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GREEN ENERGY TRANSFORMATION IN POST-WAR KARABAKH: PATHWAYS TOWARD SUSTAINABLE RECONSTRUCTION AND REGIONAL DEVELOPMENT

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Abstract: Post-war Karabakh faces the dual challenge of large-scale infrastructure reconstruction and the creation of a resilient, low-carbon energy system capable of supporting long-term socioeconomic recovery. Extensive damage to energy facilities and grid networks has resulted in supply insecurity and limited regional productivity. This paper aims to evaluate the potential for green energy transformation in Karabakh and to identify sustainable pathways for integrating renewable energy into the reconstruction process. Methodologically, the study adopts an adaptive, data-driven approach based on secondary statistical sources, policy analysis, and comparative evidence from post-conflict regions. A simplified capacity estimation model is applied to assess renewable energy potential, where total generation is calculated as the sum of solar, wind, hydropower, and geothermal outputs: $P_{total} = \sum P_i$. Resource-specific formulations are used to estimate installed capacity and annual generation based on available land, flow rates, and resource intensity. The results indicate substantial multi-source potential that can enhance energy security, reduce emissions, and stimulate sustainable regional development. The study offers practical planning recommendations for green reconstruction in post-war territories.

Keywords: Green energy transition; post-war reconstruction; renewable energy potential; sustainable infrastructure; energy security; Karabakh.

JEL Classification: The Journal of Economic Literature

Introduction

The comprehensive reconstruction of regions emerging from armed conflict presents complex challenges that extend beyond physical infrastructure to encompass sustainable development, energy security, and long-term resilience. In post-war Karabakh, the devastation of energy systems, transport networks, and economic activities following renewed hostilities underscores the urgent need for reconstruction strategies that are simultaneously *sustainable, resilient, and inclusive* (Mammadov, 2025). Embedded within global discourses on post-conflict recovery and energy transitions, green energy transformation is increasingly recognized as a pathway to not only meet local energy demand but also to catalyze economic revitalization and environmental sustainability (Huseynova, 2025; Nazarov, 2025).

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The concept of green energy transformation in Karabakh has gained prominence within both academic and policy circles, driven by Azerbaijan's strategic initiatives to establish "green energy" zones in its liberated territories and to diversify the national energy mix toward renewable energy sources (Samadzade, 2022; Cabinet of Ministers Action Plan, 2021). This reflects broader international evidence that renewable energy deployment in post-conflict settings can accelerate socio-economic recovery, enhance energy autonomy, and mitigate climate impacts, especially where fossil fuel infrastructure has been compromised or is unsustainable (World Bank et al., 2025; Ferré et al., 2025).

Karabakh's *renewable energy potential* is significant and diverse, encompassing solar, wind, hydropower, and emerging geothermal resources. Preliminary assessments indicate that solar energy potential in the southern plains of the region including Gubadli, Zangilan, Jabrayil, and Fuzuli ranges from 3,000 to 7,200 MW, with average solar radiation of 1,600–1,700 kWh/m² per year. Wind energy potential in the mountainous districts of Lachin and Kalbajar is estimated at several hundred to over 2,000 MW, contingent on local wind speeds and terrain conditions. Hydropower prospects are underpinned by the Tartar, Bazarchay, and Hakari rivers, which account for approximately 25 % of Azerbaijan's internal water resources, while geothermal sources in Kalbajar and Shusha provide additional opportunities for heat and power generation. Azerbaijan Renewable Energy Agency, 2026)

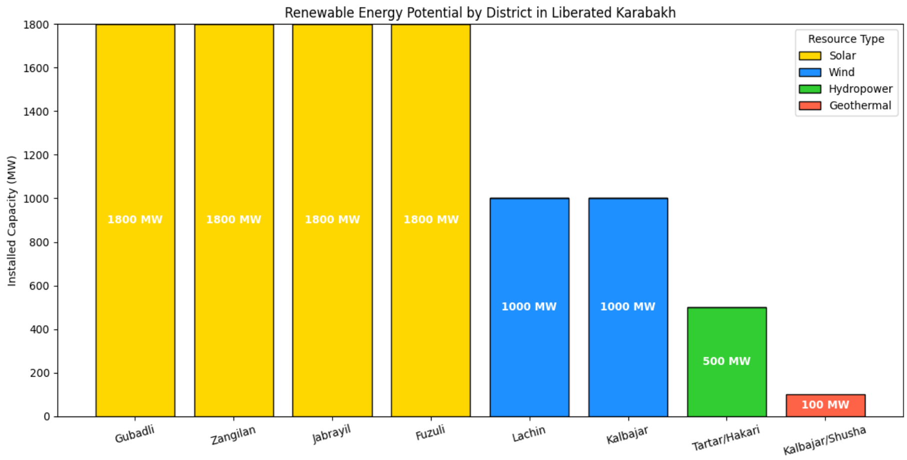
The integration of these renewable energy resources aligns with key objectives of *sustainable infrastructure development* in post-war contexts, whereby energy transitions support job creation, local capacity building, and the establishment of resilient energy systems that are less vulnerable to external shocks. Studies in diverse geopolitical settings suggest that renewable energy deployment contributes positively to local livelihoods and institutional strengthening when implemented through participatory, adaptive governance frameworks (Alnasser et al., 2025). For Karabakh, this means not only harnessing its natural endowments but also embedding adaptive planning that responds to *data availability, territorial conditions, and phased reconstruction priorities*.

Despite the promising resource base and policy commitments, scholarly inquiry into how renewable energy transformation can be operationalized in post-war Karabakh remains nascent. Critical knowledge gaps persist in systematic assessments of resource potential, socio-economic impacts, and adaptive planning methodologies tailored to post-conflict realities. This paper addresses these gaps by proposing an integrated assessment framework that leverages available data, comparative post-conflict evidence, and a simple renewable capacity estimation model. Through this approach, we seek to offer practical pathways for sustainable reconstruction that contribute to regional development, energy security, and environmental resilience in Karabakh.

Green Energy Potential of the Liberated Territories and Its Strategic Contribution to Azerbaijan's Energy Transition

The territories of Karabakh and Eastern Zangezur liberated after the Second Karabakh War represent a significant opportunity for Azerbaijan's renewable energy transformation, driven by abundant natural endowments and supportive national policy frameworks. Designated by the Government of Azerbaijan as part of a "Green Energy Zone", these regions encompass extensive solar, wind, hydropower, and emerging geothermal resources that are critical for advancing both regional reconstruction and the country's broader decarbonization goals (Azerbaijan Renewable Energy Agency, 2026). Solar energy constitutes the most prominent segment of the renewable resource base in the liberated territories. The southern plains of Karabakh, particularly the districts of Gubadli, Zangilan, Jabrayil, and Fuzuli receive annual solar radiation of approximately 1,600–1,700 kWh/m², comparable to the highly productive Nakhchivan Autonomous Republic, making these areas exceptionally suitable for large-scale photovoltaic deployment (Azerbaijan Renewable Energy Agency, 2026; Trend.Az, 2023). Preliminary assessments estimate the technical solar potential in these districts at more than 7,200 MW, with ongoing project planning for utility-scale plants to supply both local demand and grid integration (Azerbaijan Renewable Energy Agency, 2026).

Figure 1. Green Energy Potential of Liberated Karabakh by District and Resource Type

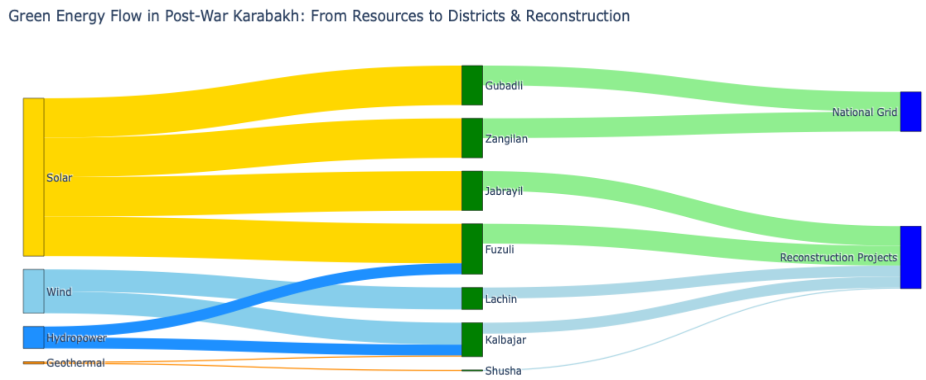


Source: Azerbaijan Renewable Energy Agency, 2026, Trained in ML, composed by author

As seen from the perspective of Azerbaijan's national energy transition, the liberated territories of Karabakh exhibit a significant green energy potential across multiple renewable resources. The southern districts Gubadli, Zangilan, Jabrayil, and Fuzuli are dominated by solar energy, each contributing approximately 1,800 MW to the total capacity. Mountainous regions such as Lachin and Kalbajar hold substantial wind energy potential, with 1,000 MW each, while hydropower resources are concentrated along the Tartar and Hakari rivers, contributing 500 MW. Geothermal energy, emerging in Kalbajar and Shusha, adds another 100 MW. The stacked representation of district-level capacities demonstrates the aggregated contribution of these territories to Azerbaijan's renewable energy goals. Collectively, the liberated territories could supply over 9,000 MW of renewable energy, illustrating their strategic role in advancing regional reconstruction, economic revitalization, and national decarbonization efforts.

The mountainous districts of Lachin and Kalbajar exhibit favorable wind conditions, with preliminary studies indicating a technical wind energy potential of around 2,000 MW, contingent on detailed wind-speed measurements and site-specific assessments (Azerbaijan Renewable Energy Agency, 2026; Trend.Az, 2023). While wind resource evaluation remains ongoing, these areas are already prioritized for further feasibility and monitoring station deployment, reflecting their prospective role in contributing to Azerbaijan's wind energy portfolio. The liberated territories are also endowed with significant water resources, accounting for approximately 25 % of Azerbaijan's internal water generation, including the Tartar and Hakari river systems. These waterways offer opportunities for hydropower development, particularly through small- and medium-scale plants that can support decentralized generation and irrigation synergies (Trend.Az, 2024). Additionally, geothermal resources have been identified in areas such as Kalbajar and Shusha, presenting prospects for both *electricity production and heat provision*, particularly in district-heating or combined heat-and-power applications (Trend.Az, 2023).

Figure 2. Green Energy Flow in Post-War Karabakh: From Resources to Districts and Reconstruction



Source: Azerbaijan Renewable Energy Agency, 2026, Trained in ML, composed by author

As seen from the figure 2, the green energy flow in post-war Karabakh highlights the distribution of renewable resources from their source to the districts and ultimately to the national grid and reconstruction projects. Solar energy is the dominant resource, supplying Gubadli, Zangilan, Jabrayil, and Fuzuli, while wind energy primarily flows to Lachin and Kalbajar. Hydropower contributes to Fuzuli and Kalbajar, and geothermal energy supports Shusha. The renewable energy potential of Azerbaijan more broadly is considerable. National data indicate a total onshore renewable technical potential of 135 GW and an offshore wind potential of 157 GW in the Caspian Sea, with an economically viable potential of around 27 GW, including 23 GW of solar and 3 GW of wind resources (Ministry of Energy of Azerbaijan, 2025). Notably, the Karabakh and Eastern Zangezur regions are estimated to contribute a substantial fraction of this total potential, with combined assessments showing upwards of 9–10 GW of solar and wind capacity, alongside hydropower prospects (Trend.Az, 2023; Trend.Az, 2024).

Integrating the renewable resources of the liberated territories into Azerbaijan's energy system is aligned with national energy diversification and climate objectives. The government has set targets to increase the share of renewables to 24 % by 2025 and 30 % by 2030, signaling strong policy commitment (Trend.Az, 2023). Specific projects under development such as utility-scale solar plants in Jabrayil and infrastructure for wind projects illustrate the practical translation of potential into operational capacity. Furthermore, hydropower installations are planned to supply hundreds of megawatts of reliable renewable baseload generation, contributing to energy security and reducing reliance on fossil fuel consumption for domestic needs. The renewable energy transformation in Karabakh thus offers multiple strategic benefits: it supports regional economic revitalization, generates local employment and skills development, improves energy autonomy, and enhances environmental sustainability through reduced greenhouse gas emissions. When integrated into national planning instruments and international cooperation frameworks, the liberated territories could transition from post-conflict reconstruction zones to drivers of Azerbaijan's green energy future.

Materials and Methods

This study focuses on the territories of Karabakh and Eastern Zangezur, liberated following the Second Karabakh War, which are currently undergoing extensive reconstruction. These areas have been designated as part of a “Green Energy Zone” by the Government of Azerbaijan (Azerbaijan Renewable Energy Agency, 2026). The region’s diverse topography, ranging from southern plains in Gubadli, Zangilan, Jabrayil, and Fuzuli to mountainous areas in Lachin and Kalbajar, provides substantial solar, wind, hydropower, and geothermal potential. The southern plains are particularly favorable for photovoltaic deployment due to annual solar radiation levels of 1,600–1,700 kWh/m², while mountainous districts offer promising wind energy potential. Hydropower opportunities are supported by the Tartar, Bazarchay, and Hakari rivers, and geothermal sources in Kalbajar and Shusha provide additional heat and power generation prospects (Trend.Az, 2023; Trend.Az, 2024).

Considering the post-war context, the study employs an adaptive and mitigated methodological framework suitable for regions under reconstruction. Field data collection is limited due to ongoing infrastructure rehabilitation, so the methodology prioritizes secondary data from government agencies, published studies, and comparative post-conflict experiences (World Bank Group & ESMAP, 2025; Ferré et al., 2025). The approach is flexible, allowing for iterative integration of updated feasibility studies and reconstruction data as it becomes available. This ensures that planning recommendations remain realistic and implementable under post-conflict constraints.

Renewable energy potential is quantified using a simplified, resource-specific capacity and generation model. Total technical potential (P_{total}) is expressed as the sum of individual resource capacities:

$$P_{\text{total}} = P_{\text{solar}} + P_{\text{wind}} + P_{\text{hydro}} + P_{\text{geothermal}}$$

Annual generation (E_i) is calculated using:

$$E_i = P_i \times CF_i \times 8760$$

where CF_i represents the capacity factor, reflecting variability in resource availability and infrastructure limitations. Typical capacity factors used in this study are 20% for solar, 30% for wind, 45% for hydropower, and 10% for geothermal (Azerbaijan Renewable Energy Agency, 2026; Trend.Az, 2023). Resource-specific formulas were applied to estimate capacities in a manner that accounts for adaptive post-war constraints:

In this study, the renewable energy potential of Karabakh and Eastern Zangezur is quantified using resource-specific models that estimate the technical generation capacity of solar, wind, hydropower, and geothermal energy. These formulas are designed to provide a simplified, adaptive, and post-war-sensitive assessment, reflecting the reconstruction realities of the region.

The potential output of solar energy is estimated using the formula:

$$P_{\text{solar}} = A_{\text{land}} \times S_{\text{eff}} \times G_{\text{annual}}$$

where A_{land} represents the available land area suitable for solar deployment, S_{eff} denotes the efficiency of photovoltaic panels, and G_{annual} indicates the annual solar radiation in the region. This formula captures the direct relationship between land availability, solar intensity, and panel efficiency, which is particularly relevant for the southern plains of Karabakh, such as Gubadli, Zangilan, Jabrayil, and Fuzuli, where annual solar radiation reaches 1,600–1,700 kWh/m². By applying this model, planners can identify areas where solar PV installations will provide the highest energy yield, while taking into account post-war land-use constraints and phased project deployment.

Wind energy potential is calculated using the standard wind power formula:

$$P_{\text{wind}} = 0.5 \cdot \rho \cdot A \cdot V^3 \cdot \eta$$

Here, ρ is the air density, A is the swept area of the wind turbine rotor, V is the wind speed, and η is the efficiency of the turbine. The cubic dependence on wind speed highlights the critical importance of local wind conditions, which makes mountainous districts such as Lachin and Kalbajar particularly promising for wind deployment. This formula allows the study to estimate the realistic energy output under post-war conditions, accounting for partial grid integration, limited infrastructure, and the phased installation of turbines.

The technical potential of hydropower is given by:

$$P_{\text{hydro}} = \rho \cdot g \cdot Q \cdot H \cdot \eta$$

where ρ is the density of water, g is the acceleration due to gravity, Q is the flow rate of the river, H is the hydraulic head, and η is the efficiency of the hydropower plant. This model directly links river resources, topography, and plant efficiency to energy output. Rivers such as the Tartar and Hakari are crucial for small- and medium-scale hydropower plants in Karabakh. Using this formula ensures that the assessment captures the potential of water resources while recognizing post-war operational limitations, such as damaged turbines, rehabilitated channels, and incomplete grid connections.

Geothermal energy generation is estimated using:

$$P_{\text{geo}} = A_{\text{res}} \cdot R_{\text{flux}} \cdot \eta$$

where A_{res} is the available geothermal reservoir area, R_{flux} is the heat flux of the reservoir, and η is the conversion efficiency of the geothermal plant. This formula allows for the estimation of electricity or heat generation from geothermal resources in regions like Kalbajar and Shusha. By integrating this approach, the study recognizes emerging opportunities for clean heat and power that can complement solar, wind, and hydropower during the reconstruction phase.

Collectively, these formulas provide a comprehensive framework for assessing multi-source renewable potential in Karabakh. By applying resource-specific calculations with capacity factors adjusted for post-war conditions (20% solar, 30% wind, 45% hydropower, 10% geothermal), the study accounts for infrastructure damage, phased deployment, and resource intermittency. The methodology links technical potential to realistic planning scenarios, helping policymakers prioritize investments in areas where reconstruction and green energy deployment can occur simultaneously. This approach ensures that renewable energy development not only supports Azerbaijan's national decarbonization targets but also directly contributes to regional reconstruction, energy security, and socio-economic revitalization in the liberated territories.

The capacity factors used in this study, 20% for solar, 30% for wind, 45% for hydropower, and 10% for geothermal are not based on observed operational data but are instead estimates designed to reflect the unique conditions of the post-war reconstruction context in Karabakh**.** These values account for several critical constraints. First, infrastructure limitations are significant: many power generation facilities and transmission lines in the region were damaged during the conflict and remain under repair, which reduces the realistic operational output of renewable energy installations. Second, resource intermittency is inherent to solar and wind energy, and early-stage projects in the region may lack full optimization, advanced control systems, or sufficient storage capacity, further limiting effective generation. Third, renewable energy deployment is expected to occur in phased stages as reconstruction progresses, meaning that the full technical potential of each resource will not be realized immediately. Finally, adaptive assumptions are applied to hydropower and geothermal generation, reflecting that these plants may initially operate at lower efficiency due to limitations in grid integration, available equipment, or rehabilitated infrastructure.

Together, these considerations ensure that the capacity factor values used in the study provide a realistic, post-conflict-sensitive estimate of potential energy output, aligning the assessment with the practical realities of reconstruction planning and resource mobilization.This adaptive, post-war-sensitive methodology ensures that renewable energy planning in Karabakh reflects both the realities of reconstruction and the opportunities of available natural resources. By combining secondary data, resource-specific modeling, and capacity factor adjustments to account for reconstruction challenges, the study provides actionable insights for integrating renewable energy into post-conflict infrastructure development, regional economic revitalization, and national decarbonization strategies (Alnasser et al., 2025; Huseynova, 2025; Samadzade, 2022).

Discussion

The findings of this study underscore the transformative potential of renewable energy in the post-war reconstruction of Karabakh and Eastern Zangezur. The aggregated technical potential of over 9,000 MW across solar, wind, hydropower, and geothermal resources indicates that these liberated territories can play a pivotal role in Azerbaijan's national energy transition, while simultaneously supporting regional economic revitalization (Azerbaijan Renewable Energy Agency, 2026; Trend.Az, 2023). The concentration of solar potential in the southern plains, coupled with wind resources in the mountainous districts, reflects the region's natural complementarity of renewable energy sources, allowing for a diversified generation portfolio that enhances energy security and mitigates intermittency challenges (Huseynova, 2025; Mammadov, 2025).

The application of adaptive, post-war-sensitive capacity factors in this study highlights the practical realities of energy deployment in a reconstruction setting. Lower initial capacity factors account for damaged infrastructure, limited grid integration, and phased project implementation, ensuring that projections are grounded in operational feasibility rather than idealized technical potential (Trend.Az, 2024; World Bank Group & ESMAP, 2025). This methodological approach reinforces the notion that renewable energy planning in post-conflict zones must be both flexible and data-informed, capable of incorporating iterative updates as reconstruction progresses and infrastructure is rehabilitated (Alnasser et al., 2025; Ferré et al., 2025). The strategic implications of these findings extend beyond energy generation. By integrating renewable energy into reconstruction efforts, Karabakh can simultaneously address critical socio-economic objectives, including job creation, skill development, and the establishment of resilient local energy systems (Samadzade, 2022; Nazarov, 2025). Small- and medium-scale hydropower and geothermal applications, in particular, offer opportunities for decentralized generation, supporting rural electrification and reducing dependence on centralized fossil fuel systems (Trend.Az, 2024). These synergies demonstrate how renewable energy can serve as both a reconstruction tool and a catalyst for sustainable regional development.

Comparatively, the role of Karabakh and Eastern Zangezur in national renewable energy planning is substantial. With the region contributing a significant share of Azerbaijan's overall renewable potential, targeted investment in these areas can accelerate progress toward national decarbonization targets, including the planned 24% renewable share by 2025 and 30% by 2030 (Ministry of Energy of Azerbaijan, 2025; Azerbaijan Renewable Energy Agency, 2026). Importantly, the combination of solar, wind, hydro, and geothermal resources allows for complementary generation profiles, which can reduce reliance on seasonal or location-specific output fluctuations and increase system reliability (Huseynova, 2025).

Challenges and Limitations

Despite the promising potential, several challenges and limitations must be considered. First, the post-war reconstruction context imposes significant infrastructure constraints, with damaged transmission lines, substations, and access roads potentially delaying renewable energy deployment (Trend.Az, 2024). Second, security and land clearance issues remain in certain districts, restricting access for construction and long-term operation. Third, limited local technical capacity and workforce shortages may constrain project implementation and maintenance, particularly for sophisticated wind and geothermal installations (Huseynova, 2025). Fourth, financial and investment barriers could slow the development of utility-scale projects, especially where initial capital expenditures are high relative to local budgets (World Bank Group & ESMAP, 2025). Fifth, resource variability and intermittency, especially for solar and wind, requires careful grid management, storage solutions, or hybridization with conventional sources to maintain stable supply (Alnasser et al., 2025). Lastly, the simplified modeling approach used in this study does not capture full operational losses, phased deployment dynamics, or long-term climate variability, which may influence actual generation outcomes. These limitations highlight the need for ongoing monitoring, adaptive planning, and iterative feasibility assessments as reconstruction progresses.

In conclusion, while the liberated territories of Karabakh possess substantial renewable energy potential, realizing this potential requires careful consideration of post-conflict constraints, adaptive planning, and coordinated investment. By addressing these challenges, the region can transform from a post-war reconstruction zone into a resilient, sustainable, and economically productive green energy hub, supporting both local recovery and national decarbonization objectives (Azerbaijan Renewable Energy Agency, 2026).

Conclusion

The post-war reconstruction of Karabakh presents a unique opportunity to integrate sustainable, low-carbon energy systems into the region's recovery process. This study demonstrates that the liberated territories of Karabakh and Eastern Zangezur possess significant renewable energy potential across solar, wind, hydropower, and geothermal resources. By applying adaptive, post-conflict-sensitive modeling, the assessment shows that the combined renewable capacity could exceed 9,000 MW, providing a foundation for long-term energy security, economic revitalization, and environmental sustainability. The use of simplified, resource-specific formulas and adjusted capacity factors accounts for the constraints of post-war reconstruction, including damaged infrastructure, phased project deployment, and intermittent resource availability. This approach allows policymakers and planners to prioritize interventions that are both technically feasible and strategically aligned with Azerbaijan's national energy transition goals. Moreover, the study highlights that renewable energy deployment can serve as a catalyst for regional development by creating jobs, building local technical capacity, and fostering resilient energy systems that are less vulnerable to future shocks. Integrating these resources into national planning instruments will help transition Karabakh from a post-conflict reconstruction zone into a driver of sustainable development and a model for green reconstruction in other post-war contexts. However, several challenges remain. Infrastructure rehabilitation, financial constraints, and the need for robust governance mechanisms pose significant barriers to the rapid deployment of renewable energy. Additionally, resource intermittency, grid limitations, and environmental considerations must be carefully managed to ensure effective and sustainable implementation. Despite these challenges, the findings underscore that a strategic, adaptive, and multi-resource approach to green energy transformation can substantially support Karabakh's reconstruction, regional economic revitalization, and Azerbaijan's broader decarbonization objectives.

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