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The Benefits and Challenges of Solar Photovoltaic (PV) Business in Pertamina's Gasoline Station: Focused on Energy Transition, Sustainability & Green Investment

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ABSTRACT

Objectives: *As the world shifts towards green energy solutions, PT Pertamina (Persero), Indonesia's state-owned energy company, is in a unique position to lead by integrating Solar Photovoltaic (PV) systems into its extensive network of gasoline stations. As per now, Pertamina has built Solar Photovoltaic (Solar PV) in 358 gasoline stations not only in Indonesia but also in East Timor. This research paper explores the benefits and challenges associated with the implementation of Solar PV. The study highlights key benefits in energy transition, sustainability & green investment. However, several challenges arise.*
Methodology: *Descriptive and qualitative methods were used. The study focuses on Solar PV in gasoline station in Pertamina area. In-depth interviews and participant observations were used to collect data.*
Finding*: reveal a significant green energy production, reduction in carbon footprint, making it a sustainable energy business for Pertamina. Nonetheless, the challenges of high upfront costs, space limitations, and potential maintenance and operation challenges are also identified.*
Conclusion*: Solar PV systems offer significant potential benefits for Pertamina's gasoline stations, including green energy production, environmental sustainability, cost reduction, and enhanced energy security. Despite challenges related to high upfront costs, space limitations, and regulatory barriers, Pertamina's leadership in renewable energy positions the company to overcome these obstacles and drive the adoption of solar PV technology across its gasoline station network. By investing in solar PV systems, Pertamina can play a critical role in advancing Indonesia's renewable energy goals, reducing carbon emissions, and demonstrating its commitment to sustainability. Through strategic partnerships, policy advocacy, and scalable deployment models, Pertamina has the potential to become a leader in solar PV adoption at gasoline stations, contributing to a cleaner and more sustainable energy future for Indonesia.*

Keywords*: Solar PV; Renewable Energy; Energy Transition; Sustainability; Green Investment; Gasoline Station; PT Pertamina (Persero).*

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INTRODUCTION

Indonesia, as one of the world's largest archipelagic nations, possesses vast renewable energy resources, yet its energy sector remains heavily reliant on fossil fuels. based on Law No. 30/2007 on Energy, the government was mandated to make a National Energy General Plan (RUEN). Following that, The National Energy Council (DEN) made RUEN which determining the primary energy mix of Indonesia by 2025, which consists of 25% oil, 22% gas, 30% coal, and 23% new & renewable energy (NRE).

Indonesia's commitment to increasing the share of renewable energy in its energy mix has gained momentum in recent years, driven by both global climate concerns and domestic energy policies. According to the Ministry of Energy and Mineral Resources (Kementerian ESDM, 2024), the Indonesian government is intensifying efforts to boost renewable energy utilization, with a targeted renewable energy mix of 23% by 2025.

As per 2023, the implementation of new & renewable energy in Indonesia primary energy supply is far from the target. DEN announced by press release dated 18 January 2024 (Kementerian ESDM, 2024) that primary energy mix is dominated by coal (40,46%), followed by oil (30,18%), gas (16,28%) and NRE (13.09*%)* as illustrated below:

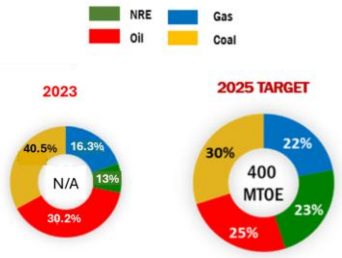

Figure 1 Indonesia Energy Mix (Progress 2023 vs target 2025)

Indonesia's renewable energy potential is vast, covering solar, geothermal, wind, and biomass energy sources. The country's location along the equator offers abundant solar energy, with high solar irradiation throughout the year, particularly in the eastern regions of the country (Handayani, Krozer & Filatova, 2017). Geothermal energy also presents a significant opportunity, as Indonesia sits on the Pacific Ring of Fire, home to numerous volcanoes and geothermal reserves (Fauzi & Samudro, 2018).

The solar photovoltaic (PV) sector has seen increased investment, with government policies aimed at scaling up development (Dewi & Handayani, 2020; Hariyanti & Aria, 2019). However, despite these efforts, solar energy development in Indonesia faces challenges, such as regulatory hurdles and financing issues, which need to be addressed to fully unlock its potential (Wicaksono & Pratama, 2020).

Indonesia's renewable energy sector is characterized by various initiatives aimed at reducing carbon emissions and expanding clean energy sources. Solar energy, in particular, has gained attention as one of the most viable options. The transition is driven by both government policies and corporate strategies. Pertamina, Indonesia's state-owned energy company, has been a key player in this sector, spearheading several renewable energy projects (Ahmad & Kurniawan, 2021).

p-ISSN: 2088-1231
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Indonesia's equatorial location provides an average solar radiation of 4.8 kWh/m² per day, making solar PV one of the most promising renewable energy technologies in the country (Dewi & Handayani, 2020). Regions such as Java, Sumatra, and Sulawesi exhibit the highest solar energy potential due to their favorable climatic conditions (Suryadi & Priambodo, 2018).

Indonesia's government has implemented several policies to promote solar energy. The Ministry of Energy and Mineral Resources (MEMR) introduced the Renewable Energy Roadmap to achieve a 23% share of renewables in the energy mix by 2025 (ADB, 2021). The government's commitment is reflected in various incentive schemes, including feed-in tariffs, tax breaks, and subsidies for solar PV installations (Susanto & Irawan, 2021). Despite these efforts, policy gaps and regulatory uncertainties continue to hinder large-scale solar PV adoption (Rachman & Nurcahyo, 2020).

Pertamina as the biggest Indonesia state owned enterprise has supported government to accelerate the implementation of renewable energy particularly Solar PV in gasoline station (Ahmad & Kurniawan, 2021). To date, Pertamina has built Solar PV in 358 gasoline stations not only in Indonesia but also in East Timor.

Handayani et al. (2017) highlight the strategic importance of electrification and renewable energy integration within the Java-Bali grid, emphasizing the need for a balance between energy security and environmental sustainability. Solar PV projects, such as those initiated by Pertamina, provide an opportunity to mitigate climate change, reduce greenhouse gas emissions, and decrease the dependency on fossil fuels.

Solar energy offers numerous benefits, including reduced operational costs and a lower carbon footprint, as demonstrated by Dewi & Handayani (2020). However, despite these advantages, the deployment of Solar PV systems also presents challenges. Financial constraints, regulatory hurdles, and the technical integration of Solar PV with existing energy infrastructure are significant barriers that must be addressed.

The subtotal capacity of 355 solar PV units in Indonesia is 1,880 kWp, and added 9 kWp solar PV in 3 locations in Timor Leste. So, the total portfolio Solar PV Pertamina is about 1,889 kWp or 1,89 MWp.

Research Gap. The integration of Solar Photovoltaic (PV) systems in gasoline stations has been explored in various studies, primarily focusing on the technical feasibility, cost-effectiveness, and environmental impact of solar energy in commercial and industrial settings. Previous research has highlighted the potential of solar PV in reducing carbon emissions, improving energy security, and decreasing reliance on fossil fuels (Hosseini et al., 2019; IRENA, 2021). However, most studies have concentrated on large-scale solar farms, residential solar applications, or industrial installations rather than the specific implementation within gasoline stations. The unique operational demands, spatial constraints, and regulatory challenges faced by fuel retail networks remain underexplored, leaving a critical gap in understanding how solar PV can be effectively deployed in such environments (Rahman et al., 2020).

p-ISSN: 2088-1231
e-ISSN: 2460-5328

While there have been some case studies on renewable energy adoption in the fuel retail sector, they often focus on developed countries with well-established policies, incentives, and infrastructure for solar energy (Sharma et al., 2021). In contrast, Indonesia presents a different landscape, where energy transition efforts are still evolving, and regulatory frameworks are continuously being adapted (MEMR, 2022). Moreover, Pertamina, as a state-owned enterprise, operates within a complex policy and business environment that differs from private-sector energy retailers. Existing literature lacks a focused examination of how solar PV can be integrated within the specific business model, operational constraints, and investment strategies of a large, government-affiliated fuel distributor like Pertamina (Widodo et al., 2023).

This study addresses these gaps by providing an in-depth analysis of the implementation of Solar PV at Pertamina's gasoline stations, focusing on the real-world benefits and challenges from a practical and strategic perspective. Unlike previous research, this study incorporates qualitative insights through in-depth interviews and participant observations, capturing firsthand experiences of stakeholders involved in the adoption process. By identifying key barriers such as high upfront costs, space limitations, and regulatory hurdles, while also highlighting successful implementation strategies, this research contributes valuable knowledge to both academia and industry. Ultimately, this study is necessary to guide policy formulation, investment decisions, and operational best practices to scale up solar PV deployment in Indonesia's fuel retail sector (IEA, 2023).

LITERATURE REVIEW

Energy Transition. Indonesia's energy landscape is dominated by fossil fuels, particularly coal and oil, contributing to significant greenhouse gas emissions. However, the government has pledged to shift towards cleaner energy sources to meet its international commitments, such as the Paris Agreement, aiming to achieve 23% of its energy mix from renewable sources by 2025 (Suharsono, Purwanto, & Nugraha, 2020). The energy transition in Indonesia is centered on reducing dependency on fossil fuels, improving energy security, and addressing environmental concerns. This transition is particularly critical for companies like Pertamina, which must balance its role as a leading fossil fuel provider with the growing demand for sustainable energy solutions (Yudha et al., 2019).

Solar PV technology, which converts sunlight directly into electricity, has become a cornerstone of renewable energy strategies worldwide. Its application ranges from residential rooftops to large-scale solar farms. Globally, solar PV installations have expanded significantly due to technological advancements, decreasing costs, and supportive policy frameworks (IEA, 2021). Indonesia, located along the equator, has significant solar energy potential, receiving abundant sunlight throughout the year. According to the Ministry of Energy and Mineral Resources, Indonesia's solar energy potential is approximately 207.8 gigawatts (GW), yet the current installed capacity remains underutilized (Kementerian ESDM, 2020).

Despite the vast potential, the development of solar PV in Indonesia has been slow due to various challenges, including regulatory hurdles, high initial capital costs, and the lack of a supportive policy framework. However, the Indonesian government has recently introduced several incentives and programs to promote renewable energy adoption, such as the solar

p-ISSN: 2088-1231
e-ISSN: 2460-5328

rooftop program and feed-in tariffs (Bridle et al., 2020). These efforts are expected to stimulate the growth of solar PV in various sectors, including the gasoline retail industry.

Sustainability. Sustainability in the energy sector refers to the ability to meet current energy needs without compromising the ability of future generations to meet their own. It involves the efficient use of resources, minimizing environmental impact, and promoting long-term economic growth through cleaner energy alternatives (Kuhlman & Farrington, 2010). According to the United Nations Sustainable Development Goals (SDGs), ensuring access to affordable, reliable, sustainable, and modern energy for all is a global priority (UN, 2015). Solar PV technology is one of the key drivers of this transition, contributing to sustainability by reducing greenhouse gas (GHG) emissions, improving energy security, and fostering the use of renewable resources (IEA, 2021).

Indonesia’s energy sector has long been dominated by coal and oil, which together account for over 80% of the country’s energy mix (Kementerian ESDM, 2020). Despite its abundant renewable energy potential, including geothermal, wind, and solar, Indonesia’s transition to clean energy has been slow due to policy, financial, and infrastructural barriers. However, the government’s commitment to achieving 23% of its energy from renewables by 2025 has led to increased interest in solar energy, particularly in the form of rooftop solar PV systems (Suharsono, Purwanto, & Nugraha, 2020). Pertamina, as a leading actor in the energy market, is well-positioned to spearhead the adoption of solar PV technology within the country’s energy transition framework.

Green Investment. Green investment refers to the allocation of capital into projects or technologies that aim to generate environmental benefits, such as reducing carbon emissions, while also offering financial returns (OECD, 2020). Solar photovoltaic (PV) technology has been a major focus of green investments due to its potential to deliver clean energy and reduce operational costs in the long term. For businesses like Pertamina's gasoline stations, green investment in solar PV systems can drive significant cost reductions by lowering energy expenses and mitigating the financial risks associated with fluctuating fuel prices and grid electricity rates (IRENA, 2021).

The concept of green investment is closely linked to the broader goals of sustainability and energy transition, as it encourages businesses to adopt renewable energy technologies that contribute to environmental conservation. Solar PV systems, in particular, represent a cost-efficient alternative to fossil-fuel-based energy sources, as they offer both immediate savings on energy bills and long-term financial benefits due to reduced maintenance and operational costs (Luthander et al., 2015). This literature review explores the role of green investment in reducing costs for businesses, particularly within the context of Pertamina's gasoline stations adopting solar PV technology.

Investing in solar PV systems can lead to substantial cost reductions for businesses by decreasing reliance on conventional electricity sources. As the global demand for energy increases, businesses are facing rising electricity costs, which affect their profitability. Solar PV systems offer a solution by providing a reliable and renewable source of energy at a fixed cost, allowing businesses to achieve energy independence and lower their operational expenses (IRENA, 2021). For Pertamina, whose gasoline stations consume significant

p-ISSN: 2088-1231
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amounts of electricity, green investment in solar PV could offset rising electricity costs and generate long-term savings.

One of the key financial advantages of solar PV systems is the reduction in energy bills. Solar energy is free once the initial installation costs are covered, meaning businesses can generate their own electricity without relying on the grid. This is particularly beneficial in regions where electricity prices are high or prone to fluctuations (Sovacool, 2016). Green investments, such as subsidies or financing through green bonds, can help cover the upfront costs of solar PV installation, allowing businesses to enjoy the cost-saving benefits of solar energy without bearing the full financial burden of the initial investment.

Various green financing mechanisms have been developed to support the adoption of solar PV systems and other renewable energy technologies. These mechanisms aim to reduce the upfront costs of installation and make it easier for businesses to invest in sustainable energy. Green bonds, for example, are a popular financial tool that allows businesses to raise capital for environmentally-friendly projects while offering investors a stable return (OECD, 2020). Pertamina could utilize green bonds to finance the installation of solar PV systems at its gasoline stations, reducing the financial barriers to entry and enabling long-term cost savings.

In addition to green bonds, power purchase agreements (PPAs) are another financing option that can help reduce costs for businesses investing in solar PV systems. Under a PPA, a third-party provider installs and maintains the solar PV system, while the business agrees to purchase the electricity generated at a fixed rate (Linnenluecke et al., 2016). This arrangement allows businesses to benefit from solar energy without having to bear the full cost of installation and maintenance, further enhancing cost efficiency.

Green investment in solar PV technology not only reduces costs for businesses but also delivers significant environmental benefits. Solar energy is a clean and renewable source of power, meaning that it does not produce greenhouse gas emissions or contribute to air pollution. For businesses like Pertamina, investing in solar PV aligns with global efforts to combat climate change and reduce carbon footprints (Sovacool, 2016). By adopting solar PV technology, Pertamina can improve its environmental performance while simultaneously reducing operational costs, creating a win-win scenario for both the business and the environment.

Moreover, businesses that demonstrate a commitment to sustainability by investing in green technologies can enhance their brand image and attract environmentally-conscious consumers. Many consumers are willing to support companies that prioritize sustainability, which can lead to increased customer loyalty and market share. For Pertamina, green investment in solar PV systems could improve its reputation as a responsible energy provider and differentiate it from competitors that rely on fossil fuels (Fox-Penner, 2020).

Conceptual Framework. The integration of energy transition, sustainability, and green investment is essential for developing a conceptual framework that explains the viability of solar photovoltaic (PV) businesses, particularly at Pertamina’s gasoline stations. The energy transition, which refers to the shift from fossil-based energy systems to renewable alternatives, is crucial for addressing global climate change and enhancing energy security (Sovacool, 2016). Solar PV technology is at the forefront of this transition, as it provides

p-ISSN: 2088-1231
e-ISSN: 2460-5328

clean, sustainable energy. Pertamina's gasoline stations, which traditionally rely on fossil fuels, are prime candidates for adopting solar PV systems as part of Indonesia's broader energy transition strategy (IRENA, 2021). Understanding the role of this transition and aligning it with sustainability objectives is key to maximizing the benefits of renewable energy technologies in this context.

Sustainability is closely linked to the energy transition, as it involves meeting present energy needs without compromising the ability of future generations to meet theirs (Brundtland, 1987). Solar PV systems contribute to sustainability by reducing carbon emissions, lowering environmental impact, and ensuring long-term energy supply. For Pertamina, integrating solar PV technology not only aligns with global sustainability goals but also enhances operational efficiency and resilience against fluctuating energy prices (Fox-Penner, 2020). Sustainability in this context is not merely about reducing environmental impact but also about ensuring long-term economic viability through cleaner energy sources. This aspect of sustainability reinforces the importance of green investments in solar PV projects for businesses like Pertamina.

Green investment plays a critical role in facilitating the energy transition and enhancing sustainability by providing the necessary capital for renewable energy projects. Green investment encompasses financial tools such as green bonds and other forms of environmental financing, which lower the barriers for companies to adopt renewable technologies (OECD, 2020). In the case of solar PV at Pertamina's gasoline stations, green investments can offset high upfront installation costs, making solar technology more financially accessible. Furthermore, such investments promote cost reduction in the long term by lowering energy bills and reducing dependency on fossil fuels (IRENA, 2019). Thus, green investment serves as a bridge between sustainability goals and economic feasibility, enabling businesses to transition smoothly to renewable energy.

From the perspective of cost reduction, green investment in solar PV systems offers numerous financial benefits for businesses like Pertamina. Solar energy generation is characterized by relatively low operational and maintenance costs compared to conventional energy sources. Once installed, solar PV systems allow businesses to generate their own electricity, reducing reliance on grid electricity and insulating themselves from rising energy prices (Luthander et al., 2015). By investing in solar PV, Pertamina can significantly cut operational costs in the long term while contributing to national sustainability targets. This cost efficiency is further enhanced by government incentives and policies aimed at promoting renewable energy, making green investment an attractive option for businesses seeking to reduce both financial and environmental costs.

The integration of energy transition, sustainability, and green investment within Pertamina's solar PV project also aligns with Indonesia's policy framework that encourages renewable energy adoption. Indonesia has set ambitious targets to increase the share of renewable energy in its national energy mix, and companies like Pertamina play a key role in achieving these goals (IRENA, 2021). By investing in solar PV systems, Pertamina can contribute to national energy transition efforts while improving its own sustainability profile. This alignment of corporate strategy with national policy objectives highlights the importance of a supportive regulatory environment in driving green investments and renewable energy adoption in the business sector.

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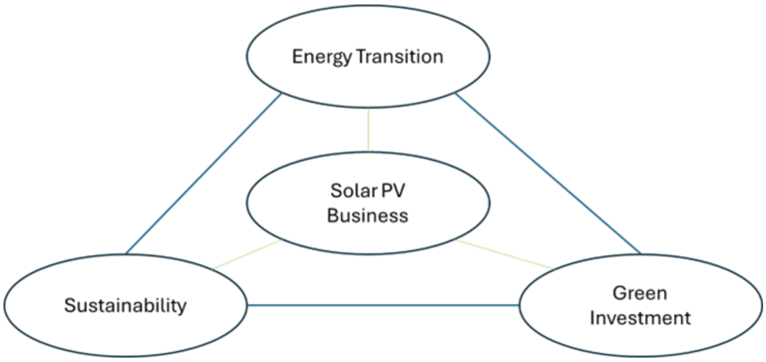

Figure 2 Gasoline Solar PV Conceptual Framework

METHOD

This research employs a qualitative approach using data collection techniques through interviews and literature studies, incorporating both primary and secondary data sources. Literature review methodology enables a thorough and reliable examination of scientific sources (Hulland & Houston, 2020; Paul & Lim, 2021). Various scientific review methods exist, such as framework-based reviews, theory-driven reviews, theory development reviews, hybrid models, and bibliometric analyses. Given the research gap, this study adopts a systematic literature review with a hybrid approach as its methodological framework.

In addition to the literature review, semi-structured interviews were conducted to gather primary data. The sampling process followed a purposive sampling technique, selecting respondents based on their direct involvement in Pertamina's Solar PV projects to ensure the relevance and depth of the insights gathered. A total of 10 respondents were interviewed, consisting of project managers, engineers, financial analysts, and sustainability officers within Pertamina's Solar PV project team. Each respondent participated in one in-depth interview, resulting in 10 interviews in total.

The interviews focused on key topics such as implementation challenges, financial feasibility, regulatory barriers, and operational benefits of Solar PV integration at Pertamina's gasoline stations. The collected data were analyzed qualitatively, applying thematic analysis to identify patterns and insights relevant to the study's conceptual framework.

RESULTS AND DISCUSSION

The results of this study align with the conceptual framework of energy transition, sustainability, and green investment while addressing the identified research gap concerning the implementation of solar photovoltaic (PV) systems at Pertamina's gasoline stations. Unlike previous studies that focus on large-scale solar farms or residential solar PV adoption (Hosseini et al., 2019; IRENA, 2021), this research provides empirical evidence of solar PV integration within Indonesia's fuel retail sector, highlighting practical benefits and challenges within a state-owned enterprise context.

p-ISSN: 2088-1231
e-ISSN: 2460-5328

1. Benefits of Solar PV in Gasoline Stations

1.1 Energy Transition

Solar PV integration at Pertamina gasoline stations represents a critical step in Indonesia's energy transition by reducing dependence on fossil fuels and incorporating renewable energy sources into conventional fuel retail operations. Unlike previous studies that primarily focus on solar energy adoption in developed countries with mature regulatory environments (Sharma et al., 2021), this research highlights the complexities of implementing solar PV within a transitional energy landscape, where policies and incentives are still evolving (MEMR, 2022).

Using the standard electricity production formula:
Electricity production (in kWh/year) = A x B x C x D x E

Where:
A = total capacity (in kWp)
B = efficiency (for Solar PV, average at 15%)
C = total hours/year (8.760 hours)

Table 1 Calculation for Energy Transition Impact

No	Parameter	Value
1	A - total capacity	1.889
2	B - efficiency	15%
3	C – total hours/year	8.760
	Electricity production kWh (A x B x C)	2.482.146

The calculated electricity production for Pertamina gasoline stations is 2.48 million kWh per year, demonstrating substantial contributions to Indonesia's energy transition objectives.

1.2 Sustainability

The integration of solar PV systems supports Pertamina's commitment to reducing greenhouse gas emissions. Solar energy is a clean and renewable source of power, which means that gasoline stations utilizing PV systems can reduce their carbon footprint and contribute to Indonesia's broader environmental goals (Mahendra & Wicaksono, 2020). The shift to solar energy at gasoline stations aligns with the global trend toward sustainability in the energy sector and reinforces Pertamina's role in advancing Indonesia's clean energy transition.

Using the emission reduction formula:
Emission reduction (in tons CO_2 equivalent per year) = A x B x C x D /1000

Where:
A = total capacity (in kWp)
B = efficiency (for Solar PV, average at 15%)
C = total hours/year (8.760 hours)
D = grid emission factor (refer to Ministry of Energy and Mineral Resources Decree No.163.K/HK.02/MEM.S/2021, the grid emission in Jamali 0.83)

p-ISSN: 2088-1231
e-ISSN: 2460-5328

Table 2 Calculation for Sustainability Impact

No	Parameter	Value
1	A - total capacity	1.889
2	B - efficiency	15%
3	C – total hours/year	8.760
4	D – Grid emission factor	0,83
	CO2e Emission reduction (A x B x C x D)/1000	2.060

The calculated CO2e reduction is 2,060 tons per year, reinforcing the role of solar PV in mitigating environmental impact within Pertamina's operational framework.

1.3 Green Investment

The financial feasibility of solar PV adoption is critical for widespread implementation. Unlike previous studies that focus on general economic benefits of solar energy in commercial applications (OECD, 2020), this study specifically quantifies the financial impact for Pertamina, highlighting direct cost savings and investment payback periods.
Cost saving formula:
Cost Saving (in IDR/year) = A x B x C x E x F

Where:
A = total capacity (in kWp)
B = efficiency (for Solar PV, average at 15%)
C = total hours/year (8.760 hours)
E = PLN tariff (average at 1.444 Rp/kWh)
F = Saving (%)

Then, the cost saving is
= 1.889 x 15% x 8.760 x 1.440 x 10%
= 357.429.024 ~ **357 million IDR/year**

Table 3 Calculation for Green Project Impact

No	Parameter	Value
1	A - total capacity	1.889
2	B - efficiency	15%
3	C – total hours/year	8.760
4	E – PLN tariff	1.440
5	F - saving	10%
	Cost Saving (A x B x C x E x F)	357.429.024

The estimated annual cost savings amount to 357 million IDR, demonstrating the financial viability of solar PV investment in gasoline stations. This aligns with prior research on the cost-effectiveness of renewable energy adoption in commercial settings (Luthander et al., 2015) but expands the analysis by incorporating real-world Pertamina case studies.

Additionally, solar PV enhances energy security, reducing reliance on an unstable grid and ensuring uninterrupted operations in remote areas (Suharto & Suryadi, 2021).

 p-ISSN: 2088-1231
e-ISSN: 2460-5328

2. Challenges in Implementing Solar PV in Gasoline Stations

2.1 High Upfront Costs

One of the primary challenges associated with solar PV deployment in gasoline stations is the high upfront capital costs required for purchasing and installing solar panels, inverters, and related equipment. Although solar PV technology has become more affordable in recent years, the initial investment remains a significant barrier for widespread adoption, especially in smaller, independently operated gasoline stations (Simangunsong & Kurniawan, 2019).

Based on experience of Pertamina team, upfront cost for solar PV project is about 65 million IDR for 3 kWp Solar PV Project and 90 million IDR for 6 kWp Solar PV Project.

We can calculate the payback period (PBP) as below:

PBP (in year) = G/(A x B x C x E)

Where:
G = Investment (in IDR)
A = total capacity (in kWp)
B = efficiency (for Solar PV, average at 15%)
C = total hours/year (8.760 hours)
E = PLN tariff (average at 1.444 Rp/kWh)

Table 4 Calculation for Payback Period

No	Parameter	Value (3 kWp)	Value (6 kWp)
1	G - Investment	65.000.000	90.000.000
2	A - total capacity	1.889	1.889
3	B - efficiency	15%	15%
4	C – total hours/year	8.760	8.760
5	E – PLN tariff	1.440	1.440
	Payback Period (G/(A x B x C x E))	11.4 years	7.9 years

The payback periods are calculated as 11.4 years (3 kWp) and 7.9 years (6 kWp), demonstrating longer ROI periods compared to solar investments in industrial settings, where economies of scale reduce payback time (IRENA, 2019).

2.2 Space Limitations

Space constraints hinder solar PV deployment in urban gasoline stations, a challenge less explored in large-scale solar farm studies (Putra & Supriyadi, 2021). This research highlights creative solutions such as solar canopy integration and carport solar structures, which optimize available space without disrupting fueling operations.

p-ISSN: 2088-1231
e-ISSN: 2460-5328

Figure 3 Solar PV in Pertamina's Gasoline Station

3.3. Maintenance and Operational Challenges

Environmental factors, such as dust accumulation and extreme weather, pose operational challenges for solar PV maintenance (Manurung & Putri, 2018). This study extends prior findings by providing industry-specific insights, emphasizing the need for regular panel cleaning, real-time monitoring, and inverter maintenance to optimize performance in gasoline stations.

3.4. Regulatory and Policy Barriers

Regulatory uncertainty remains a key challenge in Indonesia's renewable energy sector. Unlike studies focusing on developed markets with stable policy frameworks (Sharma et al., 2021), this research highlights Indonesia's evolving regulatory landscape, including inconsistent incentives and feed-in tariffs, complex permitting processes, and bureaucratic approval procedures for solar installations

CONCLUSION

Solar PV systems offer significant potential benefits for Pertamina's gasoline stations, including new energy production (energy transition), emission reduction (sustainability), cost reduction and enhanced energy security (green investment). Despite challenges related to high upfront costs, space limitations, and regulatory barriers, Pertamina's leadership in renewable energy positions the company to overcome these obstacles and drive the adoption of solar PV technology across its gasoline station network.

By investing in solar PV systems, Pertamina can play a critical role in advancing Indonesia's renewable energy goals, reducing carbon emissions, and demonstrating its commitment to sustainability. Through strategic partnerships, policy advocacy, and scalable deployment models, Pertamina has the potential to become a leader in solar PV adoption at gasoline stations, contributing to a cleaner and more sustainable energy future for Indonesia.

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