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Azerbaijan's Strategic Role in the Global Energy Transition: A Regional Model for Balancing Hydrocarbon and Renewable Energy Development

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ABSTRACT

Azerbaijan's energy transition presents a distinctive case among hydrocarbon-exporting economies: rather than treating renewable energy and oil and gas development as competing trajectories, the country pursues an integrated strategy that leverages its hydrocarbon infrastructure, capital base, and technical expertise to support renewable deployment. This paper examines how Azerbaijan's exceptional climatic diversity — spanning nine of the eleven Köppen climate zones (World Bank & Asian Development Bank, 2021) — enables a regionally differentiated approach to renewable energy, in which solar, wind, and biofuel technologies are matched to the specific conditions of regions such as Baku, Nakhchivan, Karabakh, East Zangezur, and Mil-Mughan. The analysis further examines the emerging synergy between hydrocarbon processing and low-carbon chemical production, captured in the industry concepts of Crude-to-Chem and Carbon-to-Chem (Nasirov, 2023), and benchmarks Azerbaijan's biofuel and waste-management initiatives against international experience in the United States, Germany, Brazil, and Sweden. Drawing on the country's renewable energy targets under the "Azerbaijan 2030" strategy and its outcomes at COP29, the paper argues that Azerbaijan's regionally differentiated, infrastructure-synergistic model offers a transferable framework for other resource-rich economies navigating the low-carbon transition. The paper concludes by identifying the principal limitations of the current evidence base and outlining directions for further quantitative research.

Keywords: Energy Transition, Renewable Energy, Hydrocarbon Economy, Regional Development, Circular Economy, Azerbaijan

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1. INTRODUCTION

The global energy system is undergoing a structural transformation in which renewable energy is shifting from a peripheral policy objective to a primary driver of economic strategy. For hydrocarbon-exporting economies, this shift raises a distinct strategic question: not whether to abandon fossil fuel-based development, but how to reconcile continued reliance on hydrocarbon revenues with credible, scalable investment in low-carbon alternatives. A growing body of literature addresses this question at the level of resource-rich economies in general—examining, for instance, how fiscal structures, green finance instruments, and industrial policy shape renewable energy uptake (Behera et al., 2024; He et al., 2023).

Resource wealth and renewable ambition are therefore not inherently in tension; the relevant question is how governance structures and regional development strategies direct capital from hydrocarbons toward renewable outcomes (Zhuo et al., 2024). What remains comparatively underexamined, however, is how such a transition unfolds within a single resource-rich economy at the regional level—that is, how a hydrocarbon-exporting state with significant internal climatic and geographic diversity might differentiate its renewable energy strategy by region rather than pursuing a uniform national approach. Azerbaijan presents a useful case for this question. The country's hydrocarbon sector remains central to its fiscal position, yet its territory spans an unusually wide range of climatic conditions, creating distinct regional endowments for solar, wind, and biomass-based energy production. At the same time, Azerbaijan's hosting of COP29 in 2024 placed the country's energy strategy under direct international scrutiny, raising the practical question of what, specifically, the country's model offers as a template for other resource-rich states.

Recent Azerbaijan-focused studies have examined solar energy forecasting, smart-grid readiness, financial-sector support for renewable energy development, and the impact of clean energy consumption on carbon emissions, indicating that Azerbaijan's energy transition should be understood as a multidimensional process involving technological, institutional, financial, and environmental factors (Hasanov, 2024; Gurbanov and Mammadli, 2024; Kartal and Pata, 2024; Musayev, 2024).

This paper addresses that question by examining Azerbaijan's energy transition as a regionally differentiated strategy that integrates renewable deployment with the continued evolution of the hydrocarbon sector. The analysis proceeds as follows. Section 2 reviews the literature on energy transition in resource-rich economies and on regional approaches to renewable deployment, identifying the gap this paper addresses. Section 3 examines Azerbaijan's climatic and regional foundations for renewable energy. Section 4 analyzes the country's solar, wind, and biofuel potential by region. Section 5 discusses the emerging synergy between hydrocarbon processing and chemical production under the Crude-to-Chem and Carbon-to-Chem paradigms. Section 6 benchmarks Azerbaijan's biofuel and waste-management initiatives against international experience. Section 7 examines investment dynamics and regional development clusters. Section 8 considers environmental and social outcomes. Section 9 places these findings in the context of COP29 and the road to COP30. Section 10 discusses how these findings relate to the literature reviewed in Section 2 and identifies the principal limitations of the analysis, and Section 11 concludes with directions for future research.

2. LITERATURE REVIEW

Research on energy transition in resource-rich economies has developed along several distinct lines. A first body of work focuses on the macro-level relationship between green finance, fiscal policy, and renewable energy uptake. Behera et al. (2024) demonstrate, using panel data from European Union countries, that fiscal decentralization combined with green finance and green technology innovation positively influences renewable energy use, though the magnitude of this effect is moderated by political risk — a finding directly relevant to resource-rich states where political and institutional stability shapes investor confidence in long-horizon renewable projects. He et al. (2023) extend this line of inquiry by showing that renewable energy investment and green finance jointly support sustainable development primarily through their interaction with industrial structure and technological innovation, suggesting that the effectiveness of green finance depends on the receiving economy's existing industrial base rather than operating independently of it.

A second body of work examines regional, rather than purely national, dynamics of green transformation. Zhuo et al. (2024) analyze coordinated regional development within major national strategic zones and demonstrate that green transformation outcomes vary substantially across regions within the same country, depending on local industrial structure, resource endowment, and policy targeting. This regional lens is significant for the present analysis: it implies that national-level renewable energy strategy is necessarily mediated by sub-national heterogeneity and that treating a country's energy transition as a single, uniform process risks obscuring the mechanisms through which transition actually occurs.

A third, more applied stream of literature addresses the technical and policy dimensions of biofuel and waste-to-energy deployment, including the role of decentralized infrastructure (relevant to Germany's experience), policy-driven market creation (relevant to the United States' Renewable Fuel Standard), and circular economy principles applied to industrial and municipal waste streams (relevant to Sweden's waste management system). This literature, reviewed in detail in Section 6, offers a set of internationally tested mechanisms — policy incentives, decentralized production, and public-private partnerships — that have not yet been systematically mapped onto Azerbaijan's regional context.

A fourth and particularly relevant body of work investigates the empirical relationship between oil prices, institutional quality, and renewable energy consumption in hydrocarbon-exporting economies. Mukhtarov et al. (2020) examine this relationship for Azerbaijan specifically, using structural time series modeling for the period 1992–2015, and finds a long-run negative effect of oil prices on renewable energy consumption: higher oil revenues generate a sense of energy security that delays the substitution of conventional sources by renewables. This "satisfaction effect" of hydrocarbon wealth—whereby resource rents reduce the urgency of transition—represents a structural constraint that Azerbaijan's current policy framework must actively counteract. Karacan et al. (2021) extend this analysis to Russia, another major hydrocarbon exporter, employing Vector Error Correction Models over 1990–2015 and arriving at an analogous conclusion: oil price increases negatively affect renewable energy uptake, while income growth exerts a positive but insufficient countervailing influence. The parallel findings across Azerbaijan and Russia suggest that this dynamic is not idiosyncratic but characteristic of hydrocarbon-dependent economies as a class.

The role of institutional quality in mediating this relationship has been examined by Mukhtarov et al. (2022a), who apply the FMOLS method to Azerbaijan for 1996–2019 and find that government effectiveness positively and significantly influences renewable energy consumption, while CO_2 emissions and economic growth alone are insufficient drivers of transition. This finding has direct policy implications for Azerbaijan: institutional reform and regulatory capacity-building complement the investment programs currently underway. In a related study, Mukhtarov and Aliyev (2024) analyze the same institutional quality channel for Russia over 1996–2022 using canonical cointegrating regression, finding that improvements in the corruption perception index and income growth positively drive renewable energy consumption, whereas trade openness exerts a negative effect—underscoring the importance of domestic institutional conditions relative to external market integration as determinants of transition pace.

The contrasting dynamics observed across oil-exporting economies are further illustrated by Mukhtarov et al. (2022b), who examine Iran over 1980–2019 using a General-to-Specific modeling approach and find that both oil prices and CO_2 emissions negatively affect renewable energy consumption—a result they interpret as a "satisfaction" effect analogous to that identified for Azerbaijan. The contrast with China, analyzed by Mukhtarov (2024) using canonical cointegrating regression over 1990–2020, is instructive: in China, an oil-importing economy, rising oil prices positively stimulate renewable energy adoption by strengthening the cost competitiveness of clean alternatives. The divergence between oil-importing and oil-exporting economies is thus a structural feature of the global energy transition landscape, and Azerbaijan's policy framework must be understood as operating under the specific constraints that characterize resource-exporting states.

Recent studies focusing specifically on Azerbaijan provide an important empirical foundation for the present analysis. Hasanov (2024) forecasts solar energy production in Azerbaijan and highlights the importance of quantitative planning tools for renewable energy policy. Gurbanov and Mammadli (2024) emphasize that the expansion of renewable energy requires smart-grid development and improved electricity security. Kartal and Pata (2024) demonstrate that the depth and efficiency of financial institutions support renewable energy consumption, suggesting that green transition is closely linked to the financial capacity of the economy. Musayev (2024) further shows that renewable energy consumption reduces carbon emissions in Azerbaijan in the long run. In addition, Aliyev et al. (2024), examining the relationship between nuclear energy consumption, economic growth, and CO_2 emissions in South Korea within the Environmental Kuznets Curve framework, provide a useful comparative reference point for how alternative low-carbon energy sources can be evaluated in relation to emissions reduction and sustainable energy transition. These findings are complemented by broader institutional and policy analyses: Hamidova et al. (2022) examine the institutional and economic challenges of implementing renewable energy sources in Azerbaijan, while Gasimli et al. (2024) analyze the economy-wide and environmental benefits of green energy development in an oil-rich country context, and Gasimli et al. (2025) directly frame Azerbaijan as an oil-exporting country seeking to reposition itself as a future green energy exporter. Taken together, these studies indicate that Azerbaijan's energy transition should be analyzed through the combined lenses of resource potential, grid infrastructure, financial development, and environmental outcomes.

Taken together, this body of empirical work identifies a consistent pattern: in hydrocarbon-exporting economies, the transition to renewable energy is structurally impeded by the revenue and behavioral effects of high oil prices and can only be accelerated through deliberate institutional and regulatory intervention. Despite the breadth of this literature, however, a specific gap remains. Existing work on resource-rich economies tends to evaluate energy transition either at the macro (national/fiscal) level or through cross-country comparison, while the regional development literature, though attentive to subnational variation, has rarely been applied to hydrocarbon-exporting states with pronounced internal climatic diversity. Azerbaijan—where renewable resource endowment varies sharply between, for example, the wind- and solar-rich Absheron Peninsula and the biomass-rich agricultural regions of Karabakh and Mil-Mughan—offers a case in which this regional heterogeneity is unusually pronounced. This paper addresses that gap by examining how Azerbaijan's energy strategy differentiates renewable technology choice by region while simultaneously pursuing synergy with its existing hydrocarbon sector, and by situating this regional model within the broader international experience of biofuel and circular-economy policy.

3. CLIMATIC AND REGIONAL FOUNDATIONS FOR RENEWABLE ENERGY

Azerbaijan's geography spans nine of the world's eleven Köppen climate zones, a degree of climatic diversity confirmed by international assessments of the country's climate risk profile (World Bank & Asian Development Bank, 2021). This diversity is not incidental to the country's renewable energy strategy; it is the structural basis for it. Rather than pursuing a single national technology pathway, Azerbaijan's regions present markedly different renewable resource endowments, allowing — and arguably requiring — a differentiated, region-specific approach to solar, wind, and biofuel deployment.

The Absheron Peninsula and Baku, historically known as the "City of Winds," illustrate this regional logic most directly. The combination of strong, persistent wind conditions and high solar irradiance makes the area well suited to hybrid wind-solar projects, and its existing hydrocarbon infrastructure — pipelines, processing facilities, and a skilled energy workforce — provides a platform onto which renewable capacity can be added without requiring entirely new industrial ecosystems. This is consistent with the broader pattern observed internationally, in which regions with established energy infrastructure tend to absorb renewable capacity additions more efficiently than regions starting without comparable infrastructure (Zhuo et al., 2024).

Nakhchivan, Karabakh, East Zangezur, and Mil-Mughan present a different regional profile. These areas combine high solar irradiance with substantial agricultural activity, creating favorable conditions for biofuel and biogas production rather than for utility-scale solar or wind. The agricultural waste streams generated in these regions — crop residues, livestock waste, and food-processing byproducts — represent an underutilized feedstock base for anaerobic digestion and related bioenergy technologies (see Section 4). Within this regional context, two interconnected technology pathways can be identified as relevant to Azerbaijan's medium-term development: a natural gas-based pathway (natural gas, including liquefied natural gas, as a transition fuel toward biogas and eventually hydrogen), and a biomass-based pathway (agricultural and organic feedstocks converted to biofuel, biogas, and ultimately bioethanol or biomethanol). Mini- and medium-scale liquefied natural gas production, using existing natural gas resources as an initial step, is one practical mechanism through which these rural and post-conflict regions could be integrated into the national energy matrix without requiring immediate large-scale capital investment.

It should be noted that these two pathways represent a conceptual framework proposed in this paper for organizing Azerbaijan's regional energy options, rather than an established technology roadmap drawn from prior literature; their value lies in clarifying the sequencing logic—transition fuel to intermediate fuel to advanced fuel — that links regions with different resource endowments into a coherent national strategy. Read together, the cases of Baku and of Nakhchivan, Karabakh, East Zangezur, and Mil-Mughan demonstrate that Azerbaijan's renewable strategy is not a uniform national program applied indiscriminately across the country, but a set of regionally tailored interventions designed around each area's specific climatic and economic conditions — a pattern consistent with the regional heterogeneity documented in the broader green-transformation literature (Zhuo et al., 2024).

4. RENEWABLE ENERGY POTENTIAL: SOLAR, WIND, AND BIOFUEL

The regional differentiation introduced in Section 3 can be examined more closely by technology. Solar energy potential is concentrated in Nakhchivan and the country's interior plains, where high solar irradiance favors small- and medium-scale photovoltaic installations designed to serve local grid demand rather than large utility-scale export-oriented capacity. Wind energy potential is concentrated along the Caspian coast and the Absheron Peninsula, where the same climatic conditions noted in Section 3 — strong and consistent coastal wind — support both standalone wind farms and hybrid wind-solar facilities. These two resource bases are visually summarized in the country's renewable resource mapping (Figure 1), which depicts wind and solar potential as broadly complementary rather than overlapping across the national territory.

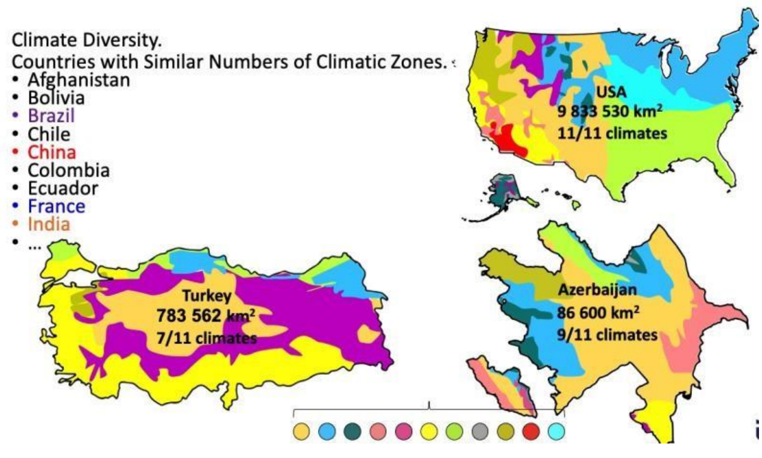

Figure 1. *Climate diversity: countries with comparable numbers of climatic zones. Azerbaijan (86,600 km²) spans nine of eleven Köppen climate zones, a density of climatic diversity comparable to far larger territories such as the United States.*

Figure 2 situates this technological potential within the country's broader spatial structure, juxtaposing climate classification, hydrocarbon production and processing activity, agricultural land use, and wind/solar resource distribution. The spatial correspondence between agricultural activity and renewable resource availability — particularly the overlap between farming regions and solar potential — reinforces the regional logic introduced in Section 3.

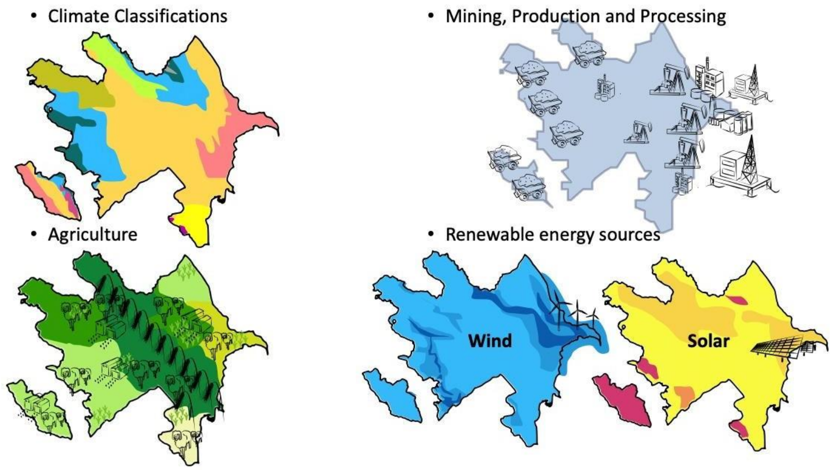

Figure 2. *Azerbaijan today: climate classification, mining and processing activity, agricultural land use, and wind/solar resource distribution.*

Biofuel and biogas production present a third, distinct technology pathway, grounded not in climatic resources but in the agricultural waste streams generated across Azerbaijan's farming regions. Crop residues, livestock waste, and food-processing byproducts constitute a feedstock base whose scale can be approximated from sectoral estimates: a regional assessment identifies roughly 1 million tonnes per year of food waste suitable for biofuel and biogas feedstock, alongside approximately 30 million tonnes per year of additional biomass available for biogas blending and approximately 0.5 million tonnes per year suitable for biofuel blending (Figure 3). The relevance of this feedstock base extends beyond energy production: anaerobic digestion and related processing pathways generate, alongside biogas itself, organic fertilizers, animal feed additives, and biofertilizers, creating value streams in agricultural support services in addition to energy output.

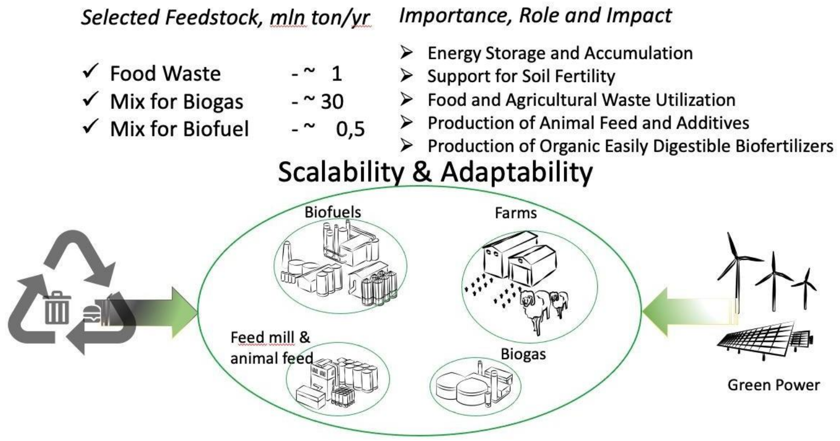

Figure 3. *Food waste processing, biofuels, and biogas: selected feedstock volumes and conversion pathways into biofuels, biogas, animal feed, and biofertilizers.*

Table 1 summarizes the principal technology pathways through which Azerbaijan's gas and biomass resources can be converted into usable fuels and chemical feedstocks, drawing on established industrial processes documented in the bioenergy and gas-processing literature.

Table 1. *Gas and Biofuel Production Processes*

Technology	Feedstock	Product	Application	Environmental Benefit
Fischer-Tropsch synthesis	Natural gas	Synthetic fuel	Transportation	Low-emission fuel production
Anaerobic digestion	Organic waste	Biogas	Power generation, heating	Utilizes waste streams, reduces methane emissions
Biomass gasification	Wood chips and crop residues	Biomethane (Bio-SNG)	Combined heat and power, grid injection	Renewable substitute for natural gas (ETIP Bioenergy, 2020)
Power-to-gas	Surplus electricity, captured CO_2	Synthetic methane	Energy storage, grid balancing	Stores excess renewable generation

Beyond these established conversion technologies, Azerbaijan's own technology requirements — as identified in sector planning — extend into more specialized areas: end-of-life management for solar panels and wind turbine blades, battery recycling, carbon capture and storage, and the conversion of agricultural biomass into both fuel and oleochemical products through modular, small-scale units (fermentation, gasification, esterification, and related processes). This indicates that Azerbaijan's renewable technology agenda is not limited to initial deployment but explicitly anticipates the second-order infrastructure — recycling, storage, and waste processing — required for a mature renewable sector (Figure 4).

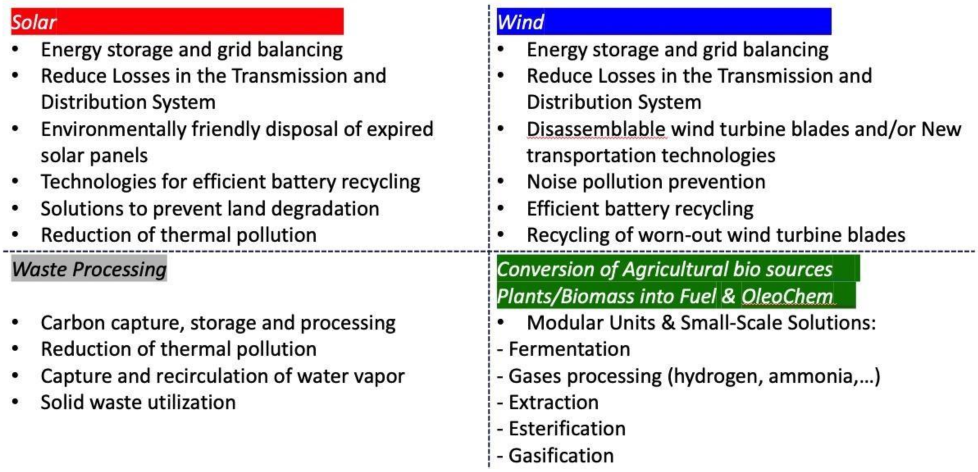

Figure 4. *Request for technologies: identified technology needs across solar, wind, waste processing, and agricultural biomass conversion.*

5. SYNERGY WITH HYDROCARBON INDUSTRIES: CRUDE-TO-CHEM AND CARBON-TO-CHEM

A central feature of Azerbaijan's energy transition is that it does not treat the hydrocarbon sector as a legacy industry to be phased out but as an asset base to be redirected toward lower-carbon outputs. This logic is captured in an industry framework articulated by Nasirov (2023), who traces the evolution of refining and petrochemical strategy through three successive stages. The first stage, "Crude Oil to Chem," describes the now largely operational shift of refining capacity toward maximizing chemical feedstock output—ethylene, propylene, and related building blocks—rather than transportation fuels, a shift driven by petrochemical demand growth substantially outpacing fuel demand growth in mature and emerging markets alike. The second, emerging stage, "Carbon to Chem," extends this logic by using captured carbon dioxide as a feedstock for chemical production, directly linking decarbonization objectives to the petrochemical value chain rather than treating them as separate agendas. A third, more nascent stage, "Electricity to Chem," anticipates a future in which renewable electricity itself becomes a primary input into chemical synthesis processes.

For Azerbaijan, this framework offers a coherent rationale for integrating hydrocarbon-sector modernization with renewable energy deployment, rather than treating the two as competing claims on capital and policy attention. Converting hydrocarbons directly into chemical products, rather than primarily into fuel, allows the country's existing refining infrastructure to remain economically relevant under conditions of declining global fuel demand growth, while the captured-carbon dimension of the Carbon-to-Chem pathway creates a direct technical link between the petrochemical sector and emissions-reduction objectives. In Baku, where hydrocarbon infrastructure and renewable resource potential are co-located (see Section 4), pilot integration of solar and wind generation into petrochemical production processes is a logical extension of this framework: renewable electricity can supply process energy for chemical conversion, reducing the carbon intensity of petrochemical output without requiring the underlying hydrocarbon feedstock base to be abandoned.

This synergy matters for the broader argument of this paper. Azerbaijan's energy transition does not require, and does not attempt, a wholesale rejection of hydrocarbons. Instead, it reimagines the function of hydrocarbon infrastructure within a lower-carbon economy—a pattern that, if successful, offers a transferable lesson for other hydrocarbon-exporting states whose refining and petrochemical assets represent sunk capital that cannot easily or rapidly be replaced but can potentially be redirected toward lower-carbon outputs.

6. INTERNATIONAL BENCHMARKING: GLOBAL BEST PRACTICES IN BIOFUEL AND WASTE MANAGEMENT

Azerbaijan's biofuel and waste-management strategies do not develop in isolation; they can be situated against international experience in four countries that have pursued distinct, well-documented models of biofuel and circular-economy development: the United States, Germany, Brazil, and Sweden. Each offers a different mechanism — policy-driven market creation, decentralized rural infrastructure, agricultural-crop-based biofuel scaling, and municipal waste-to-energy conversion, respectively — with direct relevance to specific aspects of Azerbaijan's regional strategy outlined in Sections 3 and 4.

United States: policy-driven market expansion. The U.S. Renewable Fuel Standard (RFS) mandates the blending of biofuels into the national transportation fuel supply and has been a central instrument in expanding domestic biorefinery capacity and demand for biofuel feedstocks (U.S. Environmental Protection Agency, 2022). For Azerbaijan, the relevant lesson is mechanistic rather than quantitative: a mandated blending requirement, even at modest initial volumes, creates predictable demand that de-risks investment in biofuel production capacity — a mechanism Azerbaijan's biofuel sector currently lacks.

Germany: decentralized biogas infrastructure. Germany operates the largest biogas sector in Europe, with approximately 9,300 biogas-generating plants and a further several hundred biomethane-upgrading facilities in operation as of the most recent industry assessment, together generating on the order of 29 terawatt-hours of electricity annually — sufficient to meet the demand of roughly 8.8 million households (German Biogas Association, 2026). These plants are overwhelmingly rural and small-scale, and the German Federal Ministry of Food and Agriculture estimates that biogas activity contributes approximately €8 billion annually to rural economies while supporting over 40,000 jobs. This decentralized model is directly relevant to Azerbaijan's agricultural regions — Nakhchivan, Karabakh, East Zangezur, and Mil-Mughan — where a comparable network of small- and medium-scale biogas facilities, rather than a small number of large centralized plants, could extend energy access and rural income generation simultaneously.

Brazil: bioethanol as a driver of rural economic activity. Brazil is the world's second-largest bioethanol producer, with total ethanol production reaching approximately 32.95 billion liters in

2023 and accounting for roughly a quarter of global ethanol output (USDA Foreign Agricultural Service, 2023). Modeling of further sugarcane-ethanol expansion suggests that scaling production by an additional 10 billion liters could raise national GDP by approximately USD 2.6 billion and generate around 53,000 full-time-equivalent jobs, with benefits distributed unevenly but generally favorably across rural microregions. For Azerbaijan, the transferable element is not the specific feedstock — sugarcane is not a regionally appropriate crop — but the underlying mechanism: large-scale cultivation of an energy crop suited to local agricultural conditions (for instance, rapeseed) can generate measurable rural employment and income effects when paired with adequate processing infrastructure.

Sweden: municipal waste-to-energy and circular economy integration. Sweden manages its municipal waste through a combination of recycling and energy recovery that leaves minimal residual landfill volume: in 2023, the country processed approximately 4.1 million tonnes of municipal waste, of which roughly 39 percent was recycled and 59 percent was converted to energy through waste-to-energy facilities (Sweden.se, 2025). This system illustrates the economic logic of treating municipal and organic waste as an energy input rather than a disposal liability — a principle directly applicable to the food-waste feedstock base identified in Section 4.

***Table 2.** International Benchmarks for Biofuel and Waste Management*

Country	Key Practice	Documented Outcome	Relevance to Azerbaijan
United States	Policy-mandated biofuel blending (Renewable Fuel Standard)	Sustained growth in bio-refinery capacity and feedstock demand	Mandated blending could de-risk investment in domestic biofuel production
Germany	Decentralized rural biogas plants (~9,300 facilities, ~29 TWh/year)	~€8 billion annual contribution to rural economies; 40,000+ jobs	Template for small-scale biogas networks in Nakhchivan, Karabakh, East Zangezur, Mil-Mughan
Brazil	Large-scale bioethanol from sugarcane (32.95 billion liters, 2023)	Projected +USD 2.6 billion GDP and 53,000 jobs from further expansion	Demonstrates rural economic impact achievable from a regionally appropriate energy crop
Sweden	Municipal waste-to-energy and recycling (4.1 million tonnes managed, 2023)	39% recycled, 59% converted to energy; minimal landfill residual	Model for converting Azerbaijan's food-waste feedstock base into energy and fertilizer outputs

Drawing on these four cases, three priorities emerge for Azerbaijan's biofuel and waste-management strategy. First, a policy framework that creates predictable, even if initially modest, demand for biofuel — following the logic of the U.S. Renewable Fuel Standard rather than its specific blending targets — would reduce investment risk for prospective bio-refinery operators. Second, decentralized, small-scale biogas infrastructure in agricultural regions, modeled on the German experience, is likely to be more appropriate to Azerbaijan's regional resource distribution than a small number of centralized facilities. Third, public-private partnerships that bring international technical expertise — a mechanism common to both the German and Swedish cases — could accelerate the development of Azerbaijan's waste-to-energy and biofuel-processing infrastructure without requiring the state to bear the full capital cost.

7. INVESTMENT POTENTIAL AND REGIONAL DEVELOPMENT CLUSTERS

Azerbaijan's national renewable energy targets provide the policy backdrop against which regional investment potential can be assessed. Under the "Azerbaijan 2030: National Priorities for Socio-Economic Development" strategy, the country aims to raise the share of renewable sources in electricity generation to approximately 30 percent by 2026 and toward 40 percent by 2030 (Ministry of Energy of the Republic of Azerbaijan, 2026). This ambition is being operationalized through a series of utility-scale projects: the 230-megawatt Garadagh solar plant, the largest solar facility in the Caspian region; the 240-megawatt Khizi-Absheron wind project developed jointly by ACWA Power and SOCAR; and the Bilasuvar and Neftchala solar projects, with capacities of 445 and 315 megawatts respectively, which reached financial close around COP29 and are projected to generate over 1.7 billion kilowatt-hours annually (Trend.az, 2026; World Economic Forum, 2026). SOCAR's renewable energy subsidiary, SOCAR Green, has committed approximately USD 2 billion to renewable investment, and the country's broader target envisions approximately 7 gigawatts of new renewable capacity by 2030, of which roughly 5 gigawatts are intended for export (Azernews, 2024).

Beyond these nationally reported figures, the authors' own regional assessment — summarized in Figure 5 — provides a more granular, technology-disaggregated estimate of investment potential across wind, solar, biogas, hydropower, clean petrochemicals and oleochemicals, and biofuel. This assessment, built on existing installed capacity, signed investment agreements, and an estimated additional investment potential by technology category, yields an aggregate investment potential on the order of USD 80 billion and an expected revenue potential on the order of USD 38 billion, with wind and solar accounting for the substantial majority of both figures and clean petrochemicals/oleochemicals representing the largest non-power contribution. These figures should be read as an internal planning estimate rather than a published government or multilateral forecast; they are presented here to illustrate the relative scale and technology composition of investment opportunity implied by Azerbaijan's existing capacity and signed agreements, and they would benefit from independent verification against future official data as Azerbaijan's renewable sector matures.

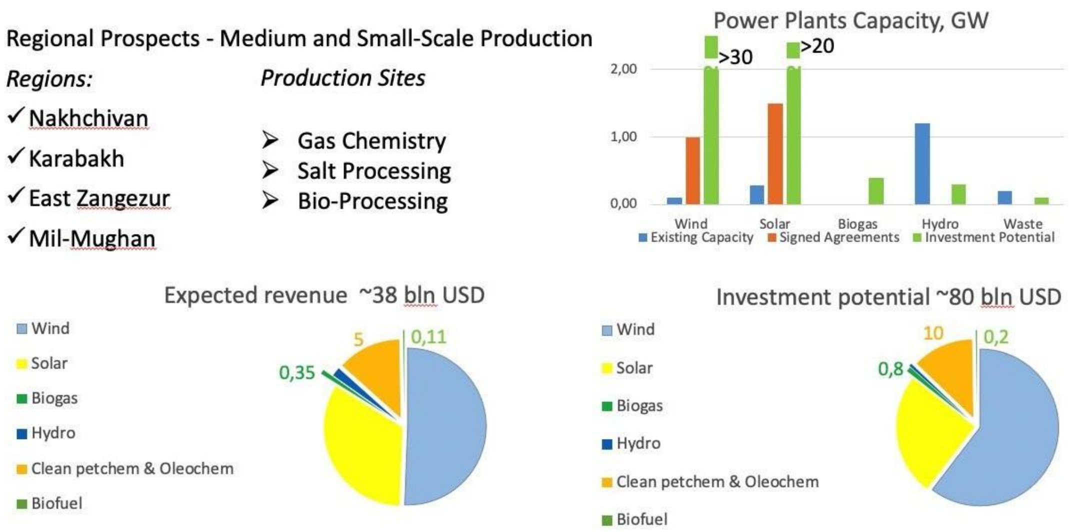

Figure 5. *Regional investment assessment (authors' estimate): power plant capacity by existing installed base, signed agreements, and investment potential (GW), with expected revenue (~USD 38 billion) and investment potential (~USD 80 billion) disaggregated by technology.*

Figure 6 presents the corresponding technology and non-energy product catalogue identified in this assessment — spanning biofuels, green hydrogen, green ammonia, mini-LNG, and biogas, alongside associated outputs such as organic fertilizers, bio-solvents, and soda ash — together with a comparative prioritization of candidate projects by environmental impact, payback period, contribution to sustainable development, and implementation timeline.

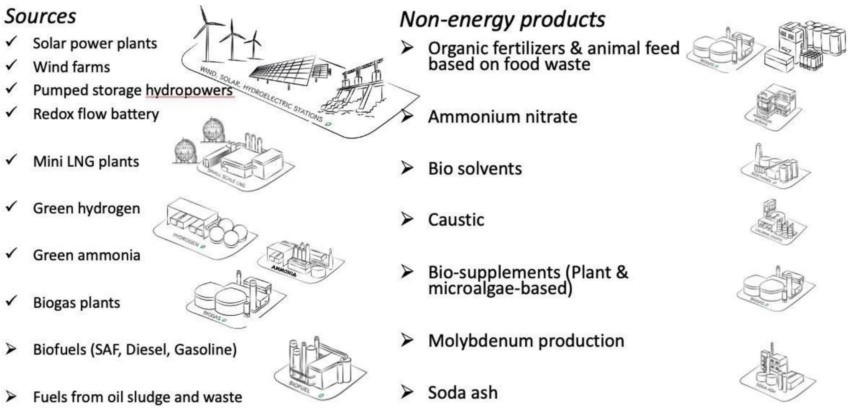

Figure 6a. *Technology and non-energy product catalogue: sources (solar, wind, hydropower, mini-LNG, green hydrogen and ammonia, biogas, biofuels) and associated non-energy products.*

Environmental impact	Payback period	Contribution to sustainable development	Implementation timeline	Comprehensive indicators
Biofuels (SAF, Diesel, Gasoline)	Biofuels (SAF, Diesel, Gasoline)	Solar power plants & wind farms	Biogas plant	I. Biofuels (SAF, Diesel, Gasoline)
Food waste based products	Mini LNG plants	Biofuels (SAF, Diesel, Gasoline)	Mini LNG plants	II. Food waste based products and Biogas plant
Solar power plants & wind farms	Molybdenum production	Pumped storage hydropowers	Biofuels (SAF, Diesel, Gasoline)	III. Solar power plants & wind farms
Pumped storage hydropowers	Ammonia & ammonium nitrate	Food waste based products	Solar power plants & wind farms	IV. Mini LNG plants
Biogas plant	Food waste based products	Mini LNG plants	Molybdenum production	V. Pumped storage hydropowers
Ammonia & ammonium nitrate	Biogas plant	Biogas plant	Pumped storage hydropowers	VI. Molybdenum production
Molybdenum production	Caustic and soda ash	Ammonia & ammonium nitrate	Caustic and soda ash	VII. Ammonia & ammonium nitrate & Caustic and soda ash
Mini LNG plants	Solar power plants & wind farms	Molybdenum production	Food waste based products	
Caustic and soda ash	Pumped storage hydropowers	Caustic and soda ash	Ammonia & ammonium nitrate	

Figure 6b. *Comparative prioritization of candidate projects by environmental impact, payback period, contribution to sustainable development, and implementation timeline.*

Regional development clusters represent a complementary mechanism for translating this investment potential into local economic outcomes. Mil-Mughan, together with the broader Karabakh and East Zangezur regions, has been identified in Azerbaijan's regional development planning as a priority area for renewable energy and biofuel production clusters, building on the agricultural feedstock base discussed in Section 4 and the post-conflict redevelopment priorities associated with these territories. Concentrating investment by region — rather than distributing it uniformly across the country — allows infrastructure, feedstock supply, and processing capacity to be co-located, which is consistent with the regional differentiation logic established in Section 3.

8. ENVIRONMENTAL AND SOCIAL IMPACTS

Azerbaijan's renewable energy initiatives connect most directly to two of the United Nations Sustainable Development Goals: SDG 7 (affordable and clean energy) and SDG 13 (climate action), alongside indirect contributions to SDG 8 (decent work and economic growth) through the rural employment effects discussed in Sections 6 and 7. This alignment is not merely rhetorical. Azerbaijan's State Agency for Renewable Energy Sources, under the Ministry of Energy, has completed a dedicated national Road Map for SDG 7, intended to provide a structured assessment of the country's progress and remaining gaps in the energy sector and to inform the country's Nationally Determined Contributions under the Paris Agreement (Report.az, 2026). This Road Map sits within the broader "Socio-Economic Development Strategy of the Republic of Azerbaijan for 2022–2026," which embeds renewable energy targets within a wider set of national development priorities, and within the country's participation in the UNDP-led Integrated SDG Insights process, which has highlighted green transformation as one of two priority dialogue areas for accelerating Azerbaijan's progress toward its national SDG commitments.

The social dimension of this transition is most directly visible in the regional employment effects associated with the biofuel, biogas, and renewable infrastructure projects discussed in Sections 6 and 7. Decentralized biogas and biofuel facilities in agricultural regions — following the rural employment patterns documented in Germany and Brazil (Section 6) — have the potential to create jobs in regions outside the capital, partially offsetting the historical concentration of energy-sector employment around Baku and the offshore hydrocarbon industry. At the same time, it should be acknowledged that Azerbaijan's overall share of renewable energy in total electricity generation has historically been small relative to its hydrocarbon-dominated energy mix, and that translating announced capacity targets and signed agreements into operating, revenue-generating, job-creating infrastructure remains an implementation challenge rather than a foregone outcome.

9. POST-COP29 OUTLOOK AND THE ROAD TO COP30

Azerbaijan's hosting of COP29 in Baku in November 2024 placed the country's energy transition strategy under sustained international attention. The principal outcome of the conference, formally known as the Baku Climate Unity Pact, centered on a new global climate finance goal: developed countries committed to mobilizing at least USD 300 billion annually by 2035 for climate action in developing countries, alongside a broader, non-binding call for USD 1.3 trillion annually from all sources, to be pursued through the "Baku to Belém Roadmap to 1.3T" (UNFCCC, 2025; Woodwell Climate Research Center, 2025). The conference also finalized the implementing rules for international carbon markets under Article 6 of the Paris Agreement, a technical outcome with direct relevance to any future Azerbaijani participation in carbon trading linked to the Carbon-to-Chem pathway discussed in Section 5. It should be noted that the finance outcome was met with considerable criticism from developing-country delegations, who viewed the USD 300 billion figure as insufficient relative to the USD 1.3 trillion figure they had sought, underscoring that COP29's outcomes were contested rather than uniformly endorsed.

Looking ahead to COP30 in Belém, Brazil, Azerbaijan's position shifts from host to a participant seeking to demonstrate the durability of the model outlined in this paper: a hydrocarbon-exporting economy pursuing region-specific renewable deployment while transforming its hydrocarbon sector through the Crude-to-Chem and Carbon-to-Chem pathways described in Section 5. The country's own sector planning identifies a range of topics it considers relevant to the COP29-to-COP30 transition, including the dynamics and drivers of energy transition, optimization of investment in ecological projects, carbon capture and storage technologies, and the harmonization of national fuel standards with international requirements (Figure 7).

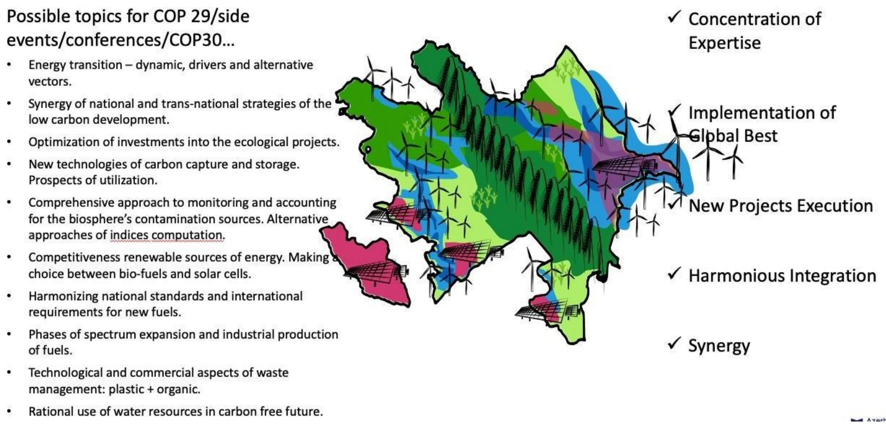

Figure 7. *Candidate topics for COP29/COP30 side events and conferences, mapped against Azerbaijan's regional renewable energy infrastructure: energy transition dynamics, investment optimization, carbon capture and storage, environmental monitoring methodologies, and harmonization of fuel standards.*

10. DISCUSSION

The preceding sections describe a model of energy transition that differs from the two dominant templates discussed in the broader literature: wholesale divestment from hydrocarbons, on one hand, and purely additive renewable deployment alongside an unchanged hydrocarbon sector, on the other. Azerbaijan's approach instead combines three elements simultaneously—regional differentiation of renewable technology choice (Sections 3–4), structural transformation of the hydrocarbon sector itself through the Crude-to-Chem and Carbon-to-Chem pathways (Section 5), and selective adoption of internationally tested biofuel and waste-management mechanisms (Section 6). This combination addresses, at least partially, the gap identified in Section 2: existing literature on energy transition in resource-rich economies has tended to treat renewable deployment and hydrocarbon-sector policy as separate domains, evaluated through separate fiscal or industrial-policy lenses (Behera et al., 2024; He et al., 2023), whereas the Azerbaijani case suggests that these domains are most usefully analyzed jointly, since the hydrocarbon sector's own transformation pathway directly shapes the economic case for renewable investment in the same regions.

The regional-differentiation literature (Zhuo et al., 2024) anticipates that green transformation outcomes vary across regions within the same country; the Azerbaijani case extends this insight by showing that the relevant unit of variation is not simply administrative region but technology-resource fit—wind and solar in coastal, infrastructure-rich areas; biofuel and biogas in agricultural, infrastructure-light areas. This distinction matters because it implies that policy instruments transferable from international experience (Section 6) cannot be applied uniformly across Azerbaijan's territory; the German decentralized-biogas model, for instance, is relevant to Nakhchivan and Karabakh but not directly to the wind/solar profile of the Absheron Peninsula.

At the same time, several limitations of the evidence presented here should be acknowledged directly, rather than treated as incidental. First, the investment potential figures discussed in Section 7 — both the nationally announced capacity targets and the authors' own technology-disaggregated estimate of roughly USD 80 billion in investment potential and USD 38 billion in expected revenue — are planning estimates rather than independently audited forecasts, and their realization depends on factors (financing conditions, regulatory implementation, and global commodity prices) outside the scope of this paper. Second, the paper does not provide a quantitative economic model of the regional employment or GDP effects analogous to the Brazilian ethanol-expansion modeling cited in Section 6; such modeling, calibrated to Azerbaijan-specific data, would substantially strengthen the empirical basis for the claims made in Sections 7 and 8. Third, the conceptual technology pathways proposed in Section 3 (the natural-gas and biomass sequencing framework) have not yet been tested against region-level feasibility data, such as actual feedstock availability, transportation infrastructure, or grid connection capacity in Nakhchivan, Karabakh, East Zangezur, or Mil-Mughan specifically.

These limitations do not undermine the central argument of the paper, but they do clarify its appropriate scope: this is a conceptual and descriptive account of how Azerbaijan's regionally differentiated, infrastructure-synergistic model is structured and what international evidence supports its component parts, rather than a quantitative impact assessment of the model's likely outcomes. The next logical step in this research agenda, outlined further in Section 11, is precisely this kind of quantitative validation.

11. CONCLUSION

This paper has examined Azerbaijan's energy transition as a regionally differentiated strategy that integrates renewable energy deployment with the structural transformation of the country's hydrocarbon sector. Drawing on Azerbaijan's exceptional climatic diversity, the analysis showed how distinct regions — the wind- and solar-rich Absheron Peninsula and Caspian coast, and the agriculturally rich Nakhchivan, Karabakh, East Zangezur, and Mil-Mughan — support different renewable technology pathways rather than a single national approach. This regional logic is complemented by an evolving model of hydrocarbon-sector transformation, captured in the Crude-to-Chem and Carbon-to-Chem frameworks, through which existing refining infrastructure is redirected toward chemical production rather than abandoned outright. Benchmarking against the United States, Germany, Brazil, and Sweden identified specific, transferable mechanisms — policy-mandated demand creation, decentralized rural infrastructure, energy-crop cultivation, and municipal waste-to-energy conversion — that map onto distinct components of Azerbaijan's regional strategy.

The paper's central contribution is to show that, for a hydrocarbon-exporting economy with substantial internal climatic diversity, "energy transition" is not usefully analyzed as a single national trajectory. It is better understood as a portfolio of regionally specific interventions, linked together by a shared transformation of the hydrocarbon sector's economic function. This framing has practical relevance beyond Azerbaijan: other resource-rich states with comparable internal geographic diversity — and a comparable stock of hydrocarbon-sector capital that cannot easily be written off — may find more traction in a regionally differentiated, infrastructure-synergistic approach than in either uniform national renewable mandates or wholesale hydrocarbon divestment.

The findings of this paper complement recent Azerbaijan-focused studies on renewable energy forecasting, smart-grid development, financial institutions, and the clean energy–carbon emissions nexus (Hasanov, 2024; Gurbanov and Mammadli, 2024; Kartal and Pata, 2024; Musayev, 2024). While previous research has mainly examined specific technological, financial, or environmental dimensions of Azerbaijan's energy transition, this paper contributes by proposing a regionally differentiated and infrastructure-synergistic framework. In this sense, Azerbaijan's transition should not be interpreted only as an increase in renewable energy capacity but as a broader transformation process in which regional resource endowments, hydrocarbon infrastructure, financial mechanisms, and environmental objectives interact with one another.

As discussed in Section 10, the analysis presented here is best understood as a conceptual and descriptive account rather than a quantitative impact assessment, and its limitations point directly to a research agenda. Future work should prioritize three directions: first, quantitative economic modeling—along the lines of the input-output modeling used to assess Brazilian ethanol expansion—calibrated specifically to Azerbaijan's regional economies; second, primary feasibility assessment of feedstock availability, transportation infrastructure, and grid capacity in Nakhchivan, Karabakh, East Zangezur, and Mil-Mughan; and third, systematic tracking of the gap between Azerbaijan's announced renewable capacity targets and signed agreements, on one hand, and operational, revenue-generating capacity, on the other, as the country's renewable sector matures toward its 2030 targets. As Azerbaijan moves from COP29 host to COP30 participant, the extent to which it can close that gap will determine whether the regional model described in this paper functions as a durable template for other resource-rich economies, or as an aspirational framework that has yet to be tested at scale.

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REFERENCES

Aliyev, F., Eylasov, N., Gasim, N., & Şahinler, A. N. (2024). Impact of nuclear energy consumption on CO_2 emissions in South Korea: Evidence from Fourier Bootstrap ARDL Bound Test. Journal of Sustainable Development Issues, 2(1), 51–66. https://doi.org/10.62433/josdi.v2i1.23

Azernews. (2024, May 10). *Azerbaijan's green energy revolution: comprehensive approach towards sustainability.* https://www.azernews.az/analysis/225756.html

Behera, P., Behera, B., & Sethi, N. (2024). Assessing the impact of fiscal decentralization, green finance, and green technology innovation on renewable energy use in European Union countries: What is the moderating role of political risk? *Renewable Energy, 229*, 120715.

ETIP Bioenergy (European Technology and Innovation Platform). (2020). *Biomethane* [Bioenergy fact sheet].

Gasimli, V., Huseyn, R., & Huseynov, R. (2024). Economy-wide and environmental benefits of green energy development in oil-rich countries: Evidence from Azerbaijan. Economic Annals, 69(241), 41–64. https://doi.org/10.2298/EKA2441041G

Gasimli, V., Huseyn, R., & Suleymanov, A. (2025). Repositioning oil exporters for the Green Energy Transition: The case of Azerbaijan. Polityka Energetyczna – Energy Policy Journal, 28(4), 181–200. https://doi.org/10.33223/epj/209658

German Biogas Association (Fachverband Biogas). (2026). *Biogas Association presents current industry figures* [Press release]. https://www.biogas.org/en/media/press/details/biogas-association-presents-current-industry-figures

Gurbanov, S., & Mammadli, L. (2024). Smart Grid and Electricity Security: Case of Azerbaijan as a Resource-Rich Country. Journal of Sustainable Development Issues, 2(1), 21–41. https://doi.org/10.62433/josdi.v2i1.22

Hamidova, L., Huseynov, A., & Samedova, E. (2022). Challenges in implementing renewable energy sources in Azerbaijan. International Journal of Energy Economics and Policy, 12(6), 441–446. https://doi.org/10.32479/ijeep.13636

Hasanov, R. (2024). Solar Energy Production in Azerbaijan: Forecast Analysis Using ARIMA Model. Journal of Sustainable Development Issues, 2(1), 11–20. https://doi.org/10.62433/josdi.v2i1.18

He, J., Iqbal, W., & Su, F. (2023). Nexus between renewable energy investment, green finance, and sustainable development: Role of industrial structure and technical innovations. *Renewable Energy, 210*, 715–724.

Karacan, R., Mukhtarov, S., Bariş, İ., İşleyen, A., & Yardımcı, M. E. (2021). The impact of oil price on transition toward renewable energy consumption? Evidence from Russia. Energies, 14(10), 2947. https://doi.org/10.3390/en14102947

Kartal, M. T., & Pata, U. K. (2024). Do Depth, Accessibility, and Efficiency of Financial Institutions Matter for Renewable Energy Development in Azerbaijan? Journal of Sustainable Development Issues, 2(1), 42–50. https://doi.org/10.62433/josdi.v2i1.24

Ministry of Energy of the Republic of Azerbaijan. (2026). *The use of renewable energy sources in Azerbaijan.* https://minenergy.gov.az/en/alternativ-ve-berpa-olunan-enerji/azerbaycanda-berpa-olunan-enerji-menbelerinden-istifade

Mukhtarov, S., Mikayilov, J. I., Humbatova, S., & Muradov, V. (2020). Do high oil prices obstruct the transition to renewable energy consumption? Sustainability, 12(11), 4689. https://doi.org/10.3390/su12114689

Mukhtarov, S., Aliyev, J., & Maharramli, S. (2022). Does institutional quality affect renewable energy in oil-rich developing countries? Evidence from Azerbaijan. In H. Dinçer & S. Yüksel (Eds.), Circular Economy and the Energy Market (pp. 173–184). Springer, Cham. https://doi.org/10.1007/978-3-031-13146-2_14

Mukhtarov, S., Mikayilov, J. I., Maharramov, S., Aliyev, J., & Suleymanov, E. (2022). Higher oil prices, are they good or bad for renewable energy consumption: The case of Iran? Renewable Energy, 186, 411–419. https://doi.org/10.1016/j.renene.2021.018590

Mukhtarov, S. (2024). Oil prices and the renewable energy transition: Empirical evidence from China. Utilities Policy, 91, 101840. https://doi.org/10.1016/j.jup.2024.101840

Mukhtarov, S., & Aliyev, J. (2024). The role of institutional quality in the transition to renewable energy consumption in the case of an oil-rich country. In S. Dincer & S. Yuksel (Eds.), Renewable Energy Economics and Sustainable Development. Elsevier.

Musayev, G. (2024). The Impact of Dirty and Clean Energy Consumption on Carbon Emissions in Azerbaijan. Journal of Sustainable Development Issues, 2(2), 76–88. https://doi.org/10.62433/josdi.v2i2.27

Nasirov, I. R. (2020). Upgrade of the oil refining dialectics. *Oil and Gas Vertical*, (17), 20–26.

Nasirov, I. R. (2023). Petrochemicals — Oil and gas processing: the new map. *Oil Review Middle East.* https://oilreviewmiddleeast.com/petrochemicals/oil-and-gas-processing-the-new-map

Report.az. (2026). *Javid Abdullayev: Development of Azerbaijan's Road Map for SDG 7 completed.* https://report.az/en/amp/energy/javid-abdullayev-development-of-azerbaijan-s-road-map-for-sdg-7-completed

Sweden.se (Swedish Institute). (2025). *Swedish recycling and beyond.* https://sweden.se/climate/sustainability/swedish-recycling-and-beyond

Trend.az. (2026). *Azerbaijan strengthens its position as clean energy hub through green corridors — SOCAR.* https://www.trend.az/business/energy/4139396.html

United Nations Framework Convention on Climate Change (UNFCCC). (2025). *Outcomes of the Baku Climate Change Conference.* https://unfccc.int/cop29/auvs

U.S. Department of Agriculture, Foreign Agricultural Service. (2023). *Brazil: Biofuels annual* (Report No. BR2023-0018). https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels+Annual_Brasilia_Brazil_BR2023-0018

U.S. Environmental Protection Agency. (2022). *Overview for Renewable Fuel Standard Program.* https://www.epa.gov/renewable-fuel-standard-program

Woodwell Climate Research Center. (2025). *Key COP29 outcomes.* https://www.woodwellclimate.org/key-cop29-outcomes/

World Bank, & Asian Development Bank. (2021). *Climate risk country profile: Azerbaijan.* http://hdl.handle.net/10986/36383

World Economic Forum. (2026). *Traditional producers are key to Azerbaijan's energy transition.* https://www.weforum.org/stories/2026/01/why-traditional-energy-producers-must-be-part-of-azerbaijan-green-transition/

Zhuo, C., Luo, K., Song, Y., Dai, L., & Liu, Y. (2024). Regional coordinated development and green transformation: Evidence from major national strategic zones. *Economic Analysis and Policy, 81*, 1290–1307.