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Techno-economic Analysis on Large-Scale Integration of Variable Renewable Energy Sources in Myanmar National Grid

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ABSTRACT

Myanmar's renewable energy sector presents significant opportunities for sustainable development, primarily through hydropower, solar, and wind energy. Hydropower, with a potential capacity of 19,567 MW, serves as the backbone of the country's energy strategy; however, its seasonal variability necessitates enhanced planning and a robust transmission network. Solar energy, boasting an estimated annual potential of 51,973.8 TWh, is increasingly recognized for its utility-scale and off-grid applications, particularly in remote areas. Wind energy, while still emerging, has a theoretical potential of approximately 80 TWh per year but currently lacks comprehensive site-specific assessments. This study employs the EnergyPLAN modelling tool to conduct a techno-economic analysis of various scenarios for renewable energy integration by 2030, supporting the Myanmar government's aim to achieve 11% of electricity generation from solar and wind sources. The analysis highlights the importance of interconnection strategies, assessing their impact on the national grid's stability and reliability, as well as their economic implications. The findings emphasize the critical need for government support, international collaboration, and strategic investments to unlock Myanmar's renewable potential, ensuring a transition toward a more sustainable and resilient energy future. This approach not only facilitates the integration of variable renewable energy sources but also positions Myanmar as a key player in regional energy markets within ASEAN.

KEYWORDS: *variable renewable energy sources (VRES); techno-economic; EnergyPLAN modelling tool; interconnection; greenhouse gas (GHG) emissions;*

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INTRODUCTION

Myanmar, endowed with rich natural resources, stands at the brink of an energy transformation through the large-scale integration of variable renewable energy sources (VRES). The country has significant hydropower, solar, and wind energy potential that can enhance energy security, support sustainable development, and reduce greenhouse gas (GHG) emissions. Currently, hydropower dominates Myanmar's energy mix, providing considerable generation capacity; however, its reliance on seasonal rainfall necessitates diversification to ensure reliability, especially during dry spells. Solar energy, with an estimated potential of 51,973.8 TWh annually, presents an appealing solution, particularly for off-grid applications that can improve electricity access for remote communities. Although wind energy is still emerging, it holds significant promise for future growth. To fully capitalize on these renewable resources, strengthening interconnections within the national grid and with neighboring countries is vital. Enhanced interconnection can improve grid stability, facilitate power exchanges, and increase resilience against fluctuations inherent to VRES. This study employs the EnergyPLAN modelling tool to conduct a techno-economic analysis of various integration scenarios, focusing on the role of interconnections. By assessing their impacts on grid stability, energy security, and environmental sustainability, this research contributes to Myanmar's objectives for renewable energy expansion by 2030, fostering a sustainable energy transition.

Renewable Energy Potential in Myanmar

Myanmar's renewable energy sector holds substantial promise, particularly in hydropower, solar, and wind. Hydropower dominates with an estimated potential of 19,567 MW [1], though seasonal variability between rainy and dry periods requires strategic planning to meet peak demand, supported by a robust transmission network and alternative power sources like thermal plants and imports. Solar power, with an estimated annual potential of 51,973.8 TWh [3], is gaining traction despite infrastructure and regulatory challenges, showing promise in both utility-scale and off-grid applications to reach remote communities. Wind energy, while in its early stages, has theoretical potential of around 80 TWh per year [9], yet site-specific data is limited to only a few locations, necessitating a comprehensive assessment to fully evaluate and harness this resource. With government support, international collaboration, and investments, Myanmar aims to generate 11% of its electricity from solar and wind by 2030, advancing toward a more sustainable energy future.

Methodology

A. EnergyPLAN Modelling Tool

This study employs the EnergyPLAN tool to model Myanmar's power system, simulating both current and future scenarios for integrating renewable energy sources (RES). The model incorporates key data, including electricity demand, generation capacity, fuel consumption, and greenhouse gas emissions, to create a comprehensive view of Myanmar's power landscape. Future scenarios are developed to assess the impact of cross-border interconnections on grid stability and RES penetration, providing insights into Myanmar's pathway for renewable energy expansion.

The EnergyPLAN tool was chosen after reviewing several modelling options for its capabilities in large-scale renewable integration analysis. Designed to support regional or national energy strategies, EnergyPLAN conducts techno-economic assessments of various long-term planning alternatives. It uses a deterministic model with analytical programming, allowing for faster calculations than iterative models, and simulates an entire year with high temporal resolution to produce hourly outputs. Key inputs include system demands, RES capacities, power plant efficiencies, costs, and regulatory options, while outputs encompass annual energy production, electricity imports and exports, greenhouse gas (GHG) emissions, and surplus generation. Though capable of representing multiple energy sectors, this study applies EnergyPLAN solely to the power sector. More details and case studies on EnergyPLAN can be found in [8].

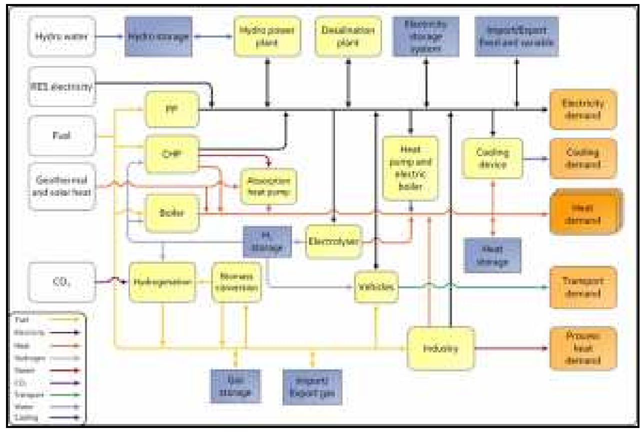

Fig 1. Overview of the EnergyPLAN modelling tool [8]

B. Development of Scenarios

Four scenarios were developed to evaluate the integration of variable renewable energy sources (VRES) into Myanmar's National Grid by 2030. These scenarios are grounded in key national plans and international commitments. Scenario 1 is based on the National Energy Master Plan (NEMP) 2014, while Scenario 2 is derived from proposals submitted to the Ministry of Electric Power (MOEP). These reference documents provide critical benchmarks for current and projected energy production, consumption, and greenhouse gas (GHG) emission targets. The scenarios explore different energy mixes and policy interventions:

1. Scenario 1: Business as Usual (BAU) 2030: Assumes no major policy changes, with Myanmar continuing to rely heavily on natural gas and hydropower. This scenario serves as a baseline for comparison [4].
2. Scenario 2: MOEP RES Combination 2030: Envisions a diversified energy strategy combining solar, wind, hydropower, and other renewable sources to meet MOEP's goals for energy security and VRES integration [2].
3. Scenario 3: RES Combination 2030: Leveraging its solar energy potential of 51,973.8 TWh/year [3], Myanmar could install between 29,600 MW and 33,170 MW of solar capacity, assuming a mid-range capacity factor of 17.5%. Additionally, with a theoretical wind resource potential of 80 TWh/year [9], the country could achieve an installed wind capacity ranging from 26,000 MW to 36,500 MW, based on a capacity factor of 30%. This scenario is based on reliable estimates of installed capacities for solar and wind power, as outlined above, and suggests further penetration

of solar and wind power plants into Myanmar's generation mix, all without interconnections.

4. Scenario 4: RES Combination 2030 with interconnection: this integration allows for the export of excess renewable energy during peak production and the import of electricity during low production, optimizing resource use and enhancing grid stability through interconnections with neighboring countries while facilitating greater penetration of solar and wind power into Myanmar's generation mix.

The inputs for the reference and future scenarios are detailed in Table I. Establishing a reference year in the EnergyPLAN model is crucial for creating a consistent baseline to evaluate energy production, consumption, and infrastructure. For this analysis, 2019 has been chosen as the reference year, as it reflects the closest characteristics of supply and demand in Myanmar. In 2019, Myanmar's total generation capacity was 4,945 MW, consisting of hydropower (3,225 MW), natural gas (1,560 MW), coal (120 MW), and solar (40 MW). This data provides a foundational understanding of the existing generation mix and helps evaluate the potential for significant increases in solar and wind power penetration. Future scenarios suggest that solar capacity could rise to 10,000 MW and wind capacity to 6,000 MW in scenarios 3 and 4, respectively. Analyzing the integration of these renewable sources is essential for optimizing resource use, enhancing energy security, and supporting sustainable development goals in Myanmar. As the country aims to address energy security and sustainability challenges, the penetration of renewable energy is increasingly recognized as a key component of its energy strategy.

Table I EnergyPLAN Input Data of Electricity Supply for the Reference Model and Future Scenarios

Description	Ref. 2019 [MW]	Scenario [MW]			
		1	2	3	4
Hydropower	3225	8896	8817	8817	8817
Natural gas	1560	4758	4986	4986	4986
Coal	120	7940	1000	1000	1000
Solar	40	1300	4175	10000	10000
Wind		700	2000	6000	6000
Nuclear			330	330	330
Inter-connection			2100		2100
Total	**4945**	**23594**	**23408**	**31133**	**33233**

[2] [4] [5] [6] [9]

Simulation Results and Discussion

A. Validation of Model

The EnergyPLAN model was validated using historical data to confirm its accuracy in simulating Myanmar's energy system. This involved comparing model outputs with actual energy production, consumption, and emissions data, utilizing 8,784 hours of detailed input for the reference year. The validation of the EnergyPLAN model, as presented in Table II, demonstrates its effectiveness in estimating monthly average electric power production when compared to actual measurements. For the month of January, the model produced a value of 2427.00 MW, closely aligning with the actual figure of 2427.40 MW, resulting in a minimal difference of 0.40 MW (0.02%). Similar close approximations were observed in April, with a difference of 4.06 MW (0.14%), and in December, where the model's output was 2428.00 MW against an actual production of 2437.79 MW, yielding a difference of 9.79 MW (0.40%). However, certain months like May and September exhibited larger discrepancies, with differences of -15.07 MW (-0.44%) and -17.59 MW (-0.66%), respectively. Overall, the EnergyPLAN model consistently provided outputs that were within a reasonable range of the actual values, with differences mostly falling under 0.75%, highlighting its reliability for energy production forecasting.

Table II Energyplan Model Validation Result for Monthly Average Electric Power Production

Month	Actual (MW)	EnergyPLAN (MW)	Difference	Percentage
January	2427.40	2427.00	0.40	0.02
February	2541.74	2547.00	-5.26	-0.21
March	2718.85	2725.00	-6.15	-0.23
April	2864.06	2860.00	4.06	0.14
May	3421.93	3437.00	-15.07	-0.44
June	2977.23	2956.00	21.23	0.71
July	2642.32	2645.00	-2.68	-0.10

August	2611.47	2601.00	10.47	0.40
September	2675.41	2693.00	-17.59	-0.66
October	2768.55	2770.00	-1.45	-0.05
November	2697.88	2682.00	15.88	0.59
December	2437.79	2428.00	9.79	0.40

The validation results for the EnergyPLAN model, as shown in Table III, indicate a mixed performance in estimating annual electricity production, load shedding, and fuel consumption. For hydropower production, the model estimated 11.15 TWh/year, which was 0.67 TWh/year higher than the actual production of 10.482178 TWh/year, reflecting a discrepancy of -6.37%. In contrast, thermal electricity production was slightly underestimated, with EnergyPLAN predicting 11.88 TWh/year compared to the actual 12.313369 TWh/year, resulting in a positive difference of 0.43 TWh/year (3.52%).

The solar production estimate was lower than the actual, showing a difference of -0.005 TWh/year (-14.29%). It is important to note that the first grid-connected solar power plant began operations in July 2019, so comparisons are limited to only six months of data; a full year's analysis may yield more accurate results. Regarding load shedding, the model estimated 0.93 TWh/year against an actual value of 0.86 TWh/year, leading to a difference of -0.07 TWh/year (-8.24%). In terms of fuel consumption, the model slightly underestimated natural gas consumption at 33.36 TWh/year versus the actual 34.55 TWh/year, resulting in a difference of 1.19 TWh/year (3.45%). Conversely, coal consumption predictions were closely aligned with the actual figure, showing a minimal difference of 0.02 TWh/year (3.39%).

Overall, while the EnergyPLAN model provided reasonable estimates, adjustments may be necessary for specific energy sources, particularly hydro and solar. For hydropower adjustments in EnergyPLAN, employing an advanced hydropower model may enhance accuracy.

Table III Energyplan Model Validation Result for Annual Electricity Production

Description	Actual	EnergyPLAN	Difference	Percentage
Electricity Production (TWh/year)				
Hydro	10.482178	11.15	-0.67	-6.37
Thermal	12.313369	11.88	0.43	3.52
Solar	0.035	0.040	-0.005	-14.29
Load Shedding (TWh/year)				
Load Shedding	0.86	0.93	-0.07	-8.24
Fuel Consumption (TWh/year)				
Natural Gas	34.55	33.36	1.19	3.45
Coal	0.59	0.57	0.02	3.39

The comparison of daily electricity production between actual values and EnergyPLAN estimates reveals a strong correlation, as illustrated in Figures 2 and 3. On 10th March, 2019, the actual daily electricity production curve closely aligns with the EnergyPLAN model output, indicating that the model accurately captures the production characteristics for that day. Both curves exhibit similar patterns, demonstrating comparable peaks and troughs in electricity generation throughout the day. This alignment suggests that the EnergyPLAN model effectively mirrors the actual operational dynamics of the electricity system, validating its reliability for daily electricity production forecasting. Such consistency between the model and actual data underscores its potential utility for planning and optimizing energy production strategies.

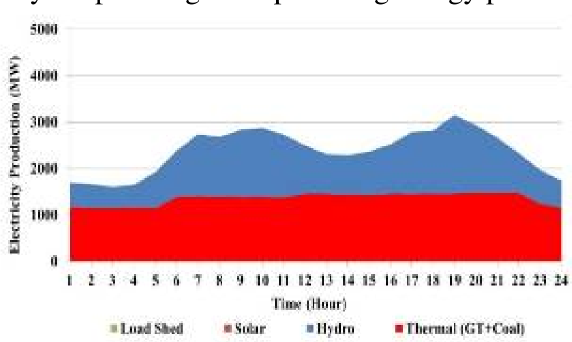

Fig 2. Actual daily eletricity production curve on 10th March 2019

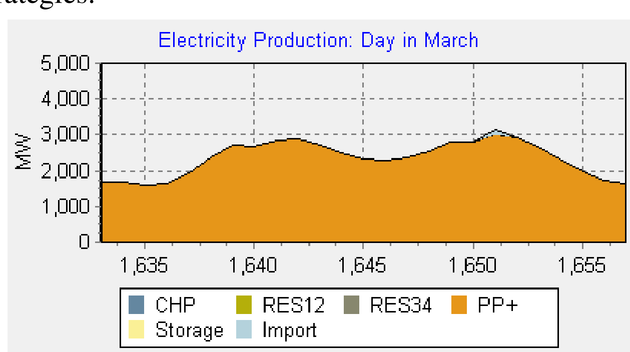

Fig 3. EnergyPLAN electricity production curve on 10th March 2019

B. Scenario Analysis

The analysis examined the integration of variable renewable energy sources (VRES) into the Myanmar National Grid, focusing on technical feasibility, economic viability, and environmental impacts. It identified a critical peak demand period from May 17 to May 23, 2030, with demands ranging from 3,265 to 3,432 hours, highlighting the necessity for optimized grid operations during high electricity consumption and the variability of renewable energy, particularly wind power.

1. Scenario 1: Business as Usual (BAU) 2030: This scenario analyzed hourly energy demand and supply data, revealing a dynamic interaction among various energy sources. The findings indicated a heavy reliance on natural gas and coal, with intermittent contributions from renewable sources, emphasizing the difficulties in achieving a balanced and sustainable energy mix in the BAU 2030 context.

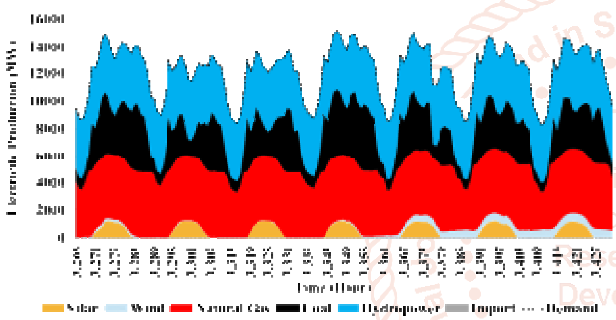

Fig 4. Hourly data of demand and supply for the BAU 2030 scenario

2. Scenario 2: MOEP RES Combination 2030: In this scenario, the hourly analysis of energy demand and supply provides important insights into the energy mix. It emphasizes a well-balanced integration of renewable sources into the grid, which reduces dependence on fossil fuels and advances towards a more sustainable energy mix by 2030. The goal is to enhance variable renewable energy source (VRES) penetration, achieve significant reductions in greenhouse gas emissions, and establish Myanmar as a regional leader in renewable energy.

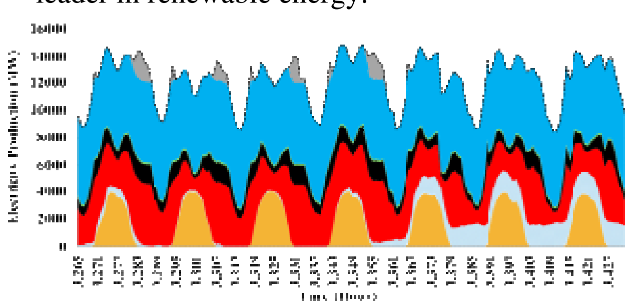

Fig 5. Hourly data of demand and supply for the MOEP RES combination 2030 scenario

3. Scenario 3: RES Combination 2030: This scenario examines the implications of Critical Excess Electricity Production (CEEP) within Myanmar's energy landscape by 2030. The hourly analysis of energy demand and supply reveals a substantial integration of renewable energy sources, particularly solar and wind, significantly reducing reliance on fossil fuels. Notably, the data shows peak solar output contributing over 9,000 MW during high demand hours, while wind energy plays a crucial role in maintaining grid stability. The substantial presence of natural gas, coal, and hydropower demonstrates a balanced energy mix that ensures reliability and sustainability. CEEP highlights the potential for exporting excess energy, with figures indicating significant export opportunities during peak renewable generation periods.

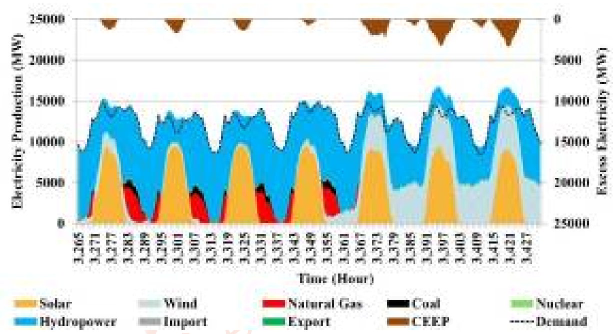

Fig 6. Hourly data of demand and supply for the RES combination 2030 scenario

4. Scenario 4: RES Combination 2030 with Inter-connection: the data illustrates the potential for Exportable Excess Electricity Production (EEEP) through a combination of renewable energy sources (RES) and conventional generation methods. The scenario shows variations in energy demand, solar, and wind energy production, alongside contributions from natural gas, coal, nuclear, and hydropower. Notably, hours with high solar and wind outputs frequently meet or exceed demand, generating surplus electricity available for export. The values indicate significant EEEP, especially during peak production times, highlighting the importance of interconnection for optimizing energy distribution and enabling effective export strategies. This analysis underscores the role of renewable energy integration in creating a robust energy infrastructure capable of supporting both local needs and export opportunities.

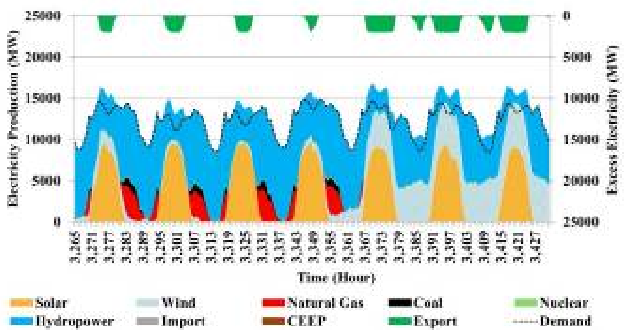

Fig 7. Hourly data of demand and supply for the RES combination 2030 with interconnection scenario

C. Penetration of Renewable Energy into Myanmar's Generation Mix

From a technical perspective, the integration of renewable energy into Myanmar's generation mix is crucial for developing a sustainable energy system. With a proposed capacity of 10,000 MW for solar and 6,000 MW for wind energy, successfully incorporating these resources necessitates a robust technical framework to manage variable generation profiles and ensure grid stability. Analyzing scenarios 3 and 4, which simulate the gradual increase in solar and wind penetration from 0% to 100%, provides vital data for optimizing grid operations, assessing system reliability, and identifying necessary infrastructure upgrades.

1. As solar and wind penetration increases within Myanmar's generation mix, Exportable Excess Electricity Production (EEEP) also rises, reflecting a growing potential for surplus electricity available for export. For solar, EEEP remains minimal and stable, with values of 0.01 TWh/year up to 30% penetration. However, as solar penetration rises beyond 50%, EEEP begins to increase significantly, reaching 2.9 TWh/year at 80% and peaking at 7.13 TWh/year at full (100%) penetration. Wind EEEP shows a more gradual rise from the start, beginning at 0.2 TWh/year and increasing consistently, with noticeable increases from 40% penetration onward. It reaches 6.1 TWh/year at 90% and matches the solar peak of 7.13 TWh/year at 100% penetration. This trend highlights that higher levels of renewable energy integration could enable Myanmar to develop a substantial export capacity, though this would require investments in transmission infrastructure and export agreements to effectively utilize the surplus electricity generated, especially beyond 60% renewable penetration.

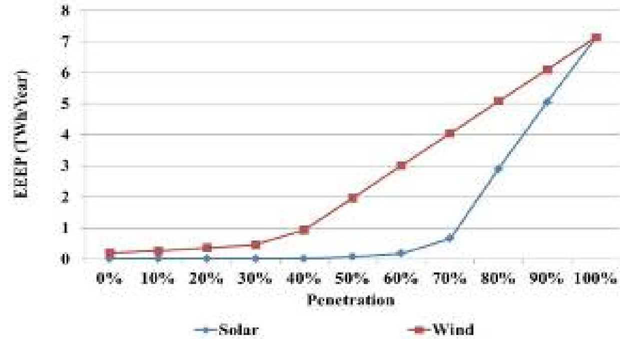

Fig 8. Variation in EEEP as solar and wind penetration increases in Myanmar's generation mix

2. As solar and wind penetration increases in Myanmar's generation mix, the Critical Excess Electricity Production (CEEP) shows a rising trend, indicating a growing mismatch between renewable generation and demand. As shown in Fig. 9, CEEP remains negligible for solar and relatively low for wind up to a 50% penetration level, suggesting that the grid can absorb renewable generation without significant excess. However, wind penetration starts affecting CEEP more notably beyond 20%, while solar penetration leads to a more pronounced increase in CEEP past 60%, reaching a peak of 0.57 TWh/year at 100% penetration. These findings highlight that higher renewable shares, particularly beyond 70%, will require advanced grid management and flexibility strategies to minimize curtailment and manage excess electricity effectively.

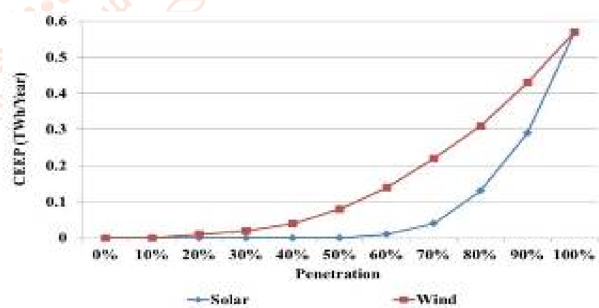

Fig 9. Variation in CEEP as solar and wind penetration increases in Myanmar's generation mix

3. As solar and wind penetration levels increase in Myanmar's generation mix, greenhouse gas (GHG) emissions, measured in $MtCO_2e$, show a significant downward trend, indicating that higher renewable shares contribute to substantial emissions reductions. For solar, emissions begin at 12.08 $MtCO_2e$ with 0% penetration and

steadily decline, reaching 4.22 $MtCO_2e$ at 50% and then continuing to decrease to 1.35 $MtCO_2e$ at full (100%) penetration. Wind energy integration shows a similar trend, starting at 4.7 $MtCO_2e$ with no wind penetration and decreasing to 1.35 $MtCO_2e$ at 100%. The steeper initial reduction in emissions at low levels of wind penetration suggests a more immediate impact on GHG reductions when wind is incorporated compared to solar, likely due to wind's high capacity factor and lower variability. Both resources ultimately achieve the same minimum emission level at full penetration, illustrating the potential of renewables to help Myanmar achieve significant emissions reductions, especially as renewable shares surpass 50%.

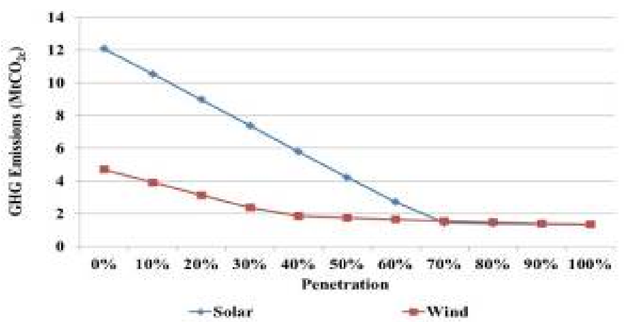

Fig 10. Variation in GHG emission as solar and wind penetration increases in Myanmar's generation mix

In Scenarios 1 and 2, no EEEP or CEEP is observed, as the installed capacities and generation levels are only sufficient to meet demand, and there are instances where electricity imports from interconnections are necessary. TABLE IV provides a breakdown of the monthly and annual averages of EEEP and CEEP under Scenarios 3 and 4, showing how excess electricity varies throughout the year in Myanmar's generation mix. In Scenario 3, which assumes a certain level of renewable penetration, CEEP values are consistently high, indicating a substantial amount of non-usable excess electricity that cannot be absorbed by the grid, especially in January (1,466 MW) and December (1,298 MW). In contrast, Scenario 4, which incorporates flexibility measures, significantly reduces CEEP, particularly in the dry and rainy season. Scenario 4 also introduces some EEEP, with up to 1,130 MW of excess electricity in January that can potentially be exported or stored. Annually, Scenario 3 results in a total of 7.69 TWh of CEEP, while Scenario 4 lowers this to 0.57 TWh and generates 7.13 TWh of EEEP, demonstrating the role of flexibility enhancements in optimizing renewable integration and minimizing excess electricity wastage.

Table IV Monthly and Yearly Average EEEP and CEEP under Scenarios 3 and 4 for Myanmar's Generation Mix

Description	Scenario 3		Scenario 4	
	EEEP	CEEP	EEEP	CEEP
Monthly average (MW)				
January	0	1466	1130	215
February	0	1237	1032	116
March	0	879	830	72
April	0	824	787	24
May	0	274	425	0
June	0	502	601	15
July	0	600	685	3
August	0	752	738	11
September	0	823	791	27
October	0	917	792	38
November	0	950	849	89
December	0	1298	1081	167
Yearly toal (TWh/year)				
2030	0	7.69	7.13	0.57

D. Greenhouse Gas (GHG) Emissions

Greenhouse gas emissions were calculated using the EnergyPLAN model, which assesses emissions based on the energy mix and emission factors specific to each energy source. Fossil fuels like coal and natural gas were assigned standard emission factors to represent their carbon intensity, while renewable energy sources were assumed to have zero direct emissions, reflecting their carbon-neutral profile. Emission factors for natural gas range from 0.35 to 0.6 tons/MWh, depending on plant efficiency, as reported by the International Energy Agency (IEA) and Energy Information Administration (EIA). For coal, emissions range from 0.9 to 1.2 tons/MWh, depending on the type of coal and efficiency, also based on IEA and EIA data [10]. GHG emissions were analyzed across all scenarios, focusing specifically on the impact and effectiveness of renewable energy integration.

The energy production scenarios for Myanmar in 2030 reveal substantial differences in greenhouse gas (GHG) emissions based on the chosen energy mix. In the Business As Usual (BAU) scenario, the energy landscape is dominated by hydropower (45.41 TWh/year) and coal (23.16 TWh/year), supplemented by natural gas (8.9 TWh/year), wind (1.45 TWh/year), and solar (3.08 TWh/year). This reliance on fossil fuels results in significant emissions of 27.82 $MtCO_{2e}$, underscoring the environmental challenges associated with the current trajectory. Conversely, the MOEP RES Combination scenario demonstrates a marked improvement, characterized by an increased share of hydropower (50.51 TWh/year) and the introduction of nuclear energy (1.02 TWh/year). In this scenario, coal usage drastically decreases to 3.88 TWh/year, while natural gas rises to 12.43 TWh/year, alongside wind (4.15 TWh/year) and solar (9.9 TWh/year). This diversified approach leads to a considerable reduction in emissions to 11.04 $MtCO_{2e}$, emphasizing the potential of integrating renewables to achieve cleaner energy objectives.

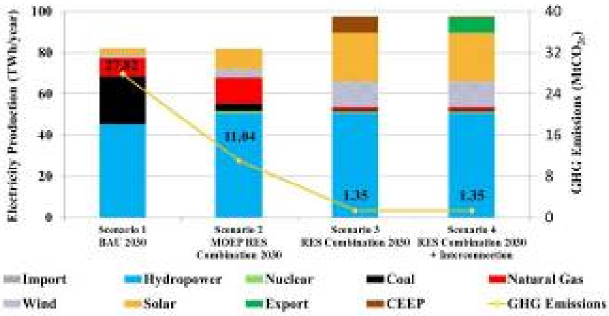

Fig 11. Electricity production and GHG emissions for all the scenarios

The RES Combination scenario further optimizes the energy mix, maintaining hydropower at 50.51 TWh/year while significantly increasing wind (12.45 TWh/year) and solar (23.72 TWh/year), with minimal contributions from coal (0.48 TWh/year) and nuclear (1.02 TWh/year). This strategic focus on renewables results in a CEEP of 7.69 TWh/year, indicating that maximizing renewable energy sources is essential for meeting sustainability targets. Finally, the RES Combination scenario with interconnection illustrates the benefits of regional energy collaboration, facilitating an additional 7.13 TWh/year of export while maintaining emissions at a remarkably low 1.35 $MtCO_{2e}$. This scenario not only highlights the potential for exporting excess renewable energy but also demonstrates that interconnections can enhance the integration of renewables and bolster energy security. Collectively, these scenarios underscore the critical need for Myanmar to transition to a diversified and renewable energy mix to effectively reduce GHG emissions and combat climate change by 2030.

E. Cost Analysis

The cost analysis for Myanmar's electricity export scenarios under ASEAN interconnections reveals the intricate balance between revenue generation and greenhouse gas (GHG) emissions costs. With the average electricity price in ASEAN estimated between USD 0.10 and USD 0.15 per kWh [11], this study adopts a conservative figure of USD 0.15 to forecast export revenue. Concurrently, a carbon price of USD 50 per tonne of CO_2 equivalent aligns with Singapore's ambitious carbon tax policy, which is set to increase to about USD 37 - 60 per tCO_{2e} by 2030 [12]. In the analysis, Scenario 1 indicates no export revenue and substantial GHG costs, resulting in a significant net loss of USD 1,391 million. Scenario 2 shows an improvement with lower GHG costs but still yields a negative result of USD 552 million. Scenario 3 further reduces costs, reflecting a minor loss of USD 67.5 million. Conversely, Scenario 4 demonstrates the potential for positive net benefits, generating USD 1,002 million by combining substantial export revenue with minimal GHG costs. This analysis underscores the critical importance of integrating carbon pricing strategies and maximizing export opportunities to bolster Myanmar's renewable energy framework, enhancing both economic growth and sustainability.

Table V Overview of Export Revenue, GHG Emission Costs, and Total Benefit/Cost in Various Scenarios

Scenario	Export Revenue (MUSD)	GHG Cost (MUSD)	Total Benefit/Cost = Export Revenue – GHG Cost (MUSD)
Scenario 1	0	1391	-1391
Scenario 2	0	552	-552
Scenario 3	0	67.5	-67.5
Scenario 4	1069.5	67.5	1002

F. Recommendation

From a techno-economic perspective, Scenario 4 is the most favorable option for the integration of Myanmar's renewable energy sources. Unlike Scenario 1, which incurs significant greenhouse gas (GHG) costs without generating export revenue, Scenario 4 achieves a balance that enhances financial sustainability while minimizing emissions. It also outperforms Scenario 2, which, despite lower GHG costs, fails to capitalize on export opportunities, and Scenario 3, which yields only marginal improvements. By optimizing the integration of renewable energy with interconnections, Scenario 4 not only positions Myanmar for regional energy collaboration but also aligns with sustainable development goals. This approach enables the country to leverage its abundant natural resources effectively while contributing to economic growth and climate resilience.

Conclusion

In conclusion, Myanmar's renewable energy potential presents substantial opportunities for a sustainable energy transition, coupled with challenges that necessitate strategic interventions. This study highlights the critical need for integrating a diverse mix of energy sources—particularly hydropower, solar, and wind—into the national grid. Utilizing the EnergyPLAN modelling tool, various scenarios indicate that achieving a significant share of renewable energy generation by 2030 is not only feasible but also beneficial. Successful implementation hinges on robust governmental support, international partnerships, and targeted investments in infrastructure, technology, and interconnection. The recommendation to pursue Scenario 4 emphasizes the importance of enhancing interconnections, both within the national grid and with neighboring countries. Strengthening these interconnections can mitigate the inherent variability of VRES by enabling resource sharing, improving grid stability, and enhancing energy security. Additionally, regional interconnections will facilitate power exchanges, providing a buffer against local supply fluctuations and fostering economic growth through enhanced trade opportunities. By prioritizing a diversified energy mix alongside strategic interconnections, Myanmar can increase its energy resilience, expand access, and actively contribute to global greenhouse gas reduction efforts. Ultimately, advancing renewable energy integration and interconnection strategies will be essential in securing a resilient, sustainable, and inclusive energy future for all citizens of Myanmar.

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