving these essential goals. Indicative of the nation's commitment to a greener and more environmentally responsible future, Indonesia has made remarkable advances in green leadership on its path to a more sustainable energy landscape.

With more capital and labor going into solar, wind, and hydropower projects, the country has made much progress in increasing its green energy capacity. These measures are vital for lowering Indonesia's reliance on fossil fuels and reducing greenhouse gas emissions. In addition, significant changes in policy, like feed-in tariffs and tax breaks made by the government, have made the private sector more interested in green energy projects. These policy changes show that Indonesia is serious about being a green star and being sustainable. At the local level, provinces and municipalities have also jumped on board with green energy options. They have started community-based renewable energy projects that show how sustainability can be done at the community level.

However, Indonesia has to deal with a number of problems and hurdles on its path to becoming a green leader. The fact that the country still relies on fossil energy, which accounts for 86% (IESR, 2022) is a big problem that needs to be solved in a way that protects both energy security and the environment. Infrastructure gaps, especially in rural and remote areas, make it harder for green technologies to be widely used because there are insufficient power connections and storage options. Also, getting investment for green energy projects is still problematic because the high start-up costs can turn off possible investors and developers. Indonesia's rules and regulations can take time to predict. For example, environmental laws and rules are sometimes changed, making long-term green project planning difficult. Lastly, getting more people to know about and understand the benefits of green energy still needs to be solved. For example, many Indonesians need to fully understand the benefits of using renewable energy or think it is hard to get. In order to advance the implementation of environmentally conscious leadership in Indonesia's energy transition, it is crucial to address and resolve these challenges.

According to WALHI (Wahana Lingkungan Hidup Indonesia-The Indonesian Forum for Living Environment) in 2014, companies are the primary cause of environmental devastation, accounting for 82.5% of all pollution in 2013 (Fahmi et al., 2020). Therefore, if efforts are not made to reduce environmental pollution, there will be a propensity for it to expand as the number of firms increases. Thus, the appropriate leadership style is required to solve this issue. Leaders need to know how to make their organizations more economically competitive, environmentally sustainable, and socially responsible. Businesses need to address today's environmental problems, hence, a company's leadership style will dictate how it reacts to its surroundings.

Harjadi, as the author of Chapter 8 trying to introduce the implementation of green leadership in Indonesia as agent of the transition at the sub-national level. Specifically, Harjadi pinpoints Central Java's energy transition that has yielded several commendable outcomes. The region has successfully developed various renewable energy projects, such as solar power and micro-hydro systems, which have become integral contributors to the local energy supply. Additionally, specific policies and programs promoting green energy adoption have positively impacted the environment and the well-being of the local population. However, despite these achievements, a series of challenges persist, including financial limitations, insufficient infrastructure, and a need for widespread public awareness regarding the benefits of renewable energy. Addressing these challenges necessitates a multidimensional approach involving the development of comprehensive and sustainable policies, improved coordination among stakeholders, heightened public education efforts, increased investment in infrastructure, and strategic partnerships with other regions to secure vital support.

These recommendations encompass several key actions. Firstly, it is advised to undertake in-depth research to identify the critical factors influencing the successful implementation of green leadership in diverse regions across Indonesia. Additionally, comprehensive studies should be conducted to analyze the multifaceted impacts of the energy transition on the environment and society of Central Java. Furthermore, a comparative analysis is recommended, involving regions that have effectively implemented green energy policies and those encountering challenges. This comparative approach aims to identify differentiating factors contributing to success or obstacles. Another aspect involves investigating the effects of national policy changes on regional green energy policies. Lastly, specialized research is advised to delve into the role of local government in facilitating the development of renewable energy projects within Central Java. Each of these actions contributes to a comprehensive understanding and strategic approach to advancing green leadership in Indonesia's energy transition.

E. Prepare to embrace the shifting tides of life

In summary, Indonesia stands at a pivotal crossroads as it anticipates a demographic bonus in the coming decade. This juncture presents a dual narrative for the nation. On one front, Indonesia is blessed with abundant renewable energy potential, ranging from its vast coastlines and deep waters offering marine energy possibilities to the equatorial sun, a potent source for solar innovation. This wealth of resources promises to reduce pollution and positions Indonesia as a global leader in sustainable energy solutions. With Indonesia assuming the esteemed G20 2022 Presidency and the ASEAN chairmanship in 2023, a remarkable occasion arises to propel economic trajectories that effectively foster growth and climate objectives.

On the other front, the nation grapples with the ongoing challenge of fossil fuel dependence, exacerbated by economic considerations and infrastructural limitations. Undoubtedly, the transition to greener energy sources is likely to take time. We hope those chapters are more than just a collection of words; it is an invitation to a consecutive opportunity for you to contribute to the narrative of Indonesia's ongoing energy transition.

As we conclude this voyage through the long and winding pathways of Indonesia's energy transition, we contemplate the profound wisdom of the timeless adage, "The only constant in life is change." It becomes clear that our ability to adapt is paramount. We cannot afford to lose momentum or, worse, go backwards. We must remain ever-prepared to embrace the shifting tides of life.

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List of Abbreviations

AC	:	alternating current
APAEC	:	Asean Plan of Action for Energy Cooperation
ASEAN	:	Association of South East Asian Nation
B20/B30/B40/B50	:	biodiesel
B3	:	*bahan berbahaya dan beracun* (dangerous and poisonous substances)
BRIN	:	Badan Riset dan Inovasi Nasional
CAPEX	:	capital expenditure
CCS	:	carbon capture and storage
CCUS	:	carbon capture, utilization, and storage
Cb	:	the block coefficient of a ship
CC	:	capital costs
CdTe	:	cadmium telluride
COW	:	Certificate of Operational Worthiness
CF	:	capacity factor
CIDS	:	concrete island drilling system

CIGS	:	copper indium gallium selenide
COE	:	the cost of electricity
COP	:	Conference of Parties
CWP	:	cold water pipes
DAK	:	*Dana Alokasi Khusus* (Special Allocation Fund)
DC	:	direct current
DG	:	distributed generator
DIY	:	*Daerah Istimewa Yogyakarta* (Special Region of Yogyakarta)
DoD	:	depth of discharge
DOW	:	deep ocean water
E-NDC	:	enhanced nationally determined contribution
EA	:	environmental assessment
EQI	:	environmental quality index
ESDM	:	*Energi dan Sumber Daya Mineral* (energy and mineral resources)
ETM	:	energy transition mechanism
EV	:	electric vehicle
FEM	:	forest ecosystem management
FRP	:	fiber reinforced polymer
G20	:	Group of Twenty
GDP	:	gross domestic product
Genco	:	Generation Companies
GHG	:	green house gas
GoI	:	Government of Indonesia
GR	:	government regulation
GSR	:	global status report
GTI	:	grid tie inverter
HTM	:	hazardous and toxic materials
HVDC	:	high voltage direct current transmission
I4Indonesia	:	Ikatan Ilmuwan Internasional Indonesia

IFSA	:	Indonesian Financial Services Authority
IKLH	:	*indeks kualitas lingkungan hidup* (environmental quality index)
IKM	:	*industri kecil dan menengah* (small and medium enterprise)
IRENA	:	International Renewable Energy Agency
ISO	:	International Organization for Standardization.
JETP	:	Just Energy Transition Partnership
Kepmen LH	:	*Keputusan Menteri Lingkungan Hidup* (Decree of The Minister of Environment and Forestry)
kW	:	kilo watt
kWh	:	kilo watt per hour
KWp	:	kilowatt peak
LRSC	:	land reforestation and soil conservation
LCOE	:	levelized cost of energy
LEED	:	leadership in energy and environmental design
LLC	:	limited liability company
LIT	:	Lembaga Inspeksi Teknis
LoA	:	length overall of ship
Lpp	:	length between perpendiculars of ship
MEMR	:	Ministry of Energy and Mineral Resources
MPPT	:	maximum power point tracking
MW	:	mega watt
MWp	:	megawatt peak
NEGP	:	National Energy General Plant
NZE	:	net zero emissions
O&G	:	oil and gas
O&M	:	operation and maintenance
OPEX	:	operating expenditure
OTEC	:	ocean thermal energy conversion
Pertamina	:	Perusahaan Tambang Minyak Negara (State-Owned Oil Company)

PLN	:	*Perusahaan Listrik Negara* (State-Owned Electricity Company)
PLTS	:	*Pembangkit Listrik Tenaga Surya* (solar power plant)
PP	:	*Peraturan Pemerintah* (Government Regulation)
PSH	:	peak sun hour
PT	:	*Perseroan Terbatas*
PV	:	photovoltaic
PWM	:	pulse width modulation
R&R	:	repair and replacement cost
REC	:	renewable energy certificates
RES	:	renewable energy source
RUEN	:	*Rencana Umum Energy Nasional* (National Energy General Plan)
SCC	:	solar charge controller
SDGs	:	Sustainable Development Goals
SHS	:	solar home system
SKK Migas	:	*Satuan Kerja Khusus Pelaksana Kegiatan Usaha Hulu Minyak dan Gas Bumi* (Special Task Force for Upstream Oil and Gas Business Activities)
SLO	:	*sertifikat laik operasi* (commisioning certification)
SMI	:	small and medium industries
SMV	:	special mission vehicle
SPC	:	solar power company
SEC	:	state electricity company
SOE	:	state owned enterprises
TII	:	Technical Inspection Institute
TW	:	tera watt
TWh	:	tera watt per hour
WP	:	watt peak

Glossary

baseline study	:	an initial assessment of environmental conditions in a project area, which serves as a reference point for future comparisons
biodiversity conservation	:	efforts to protect and preserve the variety of life on Earth, including the conservation of species and ecosystems
biomass energy	:	energy derived from biomass
biomass	:	It includes any organic material from plants or animals—such as wood, crop residues, and animal waste—that can be used as a source of energy or other products. It is a renewable and sustainable resource because it is derived from living or recently living organisms.
capacity factor	:	overall utilization of a power generated by OTEC power plant
capital expenditure	:	large one-time expenses of OTEC plant, such as floating platform and cold water pipe

carbon footprint	:	the total amount of greenhouse gases produced directly or indirectly by an individual, organization, event, or product
carbon neutrality	:	a state of balance between the amount of greenhouse gases emitted into the atmosphere and the amount removed or offset
centrallized electricity	:	the power electricity that is generated and transmitted from one central location at a macro level
climate change adaptation	:	strategies and actions aimed at reducing vulnerability to the effects of climate change, including rising temperatures and sea levels
climate mitigation	:	actions aimed at reducing or preventing the emission of greenhouse gases to mitigate climate change impacts
cold water pipes	:	the pipe used to transport deep ocean water to the OTEC condenser
community involvement	:	It is the active participation of individuals, organizations, and groups in activities, initiatives, and projects within their local or broader communities. It encompasses a wide range of actions and contributions aimed at improving the well-being, social fabric, and quality of life within a community. Community involvement is essential for building stronger, more vibrant, and resilient communities.
community participation	:	It is a process that involves individuals, groups, and communities actively engaging in decision-making, problem-solving, and activities that affect their lives and the well-being of their community. It is a fundamental aspect of democratic governance and community development, emphasizing the importance of involving community members in shaping the future of their local area.

community resilience	:	It is a community's ability to withstand, adapt to, and recover from various shocks, stresses, crises, or disasters while maintaining its essential functions, structures, and identity. Resilient communities are better equipped to cope with adversity, whether it's a natural disaster, economic downturn, public health crisis, or other challenges. Community resilience involves a combination of social, economic, environmental, and cultural factors that contribute to a community's ability to bounce back and thrive in the face of adversity.
condenser	:	a component used to condense working fluid vapor into saturated liquid conditions, usually placed after turbine
DAK (Dana Alokasi Khusus)	:	funds that are sourced from the State Budget allocated to certain regions with the aim of helping to fund special activities of regional affairs and in accordance with national priorities.
deep ocean water	:	Cold deep sea water, found below the surface of the oceans, was the by-product of the OTEC cycle.
distributed generation	:	electric power generation within distribution networks or on the customer side of the network
economic growth	:	It is the increase in the production of goods and services in an economy over time. It is typically measured by the increase in a country's Gross Domestic Product (GDP) or Gross National Product (GNP). Economic growth is a fundamental goal of most governments and is often seen as a key indicator of a nation's overall economic health and development.
electric power	:	It is the rate of transfer of electrical energy by an electrical circuit. The SI unit for power is the watt, one joule per second.
emission	:	Exhaust gas-related emissions are the remaining products of fuel combustion in internal combustion engines, external combustion engines, jet engines. They are released through the engine exhaust system.

energi consumption	:	It is the total amount of energy required for a given process and is measured in kilowatt hours (kWh). This includes the use of electricity, gas, diesel, oil, and biomass.
energy efficiency	:	the practice of using less energy to provide the same or greater service, often through technological and behavioral changes
energy independence	:	reducing reliance on external energy sources to ensure a stable and sustainable energy supply
energy recycling	:	Also known as energy recovery or energy conversion, it is a process that involves capturing and reusing energy that would otherwise be wasted during various industrial, commercial, or natural processes. The goal of energy recycling is to improve energy efficiency, reduce energy consumption, and minimize environmental impacts. Energy recycling can take various forms and is used in different sectors to harness wasted energy and convert it into a usable form.
energy security	:	ensuring a stable and reliable energy supply to meet the needs of a nation or region
energy transition	:	It refers to the global energy sector's shift from fossil-based systems of energy production and consumption (including oil, natural gas and coal) to renewable energy sources (like nuclear, wind, and solar, as well as lithium-ion batteries). It drives significant structural change in an energy system regarding supply and consumption. shifting from traditional, fossil fuel-based energy sources to cleaner, more sustainable alternatives.
environmental assessment	:	a comprehensive evaluation of the potential environmental impacts of a project, policy, or program, often involving the identification and mitigation of adverse effects.
environmental compliance	:	adhering to laws and regulations to ensure projects meet environmental standards
environmental conservation	:	the protection and sustainable use of natural resources and ecosystems

environmental impact assessment	:	a systematic process to identify, predict, and evaluate the environmental effects of proposed projects, often required by law
environmental monitoring	:	continuous or periodic surveillance of environmental conditions to assess and manage impacts over time
environmental policies	:	It is a set of guidelines, regulations, laws, and initiatives enacted by governments, organizations, or institutions to address various environmental issues and concerns. These policies are designed to protect and preserve the environment, natural resources, and ecosystems, as well as to promote sustainable practices and mitigate the negative impacts of human activities on the planet. Environmental policies can encompass a wide range of areas, including air and water quality, biodiversity conservation, climate change, waste management, and more.
ETM (energy transition mechanism)	:	a program to increase Indonesia's energy infrastructure development and accelerate the energy transition towards net zero emissions (Net Zero Emission) with the principles of fairness and affordability in 2060 or faster
evaporator	:	a component, usually located upstream of the turbine, used to evaporate the working fluid
floating platform	:	It is an offshore OTEC plant platform used to house the main component of the OTEC cycle. Typically equipped with mooring systems.
fuell cell	:	It is an electrochemical device similar to a battery, but differs in that it is designed to be continuously filled with consumed reactants; that is, it produces electricity from the supply of hydrogen and oxygen fuel from outside.

gas emissions	:	Often referred to as greenhouse gas emissions, it is the release of certain gases into the Earth's atmosphere, primarily as a result of human activities. These gases have the ability to trap heat from the sun within the Earth's atmosphere, creating what is known as the greenhouse effect. The greenhouse effect is essential for maintaining the Earth's temperature within a range that is suitable for life. However, an excess of greenhouse gas emissions, especially carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), can lead to global warming and climate change, with potentially significant environmental and societal consequences.
generator	:	main component of the OTEC cycle that converts the kinetic energy of the turbine into electrical energy
geothermal energy	:	energy harnessed from the Earth's internal heat, often through the use of steam or hot water reservoirs
GHG (greenhouse gases)	:	They are gases in the atmosphere that cause the greenhouse effect. These gases appear naturally in the environment, but can also arise due to human activities, especially by burning fossil fuels.
green leadership	:	Also known as environmental leadership or sustainable leadership, it refers to a style of leadership that prioritizes environmental sustainability, social responsibility, and ethical decision-making in both organizational and broader societal contexts. Green leaders are individuals who take proactive measures to address environmental challenges, promote sustainable practices, and drive positive social and environmental change.
green technology	:	innovative and sustainable technologies that help reduce environmental impacts

greenhouse	:	It is a structure or enclosed space with transparent walls and roof that allows sunlight to enter while trapping heat inside. It is designed to create a controlled environment for growing plants, particularly in conditions that may not be suitable for their natural growth. Greenhouses are used for various purposes, including cultivating crops, flowers, and ornamental plants. They provide a stable and controlled microclimate, which allows for extended growing seasons, protection from harsh weather conditions, and the ability to grow plants that might not thrive in the local climate.
grid	:	It is an interconnected network for electricity delivery from producers to consumers. Electrical grids vary in size and can cover whole countries or continents.
hydropower	:	electricity generated by the movement of water, typically through dams and turbines
initial capital	:	initial funding required to build OTEC power plant
irreversible losses	:	inevitable energy losses in the entire OTEC cycle system which could occur due to suction pressure, leakage, heat transfer, and friction
islanding	:	The condition in which a distributed generator (DG) continues to power a location even though external electrical grid power is no longer present. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic re-connection of devices
JETP	:	It is an agreement to mobilize an initial $20 billion in public and private financing to decarbonize Indonesia's energy sector, using a mix of grants, concessional loans, market-rate loans, guarantees, and private investments. It supports a global trajectory consistent with keeping the 1.5°C global warming limit within reach.

land use planning	:	a systematic process for allocating and managing land resources to meet the needs of the community and the environment
landscapes	:	It is the visible features and characteristics of an area of land, including its physical, natural, and human elements. Landscapes encompass a wide range of environments, from natural wilderness areas to urban and rural settings shaped by human activity. They are the result of complex interactions between geological, biological, climatic, and cultural factors. Landscapes are often appreciated for their aesthetic, ecological, cultural, and recreational values.
levelized cost of electricity	:	a measure of the average net present cost of generating electricity from an OTEC power plant over its lifetime
lifecycle assessment	:	a comprehensive analysis of the environmental impacts of a product, process, or service throughout its entire lifecycle
local resources	:	They are the natural and human-made assets that are available within a specific geographic area or locality. These resources are essential for the well-being, economic development, and sustainability of communities and regions. Local resources can encompass a wide range of elements, including natural resources like land, water, minerals, and forests, as well as human resources, infrastructure, and cultural assets.
mass flow rate	:	mass of a liquid/vapor substance passing per unit time
mitigation measures	:	actions or strategies implemented to reduce, control, or offset adverse environmental impacts associated with energy projects
mooring system	:	a system used to secure the position of an OTEC floating platform consists of an anchor set in or on the seabed
net power	:	the amount of electricity available for use from the OTEC plant

noise reduction	:	It is the process of reducing or minimizing unwanted or disruptive sounds in a particular environment or setting. Unwanted noise, often referred to as noise pollution, can have adverse effects on human health, well-being, and the quality of the environment. Noise reduction measures aim to mitigate these negative impacts by either reducing the intensity of the noise source or isolating individuals or areas from the noise.
nuclear power	:	electricity generated through controlled nuclear reactions, which produce heat that is converted into electrical energy
NZE (net zero emissions)	:	a state in which emissions caused by human activities are balanced by carbon dioxide removal caused by human activities over a certain period of time.
operating expenditure (OPEX)	:	daily operating costs of an OTEC power plant
Paris Agreement	:	It is a legally binding international treaty on climate change. The agreement was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016. Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."
policy alignment	:	It is the process of ensuring that various policies, strategies, and initiatives within an organization or across different levels of government or institutions are harmonized and consistent with each other. This alignment is essential to achieving common goals, minimizing conflicts, and optimizing resources. Policy alignment can occur in various contexts, including government, businesses, non-profit organizations, and international collaborations.

power plant	:	It is an industrial facility for the generation of electric power and connected to the power grid. Many power plants have one or more generators, rotating machines that convert mechanical power into three-phase electrical power.
radial flow turbine	:	turbine in which the working fluid flows in a radial direction with respect to the shaft
rankine cycle	:	the basic thermodynamic operating cycle of the OTEC closed cycle, in which the working fluid is continuously evaporated and condensed
regulatory compliance	:	adhering to laws, regulations, and standards related to environmental protection and energy transition
renewable energy	:	energy generated from sources that are naturally replenished, such as solar, wind, and hydropower
resilience	:	the ability of an energy system to withstand and recover from disruptions, such as natural disasters or supply chain issues
saturated state	:	a state in which, at a given temperature and pressure, a mixture of vapor and liquid can exist together
seakeeping	:	the motion of a structure on the water in the presence of waves
solar cell	:	an electronic device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical phenomenon
spar structure	:	floating platform with a large vertical cylinder support deck on which the equipment can be placed
specific enthalpy	:	enthalpy per unit mass of a system
sustainability	:	the ability to meet current energy and environmental needs without compromising the ability of future generations to meet their needs
Sustainable Development Goals	:	A set of global goals established by the United Nations to address various global challenges, including energy access and climate action, to be achieved by 2030

sustainable practices	:	actions and behaviors that promote environmental conservation and social responsibility while meeting economic goals
toxic materials	:	Also known as hazardous materials or hazardous substances, they can cause harm, injury, illness, or even death when released into the environment or when exposed to living organisms (including humans). These substances have the potential to be harmful due to their chemical, physical, biological, or radioactive properties. Toxic materials can be found in various forms and settings, including industrial processes, household products, waste disposal sites, and natural sources.
T-S Diagram	:	type of diagram often used to analyze the cycles of energy transfer systems
urban livability	:	It is the quality of life in urban areas and the extent to which a city or town provides a safe, healthy, and satisfying environment for its residents. It encompasses various factors that contribute to the overall well-being and satisfaction of urban dwellers. Urban livability is a complex concept and can vary from one city to another and from one individual to another.
waste management	:	strategies for collecting, storing, and disposing of waste materials, including hazardous waste from energy projects
water resource management	:	the sustainable use, allocation, and protection of water resources in the context of energy projects
working fluid	:	a fluid to which heat is transferred and from which heat is transferred during a thermodynamic cycle

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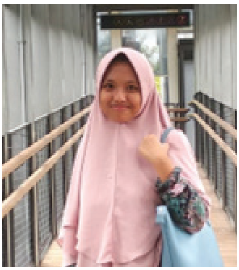

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Energy transition is a shift in the system of energy production and consumption, from fossil-based materials (oil, natural gas, coal) to renewable energy sources (nuclear, wind, solar). Indonesia's national energy transition roadmap has set the vision towards a cleaner and more sustainable energy future in 2045. The ultimate goal is to reach net zero emission, the state in which emissions caused by human activities are balanced by carbon dioxide removal over a certain period of time. With this vision, Indonesia stands as a beacon of promise in the global pursuit of green energy solutions, navigating the path towards a more sustainable and resilient future.

Indonesia's Energy Transition Preparedness Framework Towards 2045 unveils a comprehensive framework that encapsulates Indonesia's energy transition readiness and elaborates the steps needed to strengthen the efforts. This book represents a significant milestone in Indonesia's commitment to foster a transition towards renewable energy. From the lush landscapes of Sumatra to the vibrant cities of Java, Indonesia's rich diversity is mirrored in its approach to energy transition—a transformative journey that encompasses not only technological advancements, but also socioeconomic considerations, policy dynamics, and the empowerment of its people.

This book will be useful for the general public to learn and understand the framework of energy transition and supplies, so that it will eventually accelerate clean energy momentum in Indonesia.

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