

Renewable Energy in Vietnam: Figures and Future Scope for Net-Zero Target

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Abstract: Vietnam has emerged as one of the most dynamic renewable energy (RE) markets in Southeast Asia, marked by impressive growth in solar and wind power. This paper aims to analyze key figures on renewable energy development in Vietnam, review legal and technical barriers, and assess the evolving policy framework towards achieving the national Net-Zero target by 2050. Between 2015 and 2021, solar capacity rose from under 100 MW to more than 18 GW, largely fueled by supportive Feed-in Tariff (FIT) policies under Decision No. 11/2017/QĐ-TTg and Decision No. 13/2020/QĐ-TTg. Wind energy also expanded, reaching about 4 GW by 2023. By 2024, renewables accounted for nearly 30% of national electricity capacity. However, challenges persist. Post-FIT uncertainty, delays in PDP8, grid congestion, and the lack of advanced storage or forecasting limit system flexibility. These issues hinder private investment, compounded by the absence of a mature carbon pricing framework. In response, Vietnam has shifted from FITs to competitive bidding schemes, with pilot auctions planned, while also drafting a carbon market framework to mobilize climate finance. The paper highlights that PDP8 (National Power Development Plan VIII), approved in 2023, sets ambitious goals: renewables to supply 47% of electricity by 2030. Policy adjustments now integrate carbon cost considerations, promoting sustainability. Furthermore, Vietnam is collaborating with international partners to enhance grid standards, develop recycling solutions for end-of-life solar panels, and apply ESG (Environmental, Social, and Governance) practices. The research provides a comprehensive overview of achievements, identifies bottlenecks, and evaluates future directions for Vietnam's renewable energy sector, underlining its critical role in realizing the Net-Zero 2050 commitment.

Keywords: renewable energy, zero carbon; FIT; COP26; PDP8, Vietnam and Renewable Energy

1. Introduction of Vietnam's Net-Zero Commitment and Renewable Energy Role

Vietnam's net-zero commitment at COP26, as articulated by Prime minister Pham Minh Chinh, reflects both moral leadership and strategic foresight. Anchored in renewable energy expansion, supported by PDP8 and the Net-Zero Roadmap, and backed by multilateral partnerships, the country aims to reconcile rapid economic growth with global climate responsibilities. Meeting the 2050 target demands not only large-scale deployment of renewables but also systemic reform: integrating carbon pricing, hydrogen economy development, smart grids, and just transition policies into national planning. The ambition places Vietnam at the forefront of renewable energy leadership in ASEAN, while emphasizing that policy coherence, international collaboration, and investment mobilization remain essential to success.

1.1 Context and COP26 Commitment

At COP26 (October–November 2021), Vietnam elevated its international climate profile by committing to net zero by 2050—emphasizing the urgency of climate mitigation amid mounting sea-level rise, extreme weather events, and socio-economic vulnerability. PM Pham Minh Chinh used his plenary address to underline that Vietnam, among the countries most exposed to climate risks, must pursue “inclusive approaches” to development while aligning with the Paris Agreement and accelerating the global transition.

Vietnam's COP26 position underscores both climate ambition and developmental pragmatism: the country seeks to leapfrog legacy infrastructure and landlocked fossil dependency by investing in renewables. The message from UNDP (United Nations Development Programme) and MOIT (Ministry of Industry and Trade) is consistent: expanding renewables must occur in tandem with equitable and inclusive development—highlighting worker retraining, rural energy access, and coastal climate resilience.

1.2 Strategic Role of Renewable Energy

As a fast-growing ASEAN economy likely to see electricity demand double by 2030 (presented in fig.1), Vietnam faces the challenge of meeting both growth and emissions reduction simultaneously. Renewables offer a scalable and economically competitive solution; wind and solar have already demonstrated rapid deployment potential under the FIT regime and remain cost-advantaged compared to new coal generation (International Energy Agency, 2017).

According to IEA (International Energy Agency) modelling in Achieving a Net Zero Electricity Sector in Viet Nam, renewables are the centerpiece of all decarbonization pathways. In the “NZE Scenario,” renewables contribute over 70–80% of power generation by 2050 (shown in fig. 2,3), with solar, wind, and potentially hydrogen-generated power leading the mix (GIZ, 2020), (Ministry of Industry and Trade (MOIT), 2023). Bloomberg NEF places renewable power (including wind and solar) as delivering approximately 36% of emissions abatement by mid-century, with clean hydrogen and carbon capture contributing further decarbonization benefits.

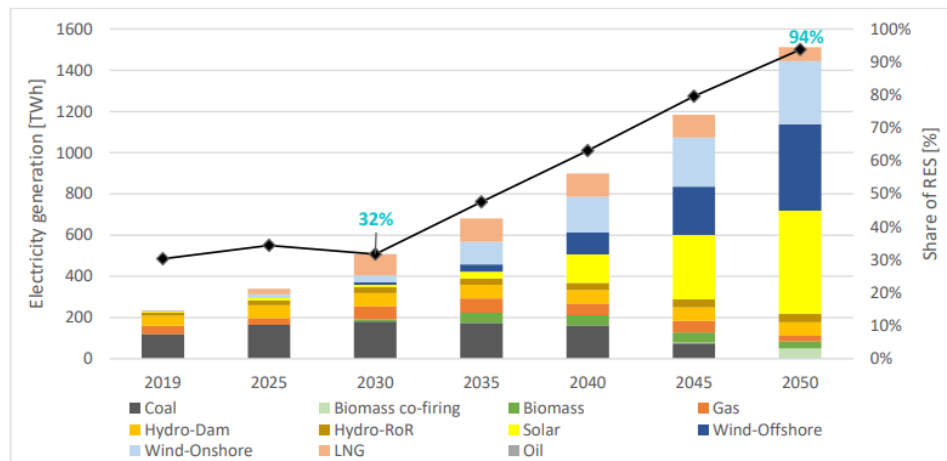


Fig. 1. VietNam electricity generation by fuel and renewable energy share, 2019-2050 (Diagnostic Study on Net-Zero for The Energy Sector in Vietnam: Deliverable 4 (Final Report): Net-Zero for the Energy Sector in Vietnam, 2023)

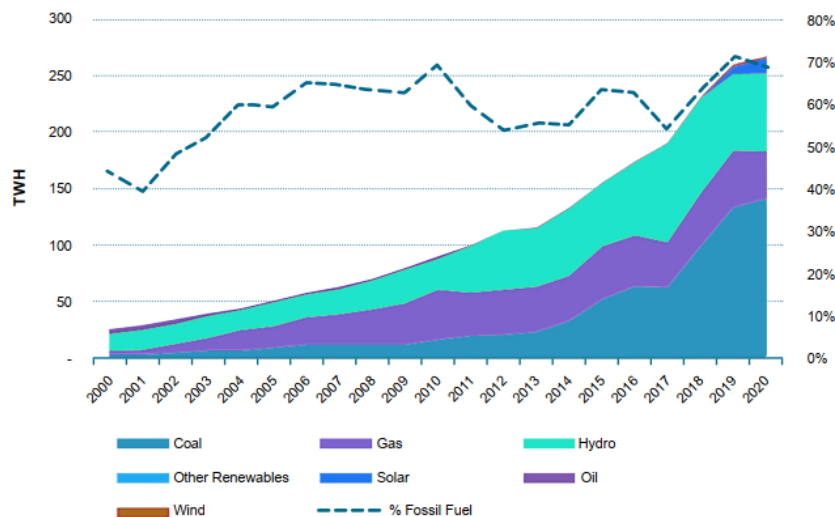


Fig. 2. Vietnam electricity's generation: Sources and % fossil fuel (2000-2020) (Ministry of Industry and Trade (MOIT), 2023)

The figure 3 illustrates Vietnam's electricity generation mix under two scenarios (ETP-NZE and ETP-Low CCS) toward 2050. Renewables dominate the growth trajectory, rising from 32% in 2030 to 94–98% by 2050, replacing coal, gas, LNG, and oil. The steep increase in renewable share highlights Vietnam's dependence on policy-driven decarbonization and rapid technological integration. Both scenarios confirm that fossil fuels will be gradually marginalized, with LNG and oil almost eliminated by 2050. The figure also underscores the urgent need for grid modernization and storage systems to manage high shares of variable renewables. Overall, the projections affirm Vietnam's strong potential to achieve its Net-Zero

targets through accelerated renewable adoption and structural energy reforms.

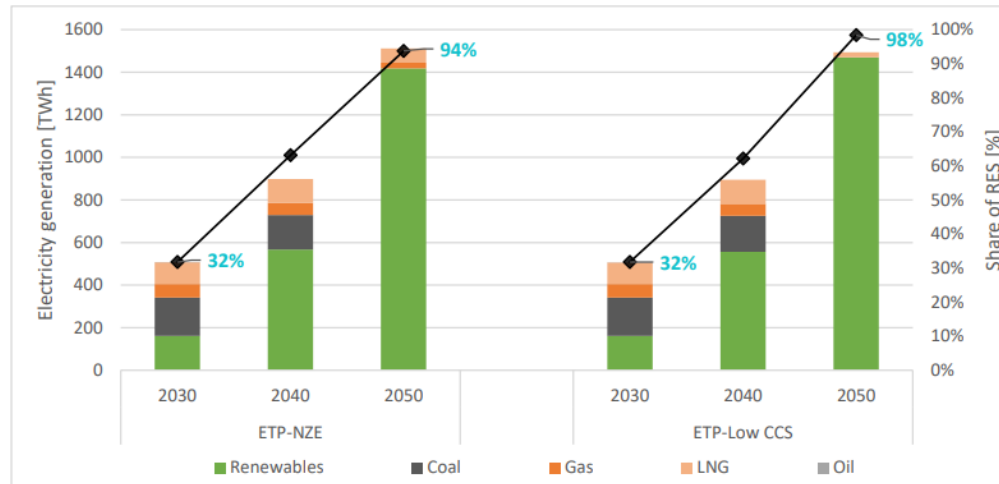


Fig. 3. VietNam electricity generation by source and RE share NZE vs Low CCS, 2030-2050 (Diagnostic Study on Net-Zero for The Energy Sector in Vietnam: Deliverable 4 (Final Report): Net-Zero for the Energy Sector in Vietnam, 2023)

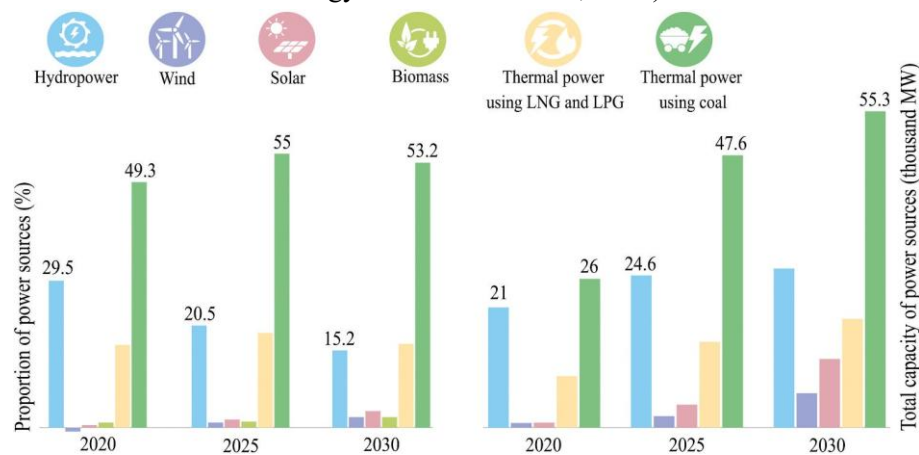


Fig. 4. Proportion and a total capacity of six energy sources in National Energy Development Strategy (Ha Duong, 2030)

According to data exhibited by EVN (EVN Report Operational, 2023), to 2023 RE is only 14% of entire energy production. Fig. 4 shows: “The entire system's power production in September 2023 reached 23.5 billion kWh (average 784.9 million kWh/day), an increase of 6.7% compared to that of the same period in 2022; The highest daily output reached 869.9 million kWh and the highest capacity reached 42,054MW (September 22). Accumulated for 9 months, the system's output reached 209.9 billion kWh, up 3.1% over the same period last year, in which the mobilization rate of some types of power sources is as follows:

- + Hydropower: 58.05 billion kWh, accounting for 27.7%. Because in early September, the water flow to the reservoirs in all three regions was good, so hydropower was increasingly exploited, especially in multi-purpose hydropower reservoirs.
- + Coal thermal power: 97.2 billion kWh, accounting for 46.3%.
- + Gas turbines: 20.82 billion kWh, accounting for 9.9%.
- + Oil thermal power: 1.23 billion kWh, accounting for 0.6%.
- + Renewable energy: 29.13 billion kWh, accounting for 13.9% (of which solar power reached 20.45 billion kWh, wind power reached 8.01 billion kWh).
- + Imported electricity: 3.1 billion kWh, accounting for 1.5%”

Hence, to get the target of 94% RE share in 2050 (shown in fig. 1) a series of complex strategy and national policy must be implemented.” (EVN Report Operational, 2023)

1.3. Institutionalization via National Policy Mechanisms

In the past ten years, the key policies are authorized as following:

1. Decision 428/QĐ-TTg set original solar targets to reach 850 MW by 2020 and 12,000 MW by 2030
2. Decision 11/2017/QĐ-TTg launched the first Feed-in Tariff at 9.35 US cents/kWh (The Rapid Development of Solar and Wind Power in Vietnam, n.d.)
3. Decision 02/2019/QĐ-TTg changed rooftop solar mechanisms from net-metering to direct consumption
4. Decision 13/2020/QĐ-TTg created separate FIT rates for ground-mounted (7.09 cents), floating (7.69 cents), and rooftop (8.38 cents) installations (Vietnam Power Generation, n.d.)
5. PDP8 Implementation Plan moved toward self-consumption models
6. Extended Producer Responsibility regulations tackled growing waste management concerns

Vietnam has institutionalized its renewable energy development through a series of binding legal instruments, notably Decision No. 896/QĐ-TTg (2022), which formally embedded the net-zero 2050 target into the National Climate Change Strategy, thus establishing a long-term regulatory framework for energy transition ((International Energy Agency, 2017), (UNDP, n.d.)). This was further reinforced by the NetZero Science and Technology Programme (2024), aimed at enhancing domestic innovation capacity and aligning R&D with decarbonization imperatives ((UNDP, n.d.), (GlobalData, 2023)). Key policy milestones, such as Decision 11/2017/QĐ-TTg, which introduced the initial Feed-in Tariff (FIT) scheme, and Decision 13/2020/QĐ-TTg, which differentiated tariffs by technology type, institutionalized financial incentives that catalyzed over 19 GW of solar capacity by 2022 ((GIZ, 2020), (IFC, 2021), (Vietnam Updates Regulations Encouraging Solar Power Development, n.d.)). The PDP8 Implementation Plan (2023) marked a transition from subsidy-based mechanisms to self-consumption models, reinforcing distributed energy development and system integration ((International Energy Agency, 2017), (IEEFA, 2024), (International Energy Agency, 2023)). Furthermore, Vietnam's engagement with the Just Energy Transition Partnership (JETP) institutionalizes multilateral financing channels to phase out coal while ensuring procedural justice and stakeholder inclusion ((IEEFA, 2024), (UNDP, n.d.), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.)). Regulatory instruments such as Circular 18/2020/TT-BCT and Decision 02/2019/QĐ-TTg facilitated grid connection and rooftop solar deployment, indicating a progressive shift toward decentralized energy governance ((GlobalData, 2023), (Vietnam Updates Regulations Encouraging Solar Power Development, n.d.)). The state utility EVN, though operating under a monopsony market structure, has been mandated to implement PPA (Power Purchase Agreement) reforms and support direct power purchase agreements (DPPAs), paving the way for a more liberalized and competitive RE market ((International Energy Agency, 2017), (Vietnam Energy Outlook, 2021), (GlobalData, 2023)). By aligning policy instruments with national planning strategies such as PDP8 and the Net-Zero Roadmap, Vietnam has created a coherent institutional architecture for RE scale-up ((World Bank, 2021), (International Energy Agency, 2023), (CEEW Vietnam Grid Integration, n.d.)). The adoption of Extended Producer Responsibility (EPR) regulations also reflects a policy effort to address lifecycle sustainability in RE development ((UNDP, n.d.), (Photovoltaic Waste Projection, 2050)). Collectively, these institutional mechanisms demonstrate Vietnam's systematic approach to embedding renewable energy within its legal, financial, and planning apparatus to support long-term decarbonization.

The National Power Development Plan VIII (PDP8) (Ministry of Industry and Trade (MOIT), 2023) represents Vietnam's central policy instrument guiding the energy transition. It outlines the government's strategy for energy security, RE investment, and emissions reduction for the period 2021–2030 with a vision to 2050. PDP8 aims to increase the RE share to 31–39% by 2030 and 67–72% by 2050. According to the World Bank (World Bank, 2021), integrating variable renewables at these levels will require significant grid modernization, forecasting systems, and energy storage. IRENA (International Renewable Energy Agency (IRENA), 2019) (International Renewable Energy Agency) estimates that under a least-cost pathway, Vietnam can meet 60% of its energy needs with RE by 2050. ASEAN Centre for Energy (ASEAN Centre for Energy, n.d.) notes the importance of regional grid integration and regulatory harmonization. Furthermore, the Vietnam Initiative for Energy Transition (Vietnam Energy Outlook, 2021) identifies gaps in existing investment frameworks and policy enforcement that may hinder implementation. The BloombergNEF report (BloombergNEF, 2022) concludes that success will require coordinated public-private collaboration and alignment of domestic laws with global climate standards.

1.4. Technical Feasibility and Comparative Regional Perspective

Modelled scenarios from IEA and BNEF show that Vietnam's emissions must peak by 2026 (Vietnam Energy Outlook Report (2024) - Pathways to Net Zero, 2024) (fig.5), driven primarily by power-

sector decarbonization. Solar and wind generation are projected to avoid roughly 99 MtCO₂ (Million tonnes of Carbon Dioxide) by 2030 (fig. 5), while energy efficiency, electrification, and hydrogen further enhance long-term reductions. Notably, achieving over 220 GW of offshore wind capacity—tied to hydrogen production—is part of the decarbonization blueprint.

Considered as regional leader (presented in fig. 6, 7) (ASEAN's renewable energy growth: Navigating rapid economic expansion, n.d.), Vietnam outperforms its ASEAN peers in renewable energy deployment across multiple dimensions: installed capacity (19 GW vs ~9 GW combined), share of electricity generation (23% vs ~12–17%), and future target pipelines (84 GW vs 44 GW in Indonesia, 30 GW in the Philippines). Its robust policy framework, driven by FIT schemes and PDP8 integration, has enabled faster scaling than in Malaysia or Thailand. ASEAN-wide initiatives such as APG (ASEAN Power Grid) and JETP further amplify Vietnam's leadership role, demonstrating that rapid renewable expansion is compatible with economic growth and regional cooperation.

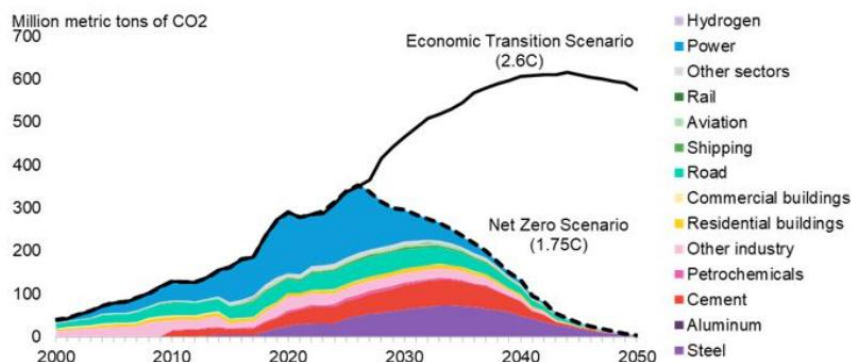


Fig. 5. Vietnam's energy-related emissions and NZ carbon budget and NZ Scenario (Vietnam's, 2050)

Although Vietnam's COP26 net-zero pledge is among the most ambitious in Southeast Asia, many ASEAN peers have yet to formally commit or have slower decarbonization trajectories. According to IEA data, only a few countries aim to exceed 225 GW of new renewables by 2030, with Vietnam leading with 84 GW of planned additions. This underscores Vietnam's leadership in regional energy transition policy.

+ Vietnam's share of renewables—including hydro, solar, and wind—reached approximately 23% of total electricity generation by 2023, outperforming Malaysia (~16.6%) and Thailand (~12%). This aligns with Vietnam's National Power Development Plan VIII (PDP8), targeting up to 39% grid renewable penetration by 2030, and surpasses the regional norm where renewable shares often range between 10% and 20% in peer economies.

+ Under ASEAN-wide pledges to triple global renewables capacity by 2030, only Vietnam and Singapore are projected to meet their 2030 targets based on current trajectories (ASEAN's renewable energy growth: Navigating rapid economic expansion, n.d.). Vietnam's target of around 84 GW by 2030 compares favorably with Indonesia's 44 GW and the Philippines' 30 GW, suggesting Vietnam's ambitions are not only aggressive but also attainable—positioning it as a benchmark for ASEAN energy transition leadership.

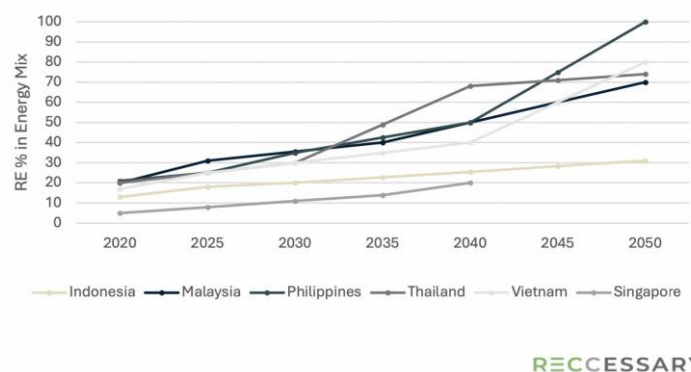


Fig. 6. ASEAN-6 RE targets (ASEAN's renewable energy growth: Navigating rapid economic expansion)

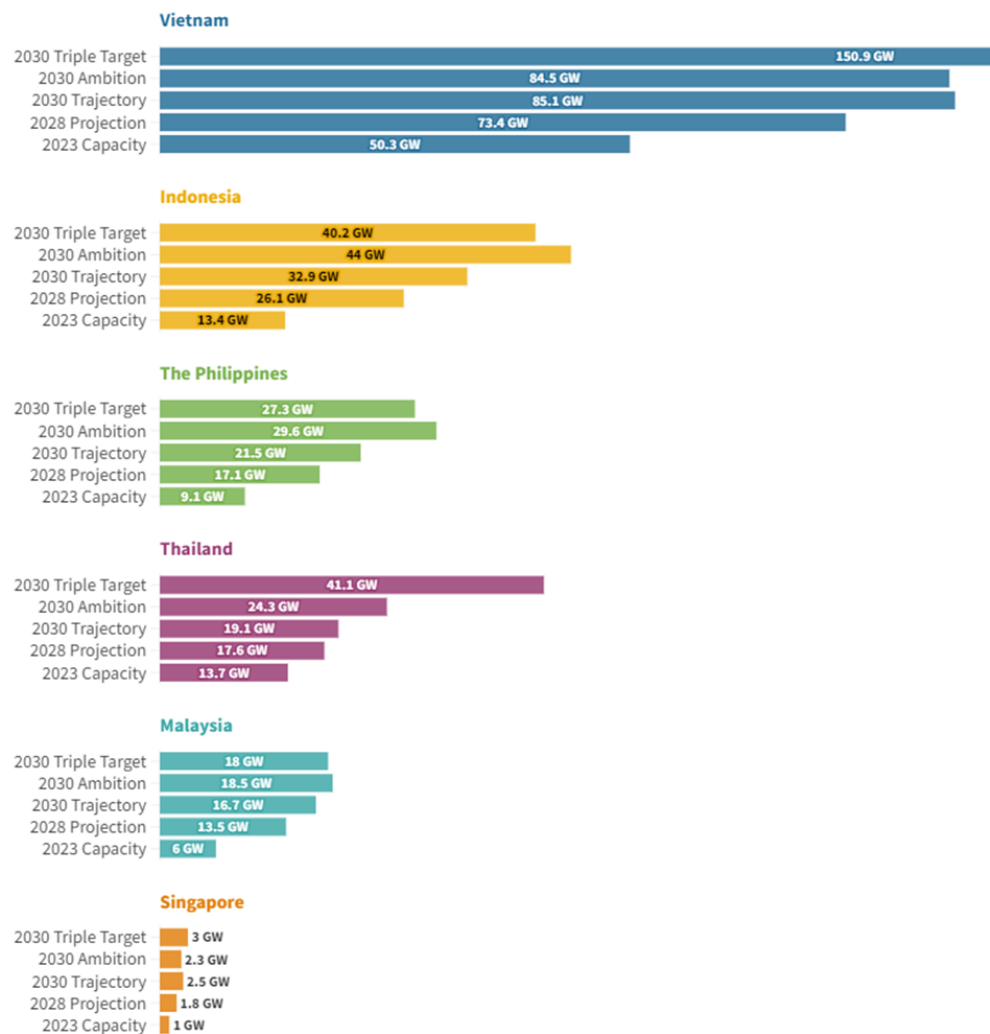


Fig. 7. Chart comparing renewables capacity, projections, trajectory, ambitions, and tripling target (Energy Transition: Southeast Asia's role in tripling global renewables capacity)

1.5. Some remarks

Over the past decade, Vietnam has experienced a remarkable surge in renewable energy development, both in scale and scope. The growing prominence of renewables has compelled policymakers to undertake frequent and intensive adjustments, not only in regulatory frameworks but also in operational governance. While the legal and technical infrastructure remains at a modest stage of maturity, these adjustments have already elevated the role of renewables as a critical pillar of national energy security and as a cornerstone of Vietnam's emerging status as a regional energy hub. Simultaneously, the rapid proliferation of renewable generation capacity, technologies, and deployment models introduces complex technical challenges and strategic considerations for medium- and long-term planning. Nevertheless, this dynamic growth trajectory has instilled in the Vietnamese government a reinforced confidence to pursue and commit firmly to the national Net-Zero objective.

The primary objective of this article is to critically assess Vietnam's renewable energy development in relation to its 2050 net-zero target. The study seeks to bridge gaps between current achievements and future ambitions by identifying where installed capacity, regulatory instruments, and infrastructure fall short of projected needs. Specifically, the paper focuses on three interconnected problems: the absence of a stable long-term pricing framework post-FIT, grid congestion in high-penetration regions, and the lack of carbon pricing and storage systems. By applying a structured framework with criteria for successful policies—policy clarity, financial viability, institutional transparency, and system sustainability—the analysis clarifies why existing targets may be difficult to achieve under current conditions. The purpose is not only descriptive but diagnostic: to reveal weaknesses, evaluate the effectiveness of policies like PDP8, and outline pathways that align Vietnam's RE sector with its net-zero trajectory.

The following parts of the paper focus on:

+ Part 2: analyzes the current status of RE in VietNam, This section evaluates installed capacity, geographic clustering, and regulatory frameworks, highlighting policy-driven growth but also structural weaknesses. The methodology centers on identifying criteria for successful policies such as balanced deployment, market adaptability, and infrastructure readiness

+ Part 3 performs Net-zero roadmap by emphasizing RE, grid modernization, and just transition as key pillars of Vietnam's 2050 strategy. This section reviews PDP8 targets, carbon pricing efforts, and financing mechanisms while applying a framework that tests policy feasibility, coherence, and alignment with climate commitments. The analysis identifies gaps between ambition and implementation

+ Part 4 exhibits the technological and market opportunities by examining how policy incentives, industrial investment, and digital grid tools can translate into socioeconomic and environmental benefits. Success criteria include innovation adoption, financial bankability, and inclusivity of energy access.

+ Part 5 mentions about challenges and barriers on the way to the NET-Zero including technical grid limits, policy instability, financing gaps, and social/environmental risks. This section systematically applies an evaluation framework to identify barriers against criteria such as policy clarity, institutional transparency, financial accessibility, and lifecycle sustainability. The findings clarify why some targets may be delayed and where reforms should focus

2. Current Status of Renewable Energy in Vietnam

2.1. Installed Capacity and Technology Mix

As of late 2023, Vietnam had surpassed 20 GW of installed solar PV capacity, it is really a boom from 850MW in 2021 (fig.8), positioning itself as the top solar market in Southeast Asia (IRENA Solar PV, 2024), (Energy Transition: Southeast Asia's role in tripling global renewables capacity, n.d.). This figure includes a mix of utility-scale farms, rooftop solar installations, and floating PV systems, reflecting a diversified deployment strategy. According to GIZ (GIZ, 2020) and the World Bank (Photovoltaic Waste Projection, 2050), solar PV capacity expanded from less than 1 GW in 2017 to over 16 GW by the end of 2020, a more than 15-fold increase in just three years. The magnitude and velocity of this growth were largely enabled by the government's Feed-in Tariff (FIT) mechanism introduced in 2017 (Government of Vietnam Declares Feed-in Tariff for Solar Power, n.d.), which offered a highly competitive rate of 9.35 U.S. cents/kWh.

Despite the FIT being phased out in 2021, legacy momentum and investor confidence sustained the sector's development, albeit at a slower pace. IFC (IFC, 2021) noted that rooftop solar became particularly attractive for commercial and industrial (C&I) consumers seeking to hedge against rising electricity prices while contributing to corporate sustainability targets.

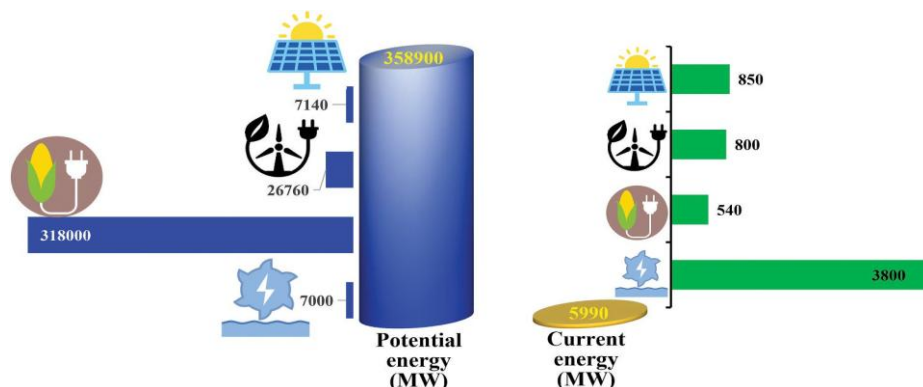


Fig.8. Structure of potential and current capacity of renewable power in Vietnam (EVN 2021)

In parallel, Vietnam's onshore wind energy capacity has expanded rapidly, reaching more than 4 GW by 2023 (Global Wind Energy, 2022), with a significant portion of the capacity becoming operational just before the wind FIT expired in October 2021. While this capacity still lags behind solar PV in absolute terms, the technical potential for wind power in Vietnam—especially offshore—is vast, with estimates suggesting a potential of over 600 GW, of which 475 GW is offshore (IUCN, 2022).

According to PDP8 (Ministry of Industry and Trade (MOIT), 2023), Vietnam aims to reach 21 GW of wind energy (including 6 GW offshore) by 2030, making it a central pillar of the country's net-zero ambition by 2050 (Vietnam Energy Outlook, 2021). This outlook aligns with international forecasts, including those from the IEA and IRENA, which predict that renewables could comprise more than 50% of total electricity generation in Vietnam by 2045 (International Energy Agency, 2017), (International Energy Agency, 2023).

2.2. Geographic and Regional Distribution

The geographical distribution of renewable energy installations in Vietnam is heavily skewed towards specific regions, primarily driven by resource availability and land-use considerations.

- Central and Southern provinces such as Ninh Thuan, Binh Thuan, Dak Lak, Gia Lai, and Soc Trang have become renewable energy hubs due to favorable solar irradiation (>5 kWh/m²/day) and consistent wind speeds (>7 m/s) (Ministry of Industry and Trade (MOIT), 2023), (Vietnam's Solar and Wind Power Success: Policy Implications for ASEAN, n.d.), (Vietnam Power Generation, n.d.). For instance, Ninh Thuan and Binh Thuan together host over 35% of the country's solar capacity and are also leaders in onshore wind development.

- Mekong Delta provinces like Bac Lieu, Soc Trang, and Tra Vinh are increasingly being targeted for offshore wind power projects, capitalizing on their extensive coastal areas and shallow seabeds that facilitate fixed-bottom turbine installations (IUCN, 2022).

- "According to statistics, the distribution of the energy industry in Vietnam is concentrated mainly in the Central and Central Highlands provinces, especially Ninh Thuan and Binh Thuan provinces with solar power and the provinces of Dak Lak, Gia Lai, and Ninh. Thuan, Binh Thuan, Binh Phuoc, Nghe An with wind power. However, these areas have the common characteristic of low energy efficiency due to lack of experience and modern equipment, along with the failure to ensure adequate transmission lines and infrastructure to connect with the areas." (Vietnam Power Generation, n.d.); (Distribution of the Energy Industry in Vietnam, n.d.)

However, this regional concentration has created significant transmission congestion and bottlenecks, particularly in provinces with limited grid capacity. The local 110 kV and 220 kV transmission lines, many of which were not designed to accommodate high variable renewable energy (VRE) inflows, have become overloaded during peak generation periods, forcing curtailments and reducing plant utilization (World Bank, 2021), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.), (IRENA Market Analysis: Southeast Asia, n.d.). To address these issues, the Vietnamese government has introduced strategic initiatives under PDP8, emphasizing grid expansion, smart grid deployment, and energy storage integration. Notably, World Bank (World Bank, 2021) and CEEW (CEEW Vietnam Grid Integration, n.d.) both highlight the urgent need for grid-responsive policies, such as dynamic pricing and flexible interconnection standards, to enable higher renewable penetration while maintaining system reliability.

2.3. Power Market and Regulatory Environment

While Vietnam has demonstrated strong ambition and early success in expanding renewable energy, sustaining this momentum requires a more adaptive and competitive regulatory environment. Critical priorities include accelerating power market liberalization, enabling demand-side participation, integrating flexible generation and storage, and ensuring grid-readiness through digitalization and forecasting. Future policy reforms must strike a balance between regulatory certainty, market innovation, and technological adaptability to support Vietnam's green transition goals.

Vietnam's power market and regulatory environment have undergone significant evolution to accommodate the rapid influx of renewable energy (RE), particularly from solar and wind sources. This transformation has been largely driven by supportive governmental frameworks, private sector participation, and growing international investment. However, the fast pace of RE deployment has also exposed several regulatory and operational bottlenecks, especially in power dispatch, grid flexibility, and tariff structures.

A cornerstone of Vietnam's RE development has been the implementation of Feed-in-Tariff (FIT) policies, particularly for solar PV between 2017 and 2021 (IFC, 2021), (Government of Vietnam Declares Feed-in Tariff for Solar Power, n.d.), (Vietnam Updates Regulations Encouraging Solar Power Development, n.d.). These FITs offered highly competitive rates—USD 0.0935/kWh for ground-mounted solar and up to USD 0.0985/kWh for rooftop PV—attracting a surge of private investments in both utility-scale and decentralized systems (GIZ, 2020), (GlobalData, 2023). As a result, Vietnam added over 17 GW of solar capacity by the end of 2020 (GIZ, 2020), (World Bank, 2021). However, these incentives also led to temporal and spatial clustering of projects, outpacing the capacity of the national transmission infrastructure and forcing curtailment in several regions (World Bank, 2021), (Ministry of Industry and Trade (MOIT), 2023), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.).

The regulatory framework is currently anchored by Vietnam Electricity (EVN), the state-owned utility responsible for generation, transmission, and distribution, which also functions as the single buyer

in the wholesale electricity market. While EVN has facilitated RE integration through PPA frameworks and connection guidelines, critics argue that the current monopsony market model limits competition and flexibility, particularly for Independent Power Producers (IPPs) (International Energy Agency, 2017), (Vietnam Energy Outlook, 2021), (GlobalData, 2023). Furthermore, the lack of a real-time or spot market and limited transparency in dispatch priority decisions have raised concerns regarding fair access and economic efficiency (World Bank, 2021), (BloombergNEF, 2022).

The government has attempted to address these challenges through a series of regulatory reforms. Notably, Circular 18/2020/TT-BCT introduced guidelines for rooftop solar metering and net-metering principles, while Decision 13/2020/QĐ-TTg defined the eligibility and duration of FITs for new RE projects (Vietnam Updates Regulations Encouraging Solar Power Development, n.d.), (Vietnam Should Increase Solar FIT to \$0.15/kWh, n.d.). Moreover, MOIT has piloted direct power purchase agreements (DPPAs) to allow large consumers to procure RE directly from generators, aiming to diversify procurement options and reduce reliance on EVN (IEEFA, 2024), (GlobalData, 2023). From a market liberalization perspective, efforts are underway to transition toward a competitive wholesale electricity market (VWEM), with plans to evolve into a fully competitive retail market beyond 2025 (International Energy Agency, 2017), (BloombergNEF, 2022), (GlobalData, 2023). However, progress remains slow due to the need for institutional capacity building, data transparency, and pricing reform. A key impediment to deeper RE market penetration is the absence of time-of-use (TOU) pricing or ancillary service compensation for flexible generators and storage assets (World Bank, 2021), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.), (CEEW Vietnam Grid Integration, n.d.).

International organizations such as the World Bank (World Bank, 2021), IEA (International Energy Agency, 2017), and GIZ (GIZ, 2020) have advocated for Vietnam to adopt a more flexible, market-based approach. These include introducing marginal pricing signals, creating regional balancing markets, and institutionalizing a grid code that supports higher RE penetration. The USAID Clean Energy Investment Accelerator further emphasizes that aligning market reform with investor expectations is critical to achieving net-zero by 2050 (IEEFA, 2024), (UNDP, n.d.).

Vietnam's regulatory environment must also grapple with the growing importance of grid reliability and forecasting. According to the World Bank (World Bank, 2021) and CEEW (CEEW Vietnam Grid Integration, n.d.), the intermittency of wind and solar has challenged EVN's load dispatch centers, which traditionally operated under stable baseload conditions. Inadequate short-term forecasting tools and the lack of grid storage compound the issue, especially during peak midday solar output and sudden wind fluctuations (World Bank, 2021), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.), (Photovoltaic Waste Projection, 2050). This calls for institutionalizing forecast-based dispatch, smart grid investments, and robust renewable energy integration plans at the provincial level (Ministry of Industry and Trade (MOIT), 2023), (IRENA Market Analysis: Southeast Asia, n.d.), (CEEW Vietnam Grid Integration, n.d.).

In response, the National Load Dispatch Centre (NLDC) has begun investing in advanced EMS/SCADA systems and digital grid analytics, as highlighted in IEA reports (International Energy Agency, 2017), (International Energy Agency, 2023). However, the scope remains limited, and Vietnam lags behind regional peers like Thailand and Malaysia in grid digitalization (International Energy Agency, 2023), (GlobalData, 2023), (CEEW Vietnam Grid Integration, n.d.). While Vietnam has taken commendable steps toward grid digitalization through EMS/SCADA upgrades at the NLDC, these remain preliminary relative to the scale of transformation required. The country's grid infrastructure must evolve rapidly to keep pace with renewable integration trajectories. Lessons from more digitally advanced neighbors such as Thailand and Malaysia, combined with policy guidance from multilateral organizations and technical support from bilateral donors, can accelerate this transition. Integrating AI-enhanced forecasting, automated dispatch, and cyber-resilient digital infrastructure into national energy policy will be pivotal to ensuring that Vietnam's power system can safely and efficiently accommodate the energy transition underway. In light of the increasing integration of variable renewable energy (VRE) sources such as solar and wind into the national grid, the modernization of Vietnam's grid infrastructure has become imperative. The National Load Dispatch Centre, under the auspices of Vietnam Electricity (EVN), has initiated strategic investments in advanced Energy Management Systems (EMS) and Supervisory Control and Data Acquisition (SCADA) technologies to address the growing complexity of real-time grid operations and enhance the visibility, flexibility, and responsiveness of dispatch systems (International Energy Agency, 2017), (International Energy Agency, 2023).

The IEA's Vietnam Power Sector Review (International Energy Agency, 2017) and the Renewables 2023 report (International Energy Agency, 2023) acknowledge these developments as necessary steps toward modernizing Vietnam's transmission and distribution systems. These efforts include digital control enhancements at the regional and provincial levels, along with the deployment of smart monitoring tools to better forecast and respond to the volatility introduced by renewables. However, despite these improvements, the scope and scale of digital transformation remain constrained by institutional inertia, technical capacity gaps, and insufficient investment frameworks (International Energy Agency, 2017), (World Bank, 2021), (International Energy Agency, 2023).

Moreover, according to comparative studies from GlobalData (GlobalData, 2023) and CEEW (CEEW Vietnam Grid Integration, n.d.), Vietnam continues to lag behind regional benchmarks in grid digitalization, particularly when compared to peers such as Thailand and Malaysia. These countries have proactively adopted wide-area monitoring systems

(WAMS), automatic generation control (AGC), and synchrophasor technologies, enabling them to accommodate high penetrations of VRE without compromising grid stability. In contrast, Vietnam's grid infrastructure is still characterized by fragmented legacy systems with limited interoperability between provincial dispatch centers (World Bank, 2021), (Ministry of Industry and Trade (MOIT), 2023), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.).

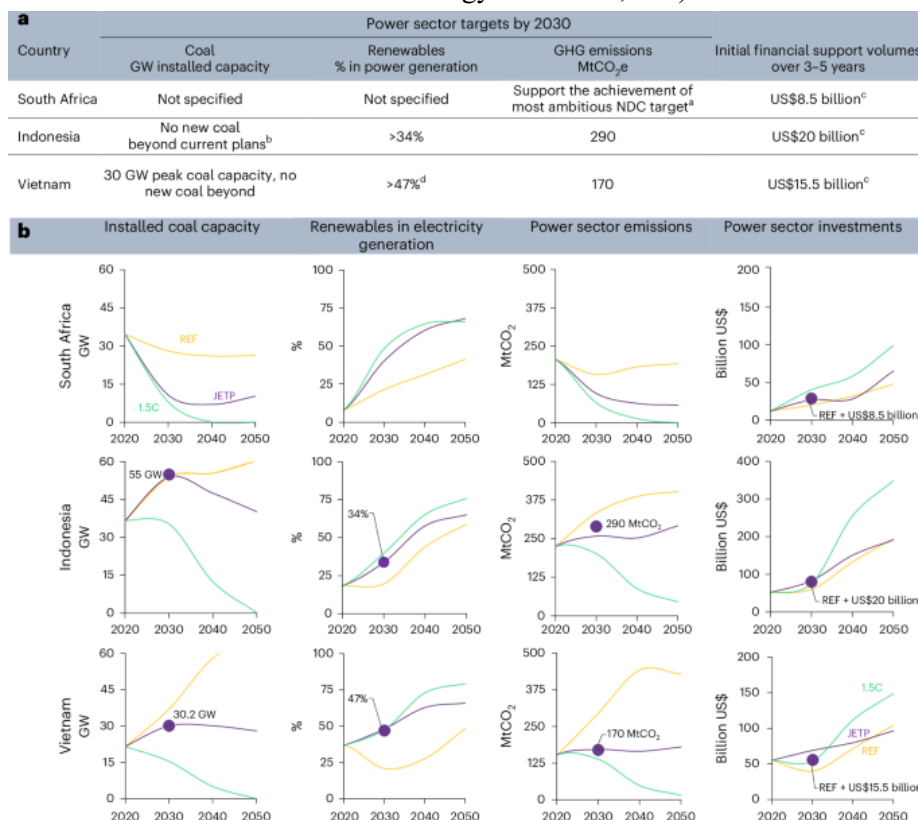


Fig.9. Quantitative JETP targets and power sector indicators across scenarios for South Africa, Indonesia and Vietnam (Ordenez, 2024)

As highlighted in the Energy Transition Partnership's report on managing Vietnam's grid issues (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.), this fragmentation hinders centralized decision-making, impairs coordination across regions, and undermines the efficient dispatch of power from renewable clusters in high-potential provinces such as Ninh Thuan and Binh Thuan. A lack of standardized communication protocols and data harmonization mechanisms further exacerbates these issues, resulting in suboptimal load balancing and unnecessary curtailment of renewable output during peak production windows (World Bank, 2021), (CEEW Vietnam Grid Integration, n.d.).

Furthermore, as the ASEAN Centre for Energy (ACE) notes in its Vietnam Country Profile (ASEAN Centre for Energy, n.d.), digital maturity in the Vietnamese grid ecosystem is still at an early stage. There is minimal deployment of Internet of Things (IoT) sensors, edge computing nodes, or blockchain-based transaction platforms, which are increasingly adopted globally for energy management and security. This has implications not only for operational efficiency but also for grid cybersecurity and resilience, two areas

of growing concern in the context of increasing digital penetration (IEEFA, 2024), (International Energy Agency, 2023).

The IEEFA (IEEFA, 2024) stresses the importance of adopting cyber-secure digital architectures, especially as Vietnam moves toward decentralized generation and direct power purchase agreements (DPPAs). As the digital interface between consumers and producers becomes more complex, ensuring the integrity, confidentiality, and availability of grid data becomes mission-critical. Yet, Vietnam's current cybersecurity protocols for energy infrastructure remain underdeveloped and are not fully aligned with international standards such as ISO/IEC 27019 (IEEFA, 2024), (UNDP, n.d.). To bridge this digitalization gap, both IEA (International Energy Agency, 2017) and the World Bank (World Bank, 2021) recommend that Vietnam adopt a comprehensive digital grid roadmap. This should include the phased integration of digital twins, machine learning-based SCADA analytics, and distributed energy resource management systems (DERMS), tailored to Vietnam's unique grid topology and operational challenges. Additionally, a coordinated data governance framework must be institutionalized to support cross-platform integration, enable real-time grid diagnostics, and promote transparency in dispatch decisions (World Bank, 2021), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.), (CEEW Vietnam Grid Integration, n.d.). UNDP (UNDP, n.d.) and PDP8 (Ministry of Industry and Trade (MOIT), 2023) further highlight the role of digital innovation in achieving net-zero emissions by 2050. Specifically, they advocate for aligning investment in grid digitalization with renewable energy expansion targets and national energy security priorities. The PDP8 emphasizes the need for grid modernization not only to accommodate growing VRE capacity but also to support emerging technologies such as grid-scale battery storage, electric vehicles (EVs), and hydrogen production, which demand real-time, flexible grid operations (Ministry of Industry and Trade (MOIT), 2023), (GlobalData, 2023).

2.4. Socioeconomic Impact

The socioeconomic implications of Vietnam's energy transition—particularly the shift from fossil fuels to renewables—are notable and multifaceted. Vietnam's solar and wind boom has stimulated significant capital flows—over US\$11 billion between 2018 and 2022, according to BloombergNEF (BloombergNEF, 2022). Not only did this investment drive infrastructure development, but it also created demand for locally delivered services including construction, logistics, electrical engineering, and operations. Offshore wind, if pursued at scale, can further catalyze blue economy growth, supporting port modernization and local supply chains (IUCN, 2022), (GlobalData, 2023). The multiplier effect is similar to what was observed in countries like Taiwan and the Philippines, where renewables catalyzed broader industrialization in energy services.

Employment and Workforce Transition

UNDP and VIETSE emphasize that a just energy transition demands workforce planning. Transitioning away from coal and fossil fuels will affect communities reliant on thermal power plants. Retraining programs and localized manufacturing development—in areas such as blade assembly, solar module fabrication, and grid automation services—are pivotal (Vietnam Energy Outlook, 2021), (UNDP, n.d.). These strategies align with international frameworks, such as the Just Energy Transition Partnership (JETP) with G7 nations (UNDP, n.d.).

Energy Access and Affordability

An expanded DER and decentralized generation model enhances energy access in rural and offgrid communities, important for Vietnam's movement toward equitable development. Particularly in rural provinces where transmission infrastructure is weak, rooftop solar and microgrid systems can ensure reliable supply for manufacturing, agriculture, and households. This is evidenced in regions like Tay Ninh and Dak Lak, which experienced grid congestion but can simultaneously leverage decentralized generation to reduce dependency on central supply (Ministry of Industry and Trade (MOIT), 2023), (Vietnam's Solar and Wind Power Success: Policy Implications for ASEAN, n.d.).

Reduced reliance on fossil fuels lowers exposure to volatile global fuel markets. This yields long-term electricity cost stabilization for consumers and state budgets alike. Vietnam's LCOE for solar—between \$0.05–\$0.07/kWh—compares favorably to imported coal-fired power costs (BloombergNEF, 2022), (Vietnam Solar Energy Costs Lowest in Southeast Asia, n.d.). Lower electricity tariffs contribute to industrial competitiveness, household income relief, and long-term economic resilience.

Environmental and Health Benefits

Transitioning to renewables significantly decreases local air pollution—particularly PM_{2.5} and SO₂

emissions—linked to coal combustion. Public health gains, such as lower incidence of respiratory illness and improved worker health, contribute to national productivity. These co-benefits are inherently difficult to price but offer substantial welfare gains not captured in traditional economic analysis.

Exposure to environmental risk also diminishes. Vietnam's coastal regions, especially in the Mekong Delta, are vulnerable to climate shifts and sea-level rise. Accelerating energy transition supports national climate adaptation goals and strengthens resilience in flood-prone zones (Vietnam Energy Outlook, 2021), (Vietnam Energy Outlook Report (2024) - Pathways to Net Zero, 2024).

3. Net-Zero Roadmap

Vietnam's commitment to achieving net-zero greenhouse gas (GHG) emissions by 2050, officially declared at COP26, marks a pivotal transformation in the country's energy and environmental policy landscape. This pledge reflects an increasing national recognition of climate change risks and the necessity for structural reforms across the energy value chain (Vietnam Energy Outlook Report (2024) - Pathways to Net Zero, 2024), (Vietnam Energy Outlook, 2021), (UNDP, n.d.). To meet its net-zero targets, Vietnam has devised a multi-phased roadmap that heavily incorporates renewable energy expansion, fossil fuel displacement, and grid modernization, as outlined in the National Power Development Plan VIII (PDP8) and supported by multilateral frameworks such as those promoted by the International Energy Agency (IEA) and IRENA (International Energy Agency, 2017), (Ministry of Industry and Trade (MOIT), 2023), (International Energy Agency, 2023).

At the core of the roadmap is the decarbonization of power generation through scaling up renewable energy. As of PDP8, Vietnam aims to reach 39.8 GW of renewable energy capacity by 2030, accounting for approximately 33% of the total installed generation capacity (Ministry of Industry and Trade (MOIT), 2023). Long-term projections envision a dominance of wind, solar, and biomass in the power mix. Offshore wind is targeted to achieve 6 GW by 2030, with potential for up to 70–91 GW by 2050 (IUCN, 2022), (Ministry of Industry and Trade (MOIT), 2023). Solar PV is set to maintain robust growth, both at utility-scale and via distributed rooftop systems, with emphasis on floating solar as a viable option to counter land scarcity (IFC, 2021), (Vietnam's Solar and Wind Power Success: Policy Implications for ASEAN, n.d.).

To support this transformation, the government is working on carbon pricing, a domestic emissions trading scheme (ETS), and mandatory reporting systems aligned with international standards (Vietnam Energy Outlook, 2021). The Ministry of Industry and Trade (MOIT) has coordinated with development partners like USAID, UNDP, and World Bank to implement policy reforms that support carbon neutrality (World Bank, 2021), (UNDP, n.d.), (IEEFA, 2024). These include revised grid codes, digitalized transmission systems, and the integration of variable renewable energy (VRE) forecasting into dispatching operations (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.), (CEEV Vietnam Grid Integration, n.d.).

The roadmap places significant emphasis on energy efficiency, demand-side management, and electrification of transport and industry, which together could reduce emissions by up to 20% by 2050 relative to a business-as-usual scenario (Vietnam Energy Outlook, 2021), (Oxford Institute for, 2021). The Vietnam Initiative for Energy Transition (VIETSE) report highlights that achieving net-zero requires a synchronized approach, involving transmission upgrades, diversification of storage technologies, and deep decarbonization of end-use sectors (Vietnam Energy Outlook, 2021).

Stakeholder alignment and financing remain critical components of the roadmap. Public-private partnerships (PPPs), concessional finance, and climate-aligned investment from international development agencies and green bonds will be required to meet the estimated \$114 billion needed by 2045 for energy transition projects (Vietnam Energy Outlook Report (2024) - Pathways to Net Zero, 2024), (UNDP, n.d.), (IEEFA, 2024), (OECD, n.d.). According to the UNDP (UNDP, n.d.) and Bloomberg NEF (BloombergNEF, 2022), mobilizing capital at scale requires transparent procurement frameworks, long-term power purchase agreements (PPAs), and risk mitigation instruments. The Clean Energy Investment Accelerator (CEIA) pilot project has already demonstrated success in aggregating demand for clean energy procurement across industrial clusters (IEEFA, 2024).

Importantly, the net-zero roadmap does not solely prioritize technical and financial dimensions. It also includes social equity considerations, recognizing the need for a just transition. Programs are underway to retrain fossil fuel workers, strengthen institutional capacity, and address affordability concerns among low-income households (UNDP, n.d.), (OECD, n.d.). Gender-sensitive planning and inclusive stakeholder dialogues are emphasized in recent UNDP frameworks (UNDP, n.d.).

Grid flexibility is a central challenge to achieving net-zero goals. Studies from World Bank (World Bank, 2021), IEA (International Energy Agency, 2017), and CEEW (CEEW Vietnam Grid Integration, n.d.) identify curtailment risks, limited inter-regional transmission capacity, and outdated SCADA systems as key barriers. Vietnam has responded by launching the National Load Dispatch Center (NLDC) modernization program and enhancing regional grid interconnections, especially between the high-resource southern provinces and the demand-intensive north (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.), (IRENA Market Analysis: Southeast Asia, n.d.).

A notable success in this context is Vietnam's rapid deployment of smart metering infrastructure and pilot virtual power plants (VPPs) to allow aggregated renewable sources to participate in real-time balancing markets (Ministry of Industry and Trade (MOIT), 2023), (International Energy Agency, 2023). According to IFC (IFC, 2021) and Energy Tracker Asia (IUCN, 2022), such technological upgrades are crucial in transitioning from passive renewable integration to active, market-responsive participation.

Vietnam's net-zero strategy also aligns with regional energy security efforts. As documented by the ASEAN Centre for Energy (ASEAN Centre for Energy, n.d.) and IRENA (IRENA Market Analysis: Southeast Asia, n.d.), cross-border energy trade and coordinated policy frameworks among ASEAN nations are essential to ensuring grid resilience and achieving regional climate commitments. Vietnam's leadership in renewable deployment positions it well to spearhead these collaborations.

In conclusion, Vietnam's net-zero roadmap is both ambitious and multi-dimensional, underpinned by policy reforms, technological innovation, and stakeholder coordination. The country has made substantial progress in laying the institutional and infrastructural groundwork required to decarbonize its power sector and meet its 2050 targets. Yet, success will depend on sustained political commitment, financial mobilization, and the ability to manage complex trade-offs between economic growth, energy security, and climate imperatives.

4. Technological and Market Opportunities

Vietnam's renewable energy expansion presents significant technological and market opportunities, particularly through offshore wind development and energy storage, with projections reaching up to 91 GW by 2050, supported by strategic planning under PDP8 and Net-Zero Roadmap. Rooftop solar and distributed energy resources (DER) have expanded rapidly, driven by favorable FIT policies and direct power purchase agreements, making Vietnam a regional leader in decentralized energy deployment. These advancements contribute to significant socioeconomic benefits, including industrial growth, job creation, increased energy access in underserved regions, and reduced exposure to fossil fuel price volatility. The transition also delivers environmental and public health co-benefits, through lower emissions and strengthened climate resilience, particularly in vulnerable regions like the Mekong Delta. Compared to ASEAN peers, Vietnam's policy framework—combining central and distributed energy strategies with inclusive development goals—positions it as a model for just and effective energy transition in emerging markets.

Vietnam's technological and market opportunities in renewables—via offshore wind, energy storage, rooftop DER, and digital innovation—are aligned with both national decarbonization goals and socioeconomic advancement. Especially impactful are the employment growth, energy access improvement, and industrial competitiveness gains derived from the energy transition. The nation's approach, underpinned by integrated policy frameworks and inclusive strategies, offers a demonstrably superior alternative to business-as-usual energy models.

4.1. Offshore Wind and Storage Development

Vietnam's renewable energy trajectory presents significant technological and market opportunities, particularly in offshore wind and energy storage. Offshore wind is central to both PDP8 and the Net-Zero Roadmap, projecting 6 GW by 2030 and reaching up to 70–91 GW by 2050 (Ministry of Industry and Trade (MOIT), 2023), (IUCN, 2022). Comparable economies such as Taiwan and the Philippines have similarly prioritized offshore wind, but Vietnam's vast shallow coastal shelf and strong coastal wind resources position it uniquely within ASEAN (IUCN, 2022), (GlobalData, 2023).

Integrating such large-scale offshore capacity (fig.10, and fig.11) necessitates modern grid infrastructure, including synchronous coordination across regions and robust interprovincial transmission lines—an area explicitly highlighted in PDP8 (Ministry of Industry and Trade (MOIT), 2023). Moreover, offshore farm construction demands deep-sea substation architecture, port upgrades, and logistics for turbine installation, all of which represent industrial-scale investment opportunities for Vietnamese manufacturing and maritime services (IUCN, 2022), (GlobalData, 2023).

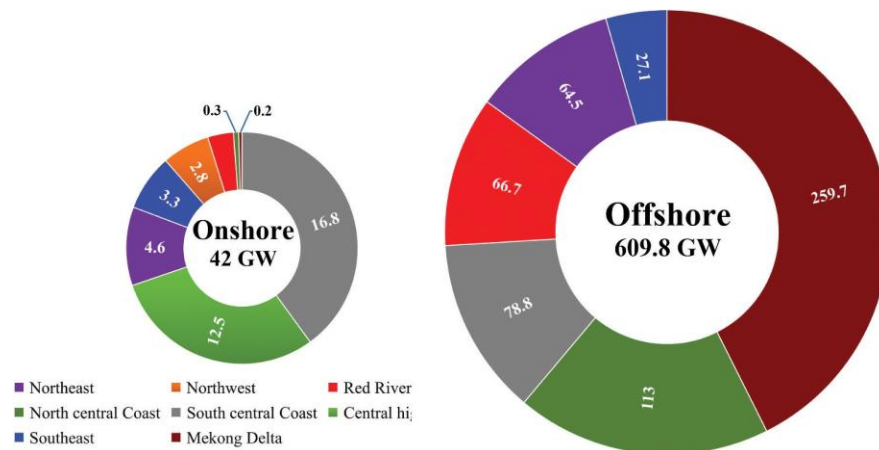


Fig.10. The potential for onshore and offshore wind power in Vietnam (Ha Duong, 2030)

Energy storage—particularly battery energy storage systems (BESS)—is increasingly recognized as essential for smooth VRE integration. PDP8 explicitly includes storage as key to mitigating grid instability, enhancing dispatch flexibility, and enabling system resilience (Ministry of Industry and Trade (MOIT), 2023). The IEA and World Bank underscore that combining offshore wind with large-scale BESS can significantly reduce curtailment and real-time balancing issues, ensuring load following and frequency stability in high RE scenarios (International Energy Agency, 2017), (World Bank, 2021).

Given Vietnam’s largely daytime solar generation profile, deploying BESS alongside offshore wind creates commercially attractive hybrid projects. These systems can shift output into evening peaks, support ancillary services markets, and participate in future demand response frameworks (World Bank, 2021), (Vietnam Energy Outlook, 2021). Crucially, investment models that integrate offshore wind with storage are attracting interest from international financiers—facilitated through green bonds and concessional climate funds under initiatives such as the Clean Energy Investment Accelerator (IEEFA, 2024), (UNDP, n.d.).

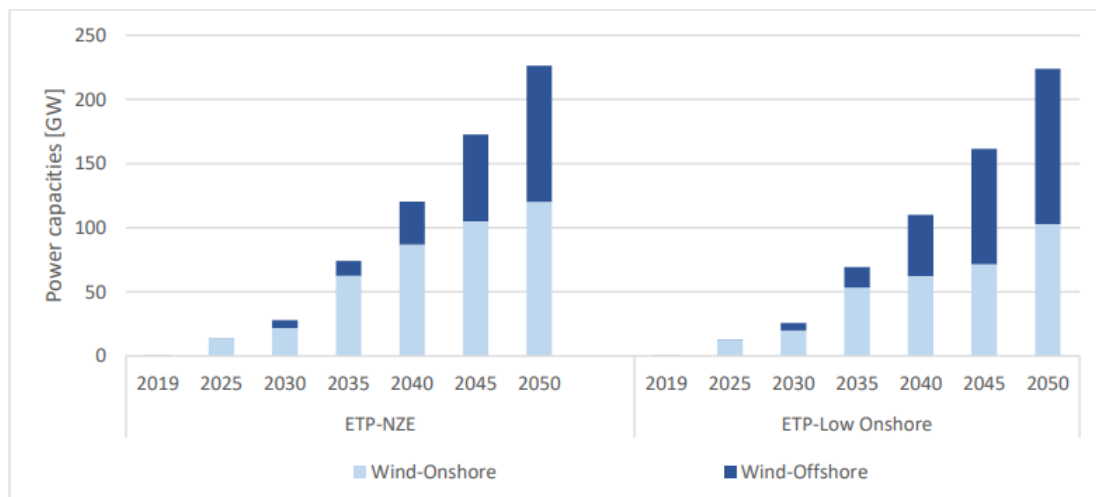


Fig.11. Onshore and offshore wind power plant capacities NZE vs Low Onshore, 2019-2050 (Diagnostic Study on Net-Zero for The Energy Sector in Vietnam: Deliverable 4 (Final Report): Net-Zero for the Energy Sector in Vietnam, 2023)

4.2. Rooftop Solar and Distributed Energy

Another cornerstone of Vietnam’s RE strategy remains rooftop solar and distributed energy resources (DER). Between 2019 and 2021, rooftop PV installations surged from almost zero to nearly 9 GW, largely fueled by FIT-based net metering schemes and favorable industrial self-consumption policies (IFC, 2021), (GlobalData, 2023). IFC (IFC, 2021) and USAID (IEEFA, 2024) document how manufacturing zones and commercial portfolios adopted rooftop systems to reduce energy costs and reinforce sustainability compliance. The flexibility and speed of DER deployment offers significant advantages. Unlike utility-scale projects, rooftop systems require less bureaucratic permitting, reduce transmission losses, and can be integrated into microgrid or Virtual Power Plant (VPP) frameworks. IEA reports show that DER adoption enhances grid resilience and consumer agency—allowing industrial consumers to engage in direct power

purchase agreements (DPPAs) and participate in demand response schemes (International Energy Agency, 2023). In contrast, countries that rely solely on centralized generation struggle to mobilize small-scale actors effectively, thereby slowing energy transition momentum.

Statista (Statista, 2023) notes that renewable energy accounted for 23% of electricity generation by 2023, with rooftop solar contributing a sizable share. This contrasts with ASEAN peers like Malaysia and Indonesia, where rooftop solar uptake remains significantly lower—primarily due to weaker distributed energy policies and less streamlined interconnection. Vietnam's early leadership in DER policy offers lessons for regional replication.

Technologically, developments in smart inverters, remote monitoring, and IoT-based performance analytics further enhance system efficiency and grid visibility. Combined with AEDB's DPPAs and net meter rollout (Circular 18/2020/TTBCT), these systems can provide responsive supply to the grid while mitigating reliability risks (IFC, 2021), (Vietnam Updates Regulations Encouraging Solar Power Development, n.d.). This contrasts with traditional feed-in tariffs, which do not incentivize dispatch flexibility or responsive behavior.

5. Challenges and Barriers

5.1. Technical and Infrastructure Challenges: Grid Integration & System Flexibility

One of the most pressing technical challenges is the insufficient grid infrastructure and its capacity to integrate a rapidly increasing volume of intermittent renewable energy sources (Nguyen, 2021). Vietnam's rapid build-up of geographically concentrated solar and wind capacity between 2018 and 2021 was not adequately matched by necessary investments in transmission assets, leading to overloaded transmission lines and significant curtailment of electricity generation for numerous projects.

As mentioned in (Vietnam Achieving 12, 2030) "The results of the grid-integration study indicate that the existing 500 kV backbone and line upgrades expected by 2020 will be sufficient to permit integration of larger amounts of VRE in the South (from 1.8 GW, 2020) without specific dispatch upgrades. In Ninh Thuan about 800 MW of VRE could be added without upgrades; in Binh Thuan, 1 GW. To integrate more than these amounts, the 220 kV Da My-Xuan Loc transmission line may have to be upgraded. In Dak Lak, the limit on additional VRE without upgrades was estimated to be about 1 GW; to increase it, the 500/220 kV Pleiku2 transformers (2 x 450 MW) might have to be upgraded. Upgrades could be financially beneficial for the system to the extent that they lower the cost of solar generation and thus keep it competitive in areas where solar irradiation is not as great as elsewhere" (Vietnam Achieving 12, 2030)

The national grid, traditionally designed for stable, base-load fossil fuel power, struggles to accommodate the instantaneous fluctuations inherent in solar and wind power production, which impacts system stability and reliability. The absence of comprehensive planning from government agencies when approving interconnection agreements, often allowing multiple projects to connect to the same substations without considering collective line capacity, exacerbated this issue. This critical disconnect between the pace of renewable energy development and grid infrastructure upgrades has created substantial "bottlenecks" in power transmission, reducing the efficiency and capacity of renewable energy utilization (IRENA Market Analysis: Southeast Asia, n.d.), (Challenges and Opportunities for the Southeast Asian Solar Market: Lessons From Vietnam and Malaysia, n.d.).

Addressing these challenges necessitates significant investment in grid modernization and enhancing system flexibility (Challenges and Opportunities for the Southeast Asian Solar Market: Lessons From Vietnam and Malaysia, n.d.). This includes upgrading and expanding transmission and distribution infrastructure, as well as deploying advanced digital solutions like distribution automation, geospatial information systems (GIS), and advanced metering technology-. Such digitalization initiatives, exemplified by Malaysia's 'Grid of the Future' programme, can vastly improve grid management, monitor power system data, and help operators more efficiently manage intermittency. Furthermore, the implementation of technologies that provide ancillary services, such as large-scale battery storage, frequency regulation, and dispatch scheduling, is crucial to improve the dispatchability of variable renewable energy and ensure grid stability. Interconnectivity with neighboring grids, such as the Lao-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP), also offers a vital avenue to alleviate strains from high variable renewable penetration and manage curtailment or supply deficits through cross-border power trade-.

5.2. Policy, Market, and Financial Barriers

Vietnam's renewable energy ambitions are frequently hampered by policy and regulatory inconsistencies and uncertainties. A significant barrier is the absence of a comprehensive national master

plan for renewable energy development and a clear, consistent, and stable legal framework. The abrupt expiration of Feed-in Tariff (FiT) schemes without immediate replacement or clear guidance on future procurement mechanisms (such as competitive auctions or corporate Power Purchase Agreements) has created considerable investor uncertainty, slowing down or halting new project development. The previous uniform application of FiT across the country inadvertently led to a concentration of projects in economically favorable regions, overstraining local grids rather than promoting balanced development. Moreover, the current regulations for rooftop solar, such as capacity limits for businesses and the double taxation on self-produced and repurchased electricity for households, are seen as unreasonable disincentives-. The lack of explicit national standards and certification for renewable energy equipment further complicates compliance and operational efficiency-.

Financial barriers also pose substantial hurdles. The initial investment costs for renewable energy projects are typically high, and existing subsidies are often less generous compared to traditional energy sources. Accessing domestic credit remains challenging, as Vietnamese banks frequently perceive the sector as high-risk, demanding high equity requirements (30-40%) and imposing high interest rates. While international loans offer significantly lower interest rates (4-5%), domestic enterprises often struggle to access them due to the stringent requirement for government guarantees, compelling many to seek foreign partnerships or even divest projects. The Power Purchase Agreements (PPAs) with Vietnam Electricity-EVN, the sole power purchaser, are widely considered un-bankable by international lenders due to unfavorable risk allocation clauses, particularly concerning curtailment, termination, force majeure, and "change in law" events, which fail to adequately protect investors and lenders. This has severely limited the availability of crucial non-recourse international project financing, especially critical for large-scale and capital-intensive projects like offshore wind. The current domestic lending market may not possess the sufficient depth or capacity to fund the ambitious targets outlined in Power Development Plan VIII (PDP VIII), particularly given the immense capital requirements for offshore wind projects.

5.3. Social, Environmental, and Institutional Barriers

While renewable energy development is crucial for environmental sustainability and meeting greenhouse gas (GHG) reduction targets, it also presents certain social and environmental considerations. Wind power stations, for instance, can generate noise pollution and disrupt natural landscapes, necessitating careful planning of construction zones at reasonable distances from residential or tourist areas. "According to the draft Power Plan VIII, solar power capacity is expected to reach about 18.89GW by 2030 and about 53GW by 2045. If these forecasts are borne out, the accumulated waste volume of panels is estimated at 404,000 tonnes by 2035 and about 1.9 million tonnes by 2045" (Vietnam mulls methods of effective solar panel recycling, n.d.), (Photovoltaic Waste Projection, 2050). Furthermore, the country's complex terrain and tropical monsoon climate expose renewable energy projects to significant risks from extreme weather events like storms, floods, and droughts, which can cause damage and disrupt operations. From a social perspective, public trust and awareness regarding the environmental benefits of solar energy, a relatively new source in Vietnam, still need to be fully cultivated.

Institutional barriers contribute to the complexity. The process of obtaining permits for new power plants is often described as complex, opaque, and susceptible to favoritism, with state-owned enterprises (SOEs) reportedly having an easier time than independent power producers (IPPs). This lack of transparency, coupled with inconsistent policy and regulatory alignment between central and provincial governments, can lead to non-transparent allocation of incentives and potentially suboptimal PPAs-. Despite the state's central role in driving the low-carbon energy transition, effective coordination across various ministries and state-owned enterprises like EVN remains a persistent challenge. Lastly, technological limitations and human resource constraints are critical, as advanced technology and substantial investment in skilled personnel are vital for the operation and maintenance of modern renewable energy projects. Vietnam faces limitations in technological expertise, inadequate infrastructure for equipment repair and maintenance, and a need for a highly skilled workforce in renewable energy and smart grids to ensure efficient and reliable system operation

6. Future Outlook and Recommendations

Vietnam's strategic shift towards renewable energy is pivotal for its energy security and sustainable development, driven by projected fossil fuel depletion and global climate change imperatives. The nation is committed to achieving net-zero emissions by 2050 and aims to significantly increase renewable energy's share in the total primary energy supply to 15-20% by 2030 and 25-30% by 2045 (Nguyen, 2021). The ambitious Power Development Plan VIII (PDP VIII) further targets renewable energy to comprise 30-39%

of the generation mix by 2030 and 67-71% by 2050 (IRENA Market Analysis: Southeast Asia, n.d.). This includes substantial capacity additions: 6 GW offshore wind, 13 GW onshore wind, and 12.8 GW solar (excluding existing rooftop) by 2030, with significant potential for further expansion, particularly in offshore wind and solar. Achieving these goals necessitates an estimated investment of US\$135 billion for power generation and grid development between 2021 and 2030, escalating to US\$400-523 billion from 2031 to 2050.

To realize this future, several key recommendations are critical:

6.1. Robust Policy and Regulatory Framework:

- It is imperative to develop a comprehensive Renewable Energy Law, moving beyond existing general electricity laws that lack specific regulations for the sector.
- Policies must be attractive and stable.
- A shift towards competitive bidding for large-scale projects is crucial to ensure transparency and optimal pricing, reserving Feed-in Tariffs (FiTs) for smaller projects.
- Regulations for rooftop solar should be refined to remove disincentives like capacity limits for businesses and double taxation, potentially adopting a net-metering mechanism.
- National standards and regulations for renewable energy technologies and equipment are vital for operational efficiency and compliance.

Vietnam enact a dedicated Renewable Energy Law to institutionalize long-term sectoral governance beyond the limitations of the current Electricity Law, which lacks specificity for RE technologies (International Energy Agency, 2017), (World Bank, 2021), (GlobalData, 2023). Stable and bankable policy frameworks are crucial to maintain investor confidence, as demonstrated by the success of Decision 11/2017/QĐ-TTg and its FIT mechanism, yet these must evolve toward competitive auctions for utility-scale projects to enhance price discovery and transparency (GIZ, 2020), (IEEFA, 2024), (GlobalData, 2023). FITs should be reserved for small-scale and off-grid systems where transaction costs are higher. Rooftop solar, in particular, requires regulatory adjustments, including lifting capacity thresholds and eliminating double taxation to facilitate private sector adoption; a revised net-metering model could be more equitable and scalable (World Bank, 2021), (Vietnam Updates Regulations Encouraging Solar Power Development, n.d.). Finally, the absence of national standards for RE technologies undermines grid safety and operational efficiency. Establishing technical codes and certification systems—as seen in Thailand and Malaysia—will be critical for Vietnam’s grid reliability and technology localization goals (ASEAN Centre for Energy, n.d.), (CEEW Vietnam Grid Integration, n.d.).

6.2. Grid Infrastructure and Technical Capacity Enhancement:

- Prioritizing substantial investment in grid modernization and expansion is paramount to integrate intermittent renewable energy sources and mitigate curtailment issues that have historically impacted project profitability. PDP VIII outlines significant grid investments.
- Implementing digitalization initiatives like advanced metering and geospatial information systems can significantly improve grid management and flexibility.
- Developing and deploying ancillary services, such as battery storage and frequency regulation, are crucial for system flexibility and stability.
- Strengthening regional grid interconnectivity can alleviate stress from high variable renewable penetration and facilitate cross-border power trade.
- Sustained investment in human resource development for renewable energy and smart grids, alongside fostering international cooperation for technology transfer, is essential to build domestic expertise.

It is strongly emphasize that grid modernization must be at the core of Vietnam’s energy transition strategy. The frequent curtailment of solar and wind projects, especially in southern provinces, has underscored the urgent need for expanded transmission infrastructure, a priority explicitly acknowledged in PDP8 (World Bank, 2021), (GlobalData, 2023), (Managing Vietnam’s Grid Issues for Effective Energy Transition, n.d.). Beyond physical upgrades, digitalization tools—such as advanced metering infrastructure (AMI), geospatial analytics, and SCADA integration—can enhance grid visibility, support dynamic load management, and enable real-time response capabilities (International Energy Agency, 2017), (International Energy Agency, 2023), (CEEW Vietnam Grid Integration, n.d.). Equally important is the scaling of ancillary services including grid-scale battery energy storage systems (BESS), which are essential

for frequency regulation, ramping support, and peak shaving under high renewable penetration (World Bank, 2021), (IEEFA, 2024), (Photovoltaic Waste Projection, 2050). Vietnam should also intensify efforts to strengthen regional interconnectivity with Laos, Cambodia, and Thailand to leverage load balancing opportunities and optimize renewable dispatch across borders (ASEAN Centre for Energy, n.d.), (International Energy Agency, 2023). Lastly, a sustainable transition demands investment in technical human capital and partnerships for international technology transfer to ensure that digital grid solutions and renewable innovations are absorbed effectively into Vietnam's domestic infrastructure (World Bank, 2021), (UNDP, n.d.), (GlobalData, 2023).

6.3. Diversified Financial Mechanisms:

Vietnam's renewable energy sector faces significant financial and economic barriers, particularly due to the high capital intensity of wind, solar, and grid infrastructure projects (World Bank, 2021), (GlobalData, 2023). While international mechanisms like JETP offer promising funding (US\$15.5 billion over 3–5 years), effective disbursement and alignment with national planning remain limited (IEEFA, 2024), (UNDP, n.d.). Existing Power Purchase Agreements (PPAs) with EVN often fall short of international bankability standards, creating challenges for attracting non-recourse financing, especially for offshore wind (International Energy Agency, 2017), (World Bank, 2021), (Managing Vietnam's Grid Issues for Effective Energy Transition, n.d.). The lack of a fully operational Corporate PPA framework further limits investment diversification and overburdens EVN's balance sheet (GlobalData, 2023), (IRENA Market Analysis: Southeast Asia, n.d.). Moreover, domestic banks have limited capacity for long-tenor, non-recourse lending, requiring institutional strengthening and possible use of green bonds or environmental levies to mobilize capital sustainably (UNDP, n.d.), (BloombergNEF, 2022), (CEEW Vietnam Grid Integration, n.d.). About financial mechanisms, there are following recommendation:

- Attracting diverse capital sources, including private and international investment, is critical given the high upfront costs.
- Effective utilization of international support frameworks such as the Just Energy Transition Partnership (JETP), which provides an initial fund of US\$15.5 billion for 3-5 years, and promoting green bonds can unlock significant funding.
- Revisiting Power Purchase Agreements (PPAs) with Vietnam Electricity (EVN) is necessary to align with international banking standards, particularly regarding clauses on curtailment, termination, force majeure, and "change in law". This is crucial for facilitating non-recourse international project financing, especially for capital-intensive offshore wind projects.
- Enabling a Corporate PPA program would further diversify funding and attract international capital by reducing the financial burden on EVN and providing a wheeling charge for transmission assets.
- Enhancing the capacity of domestic banks to provide non-recourse financing and longer tenors is vital, potentially through capacity building by development aid programs. Consideration of environmental fees on fossil fuel users to fund renewable energy development through a dedicated fund is also a potential solution

7. Conclusion

The imperative for nations worldwide to prioritize renewable energy (RE) in their electricity mix is intensifying as they strive to meet greenhouse gas (GHG) reduction targets under the Paris Agreement framework established at COP21. RE is central to the global energy transition—promising a sustainable, less carbon-intensive future. Yet, technologies such as wind, solar, biomass, and tidal power inherently face intermittency due to their dependence on weather, climate, and resource geography. This variability challenges grid reliability and requires complementary investments in grid flexibility, energy storage, and backup capacity—often entailing multibilliondollar infrastructure inputs.

Vietnam is exceptionally well-positioned to harness its diverse and abundant renewable resources. The country is endowed with high solar irradiation, consistent wind corridors, hydropower capacity, biomass feedstocks, and geothermal prospects. As evidenced by rapid deployment of hydropower over decades followed by the solar and wind boom since 2017 (tracking 20 GW+ of solar and over 4 GW of wind capacity by 2023 (GIZ, 2020), (Ministry of Industry and Trade (MOIT), 2023), (Statista, 2023), (Global Wind Energy, 2022)), Vietnam has the natural and socioeconomic foundations to lead renewable deployment in Southeast Asia. To overcome “bottlenecks” and translate resource potential into sustainable capacity, the Vietnamese government has engineered a robust policy and institutional framework. Firstly, the synchronization of energy strategy and sectoral planning, embedding electricity planning at the core of

national energy security, establishes a strategic alignment between resource potential and execution capacity. Instruments such as PDP8 ensure that renewable expansion aligns with system reliability, grid readiness, and economic viability (Ministry of Industry and Trade (MOIT), 2023), (International Energy Agency, 2017).

Second, Vietnam has offered financially credible and enduring incentives to stimulate investment. Landmark policies include Decision 11/2017/QĐTTg, which introduced a competitive Feedin Tariff (FIT) of 9.35 US ¢/kWh; Decision 13/2020/QĐTTg, which refined tariffs across technology types (ground, floating, rooftop); and Decision 02/2019/QĐTTg, transitioning rooftop schemes toward selfconsumption (GIZ, 2020), (IFC, 2021), (Vietnam Updates Regulations Encouraging Solar Power Development, n.d.). These policies fostered investor certainty, with the country surpassing solar targets ahead of projections.

Third, the codification of NetZero targets through Decision 896/QĐTTg (2022) and integration into the National Climate Change Strategy (2022–2050) institutionalizes longterm carbon neutrality, anchoring energy policies to broader climate commitments (International Energy Agency, 2017), (UNDP, n.d.). The 2024 NetZero Science and Technology Programme further reinforces technological readiness and domestic innovation capacity aligned with decarbonization goals (UNDP, n.d.), (GlobalData, 2023).

Fourth, Vietnam’s involvement in the Just Energy Transition Partnership (JETP) demonstrates international institutional coordination. JETP has mobilized multilateral financing to facilitate coal phaseout, renewable scaleup, grid expansion, and just transition programs for affected workers and communities (IEEFA, 2024), (UNDP, n.d.). This multilateral alignment reduces financing risk and institutional fragmentation.

Fifth, institutional innovations such as Extended Producer Responsibility (EPR) regulations address the circular economy aspects of RE deployment—specifically PV waste and lifecycle sustainability issues (UNDP, n.d.), (Photovoltaic Waste Projection, 2050). Such policies reflect a mature regulatory environment that internalizes both energy and environmental externalities.

Finally, the evolution of Vietnam’s market structure—from FITbased models towards selfconsumption, DPPAs, and auction-based procurement—signals a shift toward a liberalized and flexible electricity market. The PDP8 Implementation Plan, supported by USAID and IEA recommendations, emphasizes competition, grid efficiency, and consumer participation (IEEFA, 2024), (International Energy Agency, 2023), (GlobalData, 2023).

In summarizing, Vietnam’s RE trajectory represents a systematically constructed model of policy coherence, institutional clarity, and economic ambition. Its resource base is backed by rigorous planning, innovative incentive structures, and international engagement. While intermittency and grid integration remain technical challenges, the comprehensive policy architecture—spanning resource mapping, tariff design, strategic planning, digital grid upgrades, and climate-governed frameworks—positions Vietnam to achieve a sustainable, reliable, and equitable energy transition. The country’s performance not only advances national climate goals but also offers a transferable blueprint for emerging economies navigating the complex integration of renewables into their power systems.

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