



Lao PDR Energy Planning

# Modelling Clean Energy Transition Pathways for Lao PDR

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## **Keywords**

Energy Modelling, Energy Transition, Renewable Energy, Electrification Transport, OSeMOSYS, Laos Energy, Policy Planning

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## **Executive Summary**

The energy system in Lao PDR, heavily reliant on hydropower, faces significant challenges related to energy security and sustainability. With a strong commitment to the Paris Agreement, the Lao government is seeking to diversify the energy mix to balance economic development, energy security, and climate objectives. This report models clean energy transition pathways using the Open-Source Energy Modelling System (OSeMOSYS) to explore various scenarios that could support Lao PDR's transition towards sustainable energy and meet SDG7 targets amidst rising energy demand.

Three scenarios were analysed: Business-as-Usual (BAU), Renewable Energy (RE) integration, and Electrification Transport (ET). All scenarios project an increase in total energy generation and installed capacity by 2050, with the RE and ET scenarios notably shifting towards a higher share of renewable energy and electrified transport. Under the BAU scenario, hydropower remains the predominant energy source, comprising about 75% of power generation by 2050. Conversely, the RE and ET scenarios demonstrate a more diversified energy mix, with solar energy potentially contributing up to 50% of power generation by 2050.

Further research is recommended in areas such as energy storage solutions, cross-border energy trade, and the impacts of global energy market fluctuations on Lao PDR's clean energy transition, with a particular focus on energy security and economic stability.

## Key Findings

- BAU Scenario: Continues reliance on hydropower with limited diversification, leading to slow progress in reducing greenhouse gas emissions.
- Renewable Energy Scenario: Offers significant potential for emissions reduction but necessitates extensive investment in renewable energy infrastructure, particularly in solar and wind.
- Electrification Transport Scenario: Presents a viable path towards enhanced energy security through the integration of electric vehicles (EVs) into the system.

## Recommendations

- Maintain hydropower as a key energy source while actively diversifying into solar and wind energy to enhance security and reliability, given hydropower's climate vulnerability.
- Prioritize expanding EV charging infrastructure and grid upgrades, along with strong policies and financial support to accelerate EV adoption and ensure a smooth transition to cleaner transportation.

## 1. Introduction

Lao PDR's energy sector is predominantly based on hydropower, which accounts for over 85% of the nation's electricity generation (MEM Lao., 2022). This reliance on hydropower has provided Lao PDR with relatively low-cost electricity; however, it also exposes the country to significant vulnerabilities due to climate variability. Droughts and other extreme weather events can severely impact the reliability of hydropower generation, which in turn constraints efforts to diversify the energy mix and make the energy system less resilient to fluctuations in energy demand and global energy markets (Kyophilavong et al., 2023).

Lao PDR has an estimated 24,000 MW to 26,000 MW of potential hydropower capacity, of which 18,000 MW are technically exploitable. As of 2023, the overall installed power generation capacity stood at 10,044 MW, with actual production estimated to be around 50,000 GWh. The breakdown includes 83% (9,615 MW) from hydropower, 16% (1,878 MW) from the Hongsa coal plant, and smaller contributions from solar 56 MW and biomass 43 MW (MEM Lao., 2022).

Recognizing the challenges posed by heavy reliance on hydropower, the government has committed to diversifying the national energy mix. This commitment aligns with Lao PDR's obligations under the Paris Agreement, with a particular focus on reducing greenhouse gas emissions and enhancing energy security (NDC Lao PDR, 2021). The ultimate goal is to transition to a clean energy system that supports sustainable economic growth, environmental protection, and long-term resilience.

## **Purpose and Scope**

The purpose of this report is to analyse and model potential clean energy transition pathways for Lao PDR. The study evaluates various scenarios that could lead to a more sustainable and diversified energy future, focusing on strategies that minimize reliance on large hydropower projects and fossil fuels while ensuring the country meets its climate commitments.

## **Objectives**

- To identify the most economical renewable energy solution, excluding new hydropower projects, for Lao PDR in the period post-2030.
- To evaluate the effectiveness of current policies, particularly those promoting electric vehicles (EVs), in facilitating the clean energy transition in Lao PDR.

The objectives of this study are achieved by exploring three different scenarios namely: the Business-as-Usual (BAU), the Renewable Energy (RE) integration, and Electrification Transport (ET).

## **2. Methodology**

This report utilizes the Open-Source Energy Modelling System (OSeMOSYS), a linear programming model designed for optimizing long-term energy planning. OSeMOSYS is employed to minimize total system costs while ensuring that energy demand is met and emissions constraints are adhered to, as outlined by Howells et al. (2011). The model's adaptability and ability to incorporate detailed national data make it particularly suitable for the context of Lao PDR's clean energy transition, where the need to balance economic growth with environmental sustainability is paramount.

The data inputs for the model were sourced from key national documents, notably the National Energy Balance Reports for 2015-2022 and the Lao National Power Development Plan (NPDP) 2020-2030 (NDC Lao PDR, 2021). These documents provided comprehensive data essential for the model's calibration, ensuring that it accurately represents the current dynamics of the energy sector in Lao PDR. By grounding the model in these authoritative sources, the study was able to simulate various transition pathways, assess their potential impacts, and identify optimal strategies for achieving a sustainable energy future for the country.

## **Modelling Approach**

The analysis conducted in this report builds upon the 'Starter Kit' available at the Zenodo Repository, which provides a foundational structure for energy modelling (Vignesh et al., 2023). However, significant adjustments were made to reflect the specific context of Lao PDR. This involved incorporating local data from the National Energy Balance Reports (2015-2022) and the

Lao NPDP (2020-2030) to ensure the model accurately represents the current and projected energy landscape in Lao PDR.

## **Data Sources**

To ensure the accuracy and reliability of the model outputs, a range of data sources were utilized, including:

- National Energy Balance Reports (2015-2022): Detailed insights into current energy production, consumption, and distribution patterns in Lao PDR.
- Lao NPDP 2020-2030: The National Power Development Plan (NPDP) outlines the government's strategy for developing the energy sector over the next decade, including planned infrastructure projects and policy initiatives.

## **Scenarios**

Three scenarios were developed to explore different pathways for Lao PDR's energy future:

- Business-as-Usual (BAU) Scenario: Maintains the current trajectory, relying heavily on hydropower with limited diversification into other renewable energy sources. This scenario offers continuity in terms of low-cost electricity generation but does little to address vulnerabilities related to climate variability.
- Renewable Energy (RE) Integration Scenario: Emphasizes a significant shift towards solar and wind energy, reducing dependency on hydropower and fossil fuels. This scenario aligns with Lao PDR's climate commitments but requires extensive investment in renewable energy infrastructure, including large-scale solar and wind farms and small-scale biomass projects.
- Electrification Transport (ET) Scenario: This represents the most ambitious pathway, incorporating substantial increases in EV penetration. This scenario envisions a future where 100% of vehicles will be electric by 2050, significantly reducing oil imports and improving air quality, particularly in urban areas. However, it also requires significant investments in charging infrastructure, grid enhancements, and policy incentives to encourage consumer adoption.

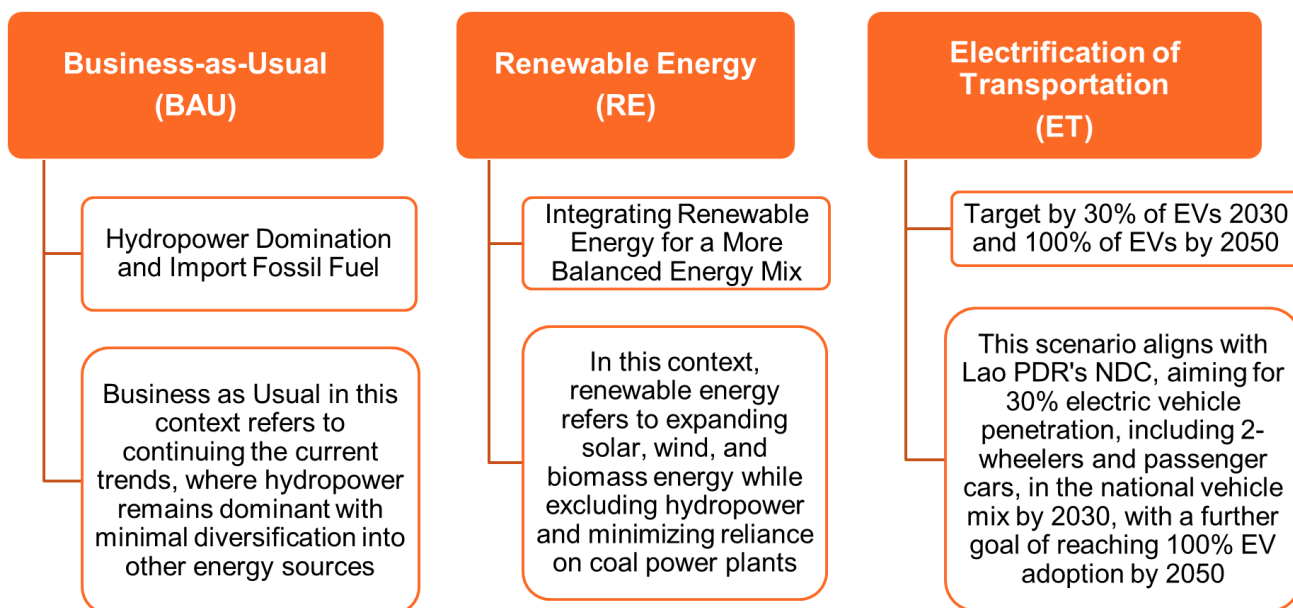


Figure 1. Description of the three scenarios

### 3. Results

The results of the modelling exercise provide valuable insights into the potential outcomes of each scenario, highlighting the trade-offs and challenges associated with different pathways.

#### Power Generation Capacity

The total power generation capacity is projected to increase substantially across all scenarios between 2015 and 2050. Under the BAU scenario, total generation capacity is expected to reach approximately 24 GW by 2050. In contrast, the RE and ET scenarios project higher capacities, reaching 41 GW and 58 GW, respectively, by 2050. The increase in capacity under the RE and ET scenarios is primarily driven by the integration of renewable energy technologies, particularly solar PV, utility-scale solar with storage, and onshore wind.

As renewable energy sources such as solar and wind have lower capacity factors compared to conventional plants, more capacity must be installed to meet the same energy demand. Furthermore, the RE and ET scenarios have the advantage of powering all demand sectors, thereby increasing the electrification rate. Hydropower remains part of the energy mix in the RE and ET scenarios due to its low emission factor and its role as a transition fuel.



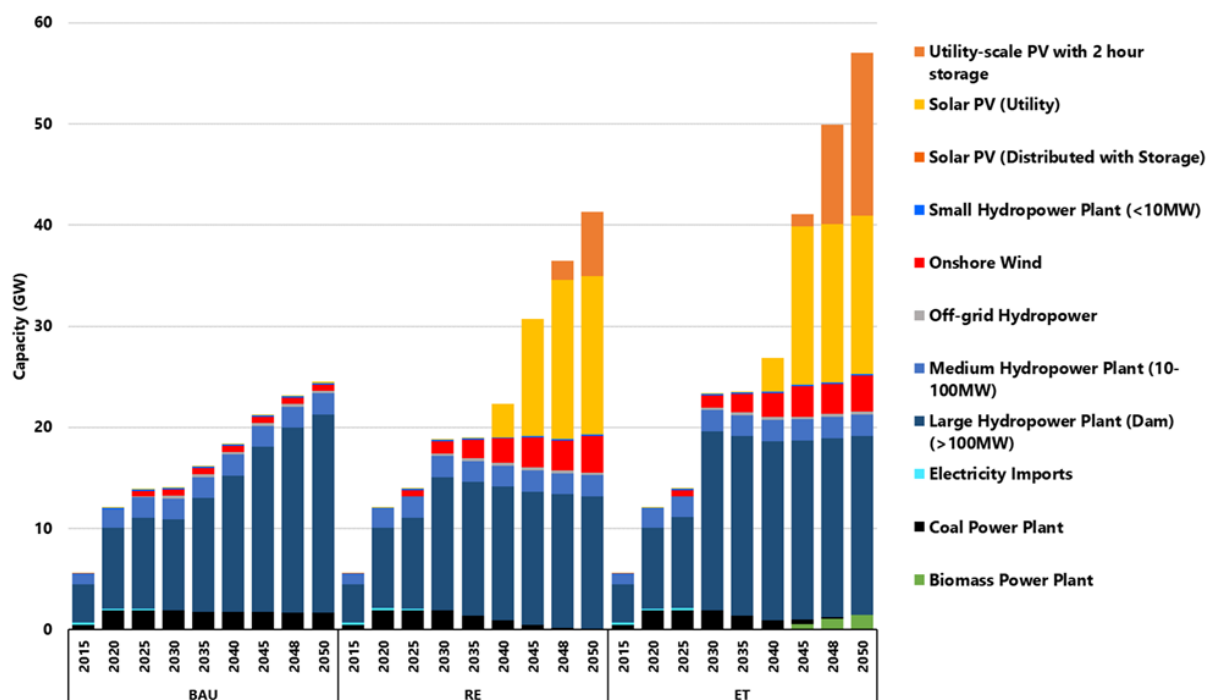


Figure 2. Total installed capacity (GW) for the different scenarios from 2015 to 2050

Figure 3 illustrates the optimal capacity expansion plans for power generation (in PJ) from various energy technologies between 2015 and 2050 across the three scenarios. All scenarios indicate a corresponding increase in power generation as energy demand rises. Under the BAU scenario, total power generation will escalate to 420 PJ by 2050, representing a 5.25 times increase from the 80 PJ generated in 2015. In contrast, the ET scenario forecasts a significantly higher total power generation, reaching 550 PJ by 2050. These scenarios project higher levels of power production to support the electrification rate and meet energy demands across all sectors.

In line with current trends in Laos' energy sector, power generation from coal plants is projected to reach approximately 30 PJ under the BAU scenario, with a gradual phase-out expected in the ET and RE scenarios by 2050. Additionally, the integration of biomass power generation is anticipated to begin between 2045 and 2050 in the ET scenario, which may warrant consideration for new investment in this technology.

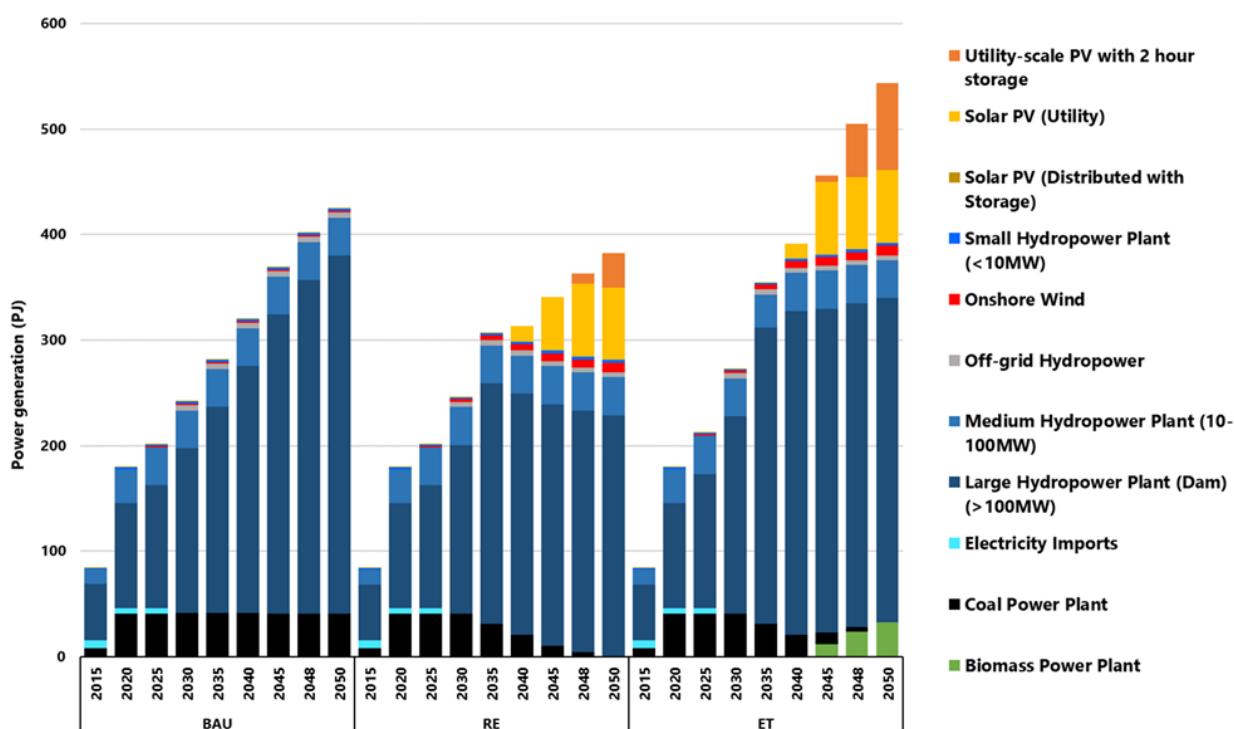


Figure 3. Power generation (PJ) by technology for 2015-2050

Figure 4 illustrates the projected total CO<sub>2</sub> emissions under different scenarios from 2015 to 2050. In the Business-as-Usual (BAU) scenario, current trends and the existing pace of the energy sector continue, leading to a significant increase in annual emissions, which are expected to reach approximately 33,000 ktCO<sub>2</sub> by 2050. In contrast, emissions are lower in both the Renewable Energy (RE) and Electrification of Transport (ET) scenarios. By 2030, total emissions are estimated to reach 25,000 ktCO<sub>2</sub> in both the BAU and RE scenarios, compared to 22,000 ktCO<sub>2</sub> in the ET scenario.

Notably, both the RE and ET scenarios show a substantial reduction in emissions by 2050 compared to the BAU scenario. These findings underscore that diversifying the energy mix and integrating clean and sustainable energy technologies can significantly reduce total emissions, aiding Laos in achieving its Nationally Determined Contributions (NDC). However, due to the increasing energy demand, the introduction of new biomass plants by 2045 is projected to result in a slight increase in carbon emissions by 2050. Consequently, to meet the goal of 100% electrification of the transportation sector, the development of additional biomass plants will be required. This expansion will necessitate increased investments and may lead to further emissions.



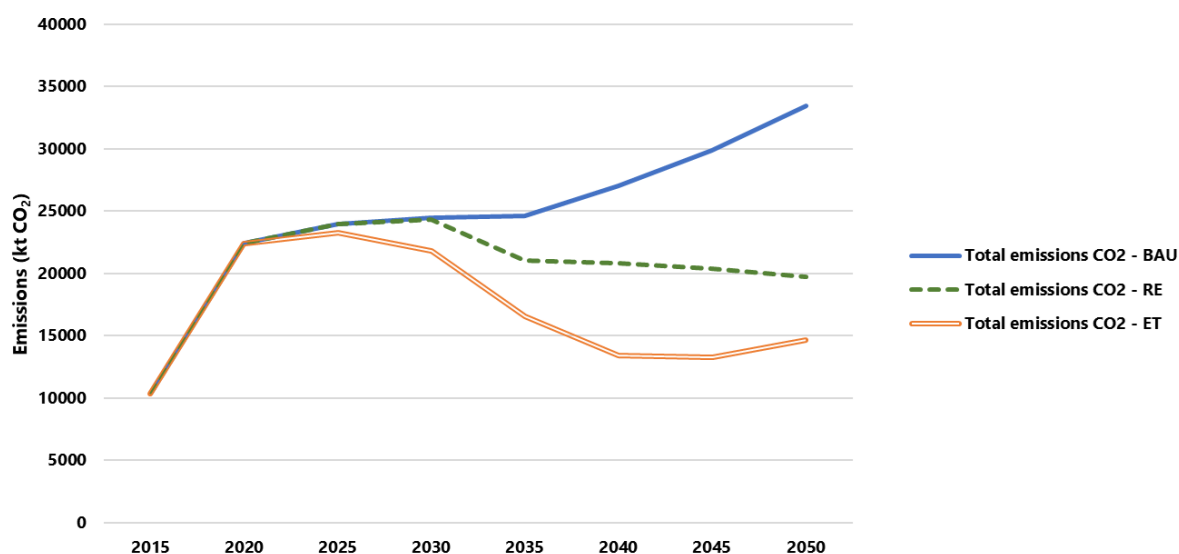


Figure 4. Total annual CO2 emissions by scenario from 2015 to 2050

Figure 5 illustrates the total cost associated with each scenario within the energy system by the year 2050. Under the Business-as-Usual (BAU) scenario, the total annual costs are projected to reach approximately USD 103,397.34 million. In comparison, the Renewable Energy (RE) scenario is estimated to incur total costs of USD 106,411.86 million, which is USD 3,014.51 million higher than the BAU scenario. The Energy Transition (ET) scenario, on the other hand, is projected to result in total annual costs of USD 120,771.93 million, representing an increase of USD 17,374.58 million compared to the BAU scenario.

**Comparison of Scenarios: Capital Costs and Strategic Implications.** The Electrification of Transport (ET) scenario presents a markedly higher capital cost compared to both the Business-as-Usual (BAU) and Renewable Energy (RE) scenarios. This underscores the need for substantial investment if the Lao government intends to integrate ET technologies by 2050. The ET scenario poses several significant challenges, particularly in terms of the widespread adoption of electric vehicles (EVs), which will necessitate major upgrades to the national grid. This includes the development of new charging infrastructure and the implementation of smart grid technologies.

Furthermore, the successful adoption of EVs will hinge on the development of supportive policies and incentives designed to encourage both consumers and businesses to make the transition. These initiatives will require considerable financial and regulatory backing, particularly in the early years leading up to 2050.

Despite these challenges, the ET scenario offers substantial benefits, particularly in reducing the country's reliance on imported oil. A shift towards EVs could lead to a significant decrease in annual oil import costs, thereby enhancing national energy security and mitigating the environmental impact of the transport sector.

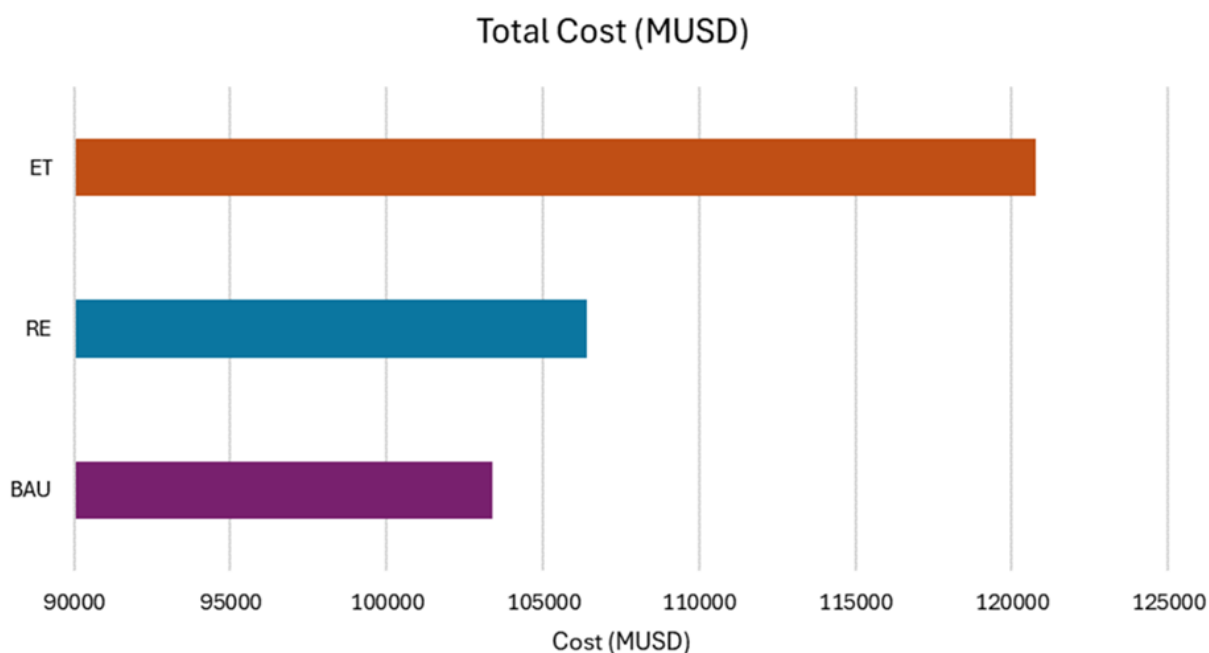


Figure 5: Total annual cost by scenario from 2015 to 2050

#### 4. Discussion

The results suggest a potential transformation in the energy landscape, marked by a significant shift toward Renewable Energy (RE) and Electrification Transport (ET) scenarios. This transition is driven by increased capacity from solar, wind, and electrified transport systems, along with a reduction in fossil fuel dependency. Such a shift is essential for achieving sustainability targets and mitigating the impacts of climate change.

The importance of these findings lies in the critical need for strategic planning and investment in renewable energy infrastructure to bring these future energy scenarios to fruition. The results provide valuable insights for decision-makers and stakeholders in the energy sector, helping to inform the development of policies that promote clean energy technologies, which are vital for Laos's socio-economic development. Future policy actions should include:

##### Lao PDR Policy Actions

- **Balancing Hydropower with Other Renewable Sources:** While hydropower will remain a cornerstone of Lao PDR's energy system, its role must be strategically complemented by integrating other renewable energy sources to enhance overall energy security and reliability. Given the inherent vulnerabilities of hydropower to climate variability, diversification is crucial to mitigate the risks associated with fluctuations in water availability. To achieve this, policy efforts should prioritize the rapid development and deployment of solar and wind energy projects. These renewable alternatives not only

provide a buffer against the risks of hydropower dependency but also contribute significantly to the country's emissions reduction targets.

- **Promoting Electric Vehicles and Developing Supporting Infrastructure:** The widespread adoption of electric vehicles (EVs) offers Lao PDR a significant opportunity to reduce dependence on imported oil and improve air quality. To fully leverage this potential, it is essential to accelerate the deployment of EV charging infrastructure, enhance the national grid, and establish robust policy frameworks that incentivize EV adoption. These measures are critical to ensuring that the transition to EVs is both successful and sustainable. Without substantial investments and strong policy support, the full benefits of increased EV penetration, including emissions reduction and improved energy efficiency, may not be fully realized. Therefore, immediate and coordinated policy actions are necessary to support the transition to a cleaner and more sustainable transportation sector.

## **Limitations and Further Research**

Several limitations should be acknowledged. The scenarios presented are based on current data and assumptions, which may not fully account for future technological advancements or shifts in global energy markets. Additionally, the exclusion of new large hydropower projects limits the scope of potential energy sources, focusing instead on smaller-scale renewables and emerging technologies.

Future research should focus on advanced energy storage solutions and cross-border energy trade in the context of Lao PDR's clean energy transition. Key areas of interest include the role of storage technologies in enhancing energy reliability and the potential of Laos as a regional clean energy exporter. Additionally, the research should examine the implications for energy security and economic stability, assessing how these developments could affect the nation's long-term resilience.

## **5. Conclusion**

Lao PDR has a pivotal opportunity to transition to cleaner, more sustainable energy. This analysis highlights that investing in renewable energy and supportive policies can significantly enhance energy security and help meet climate goals.

The energy modelling results from Osemosys indicate that the Electrification of Transport (ET) scenario projects the highest total installed capacity and power generation, reaching 58 GW and 550 PJ by 2050, respectively. However, by 2050, the Business-as-Usual (BAU) scenario is projected to have the highest CO<sub>2</sub> emissions at 33,000 ktCO<sub>2</sub>, followed by the Renewable Energy (RE) scenario at 20,000 ktCO<sub>2</sub>, and the ET scenario at 13,500 ktCO<sub>2</sub>. The total annual costs by 2050 are estimated to be approximately USD 103.5 billion under the BAU scenario, USD 105.2 billion under the RE scenario, and USD 121 billion under the ET scenario. Projections from 2015 to 2050 indicate that continuing on the current Business-as-Usual (BAU) path will lead to

increased CO<sub>2</sub> emissions. However, a shift to renewable energy and the electrification of transport can offer a more sustainable future by reducing emissions and fostering long-term resilience.

Although transitioning to renewable energy and electrified transport requires higher initial investments, especially in the Electrification Transport scenario, these costs are outweighed by the long-term benefits, including reduced reliance on fossil fuels, improved air quality, and economic sustainability. In summary, while the journey to a sustainable energy future involves challenges, the potential benefits for Lao PDR are substantial, promising a cleaner, more resilient future.

## **Policy Insights**

1. Maintain hydropower as a key energy source while actively diversifying into solar and wind energy to enhance security and reliability, given hydropower's climate vulnerability.
2. Prioritize expanding EV charging infrastructure and grid upgrades, along with strong policies and financial support to accelerate EV adoption and ensure a smooth transition to cleaner transportation.

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