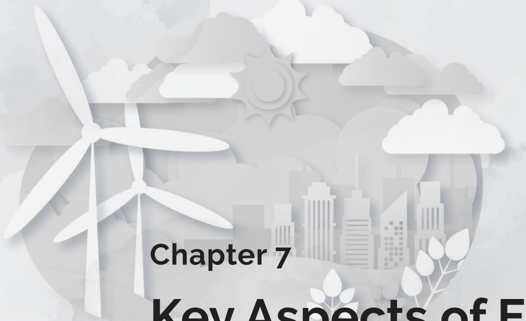

Chapter 7

Key Aspects of Environmental Assessment for Indonesia Energy Transition

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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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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.

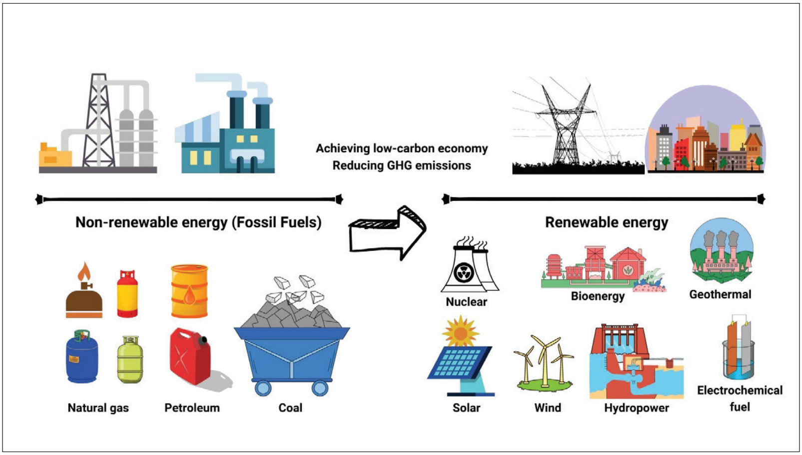
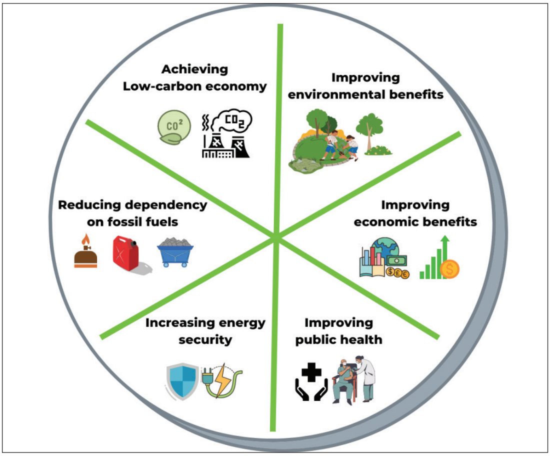


Figure 7.1 A Proposed Energy Transition Technology Shifts from Traditional (Non-Renewable) Energy Sources such as Fossil Fuels to Renewable Energy Sources



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).

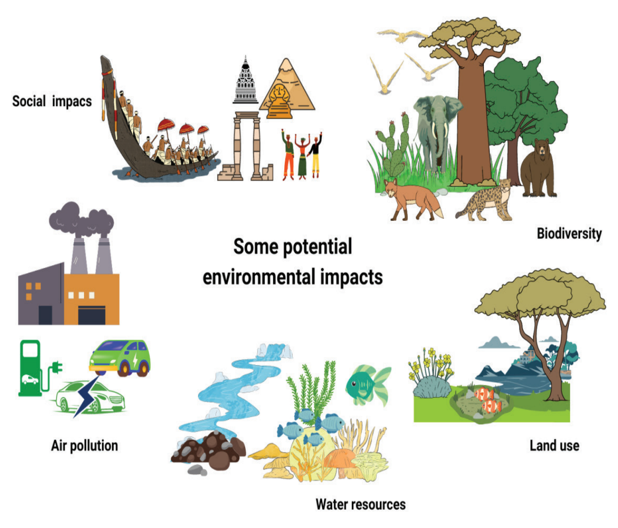


Figure 7.3 Some Potential Environmental Impacts Associated with the Transition to Renewable Energy Sources

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.

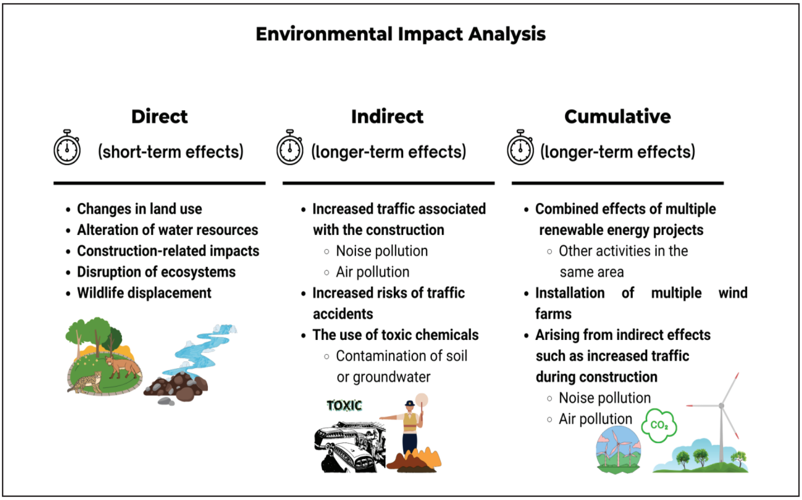
Although Indonesia has a significant potential for renewable energy sources, there is still a significant challenge—the lack of openness in coordinating a just energy transition. Future policies and plans must be centered on the needs of the community, especially the marginalized, to guarantee that they 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).

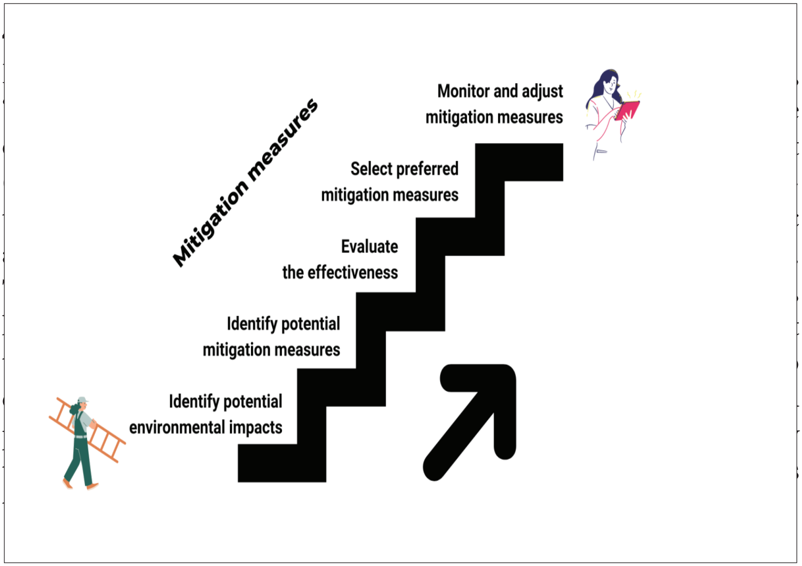


Figure 7.5 Five Steps to Identify and Assess How to Reduce or Avoid Potential Environmental Impacts Associated with the Proposed Energy Transition Technology

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.

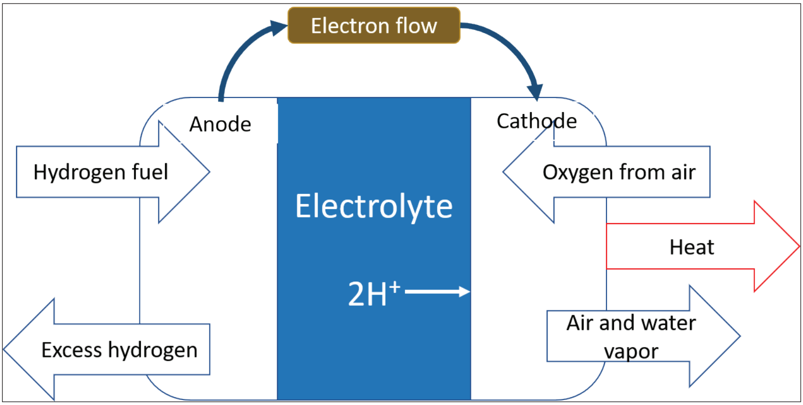


Figure 7.6 Reaction Mechanism in Hydrogen Fuel Cell

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.

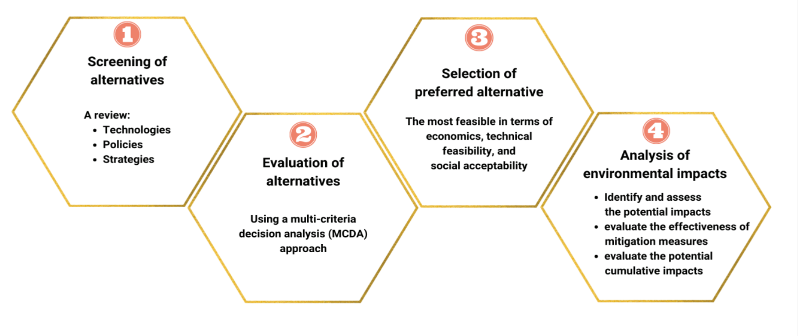


Figure 7.7 Identifying and evaluating reasonable alternatives to the proposed energy transition technology is crucial to the environmental assessment (EA).

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, effectiveness, 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

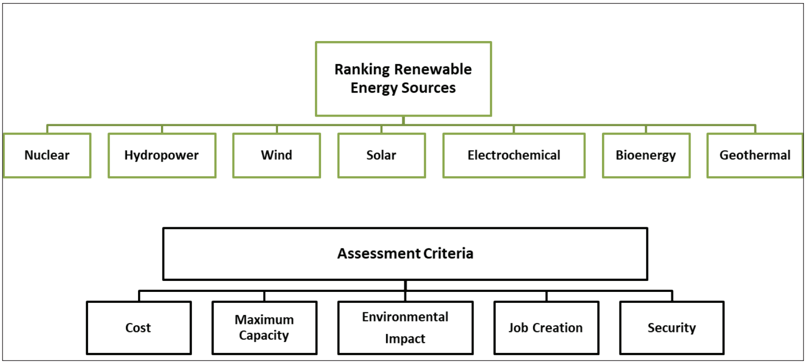
A preferred alternative can be selected once the comparative analysis is conducted and the various alternatives are evaluated based on the established criteria. The preferred alternative should have the most negligible environmental impact, meet the project objectives, and be the most cost-effective (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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