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Beyond Carbon Reduction and the Green Transition Dilemma in Reconciling Renewable Energy Expansion with Nature Conservation

Alief Muhammad[1*], Hartawan Abdillah[1], Mas Ahmad Baihaqi[1], Tamam Asrori[1]

[1] Faculty of Engineering and Informatic, Panca Marga University, 67271, **Indonesia**

* aliefmuhammad@upm.ac.id

Abstract

The global energy transition has accelerated the deployment of renewable energy as a primary strategy for reducing greenhouse gas emissions and achieving climate targets. However, evaluating sustainability predominantly through carbon reduction may overlook significant ecological consequences associated with renewable energy expansion, including land-use change, biodiversity disturbance, critical mineral extraction, resource dependency, and ecosystem degradation. This article examines the emerging green transition dilemma in which efforts to mitigate climate change may generate new environmental pressures when renewable energy development is pursued without adequate ecological planning and resource governance. It argues that sustainability should not be determined solely by whether an energy source is classified as renewable or fossil-based, but by its overall environmental and social performance throughout its lifecycle. To address this limitation, the article proposes an Ecological Energy Transition Framework consisting of four interconnected dimensions: carbon performance, ecological integrity, resource sustainability, and energy security with social responsibility. The framework shifts the energy transition paradigm from a technology- and source-centered approach toward an ecosystem-centered and performance-based perspective. Renewable energy remains essential for global decarbonization, but its expansion should be accompanied by biodiversity protection, environmentally responsible spatial planning, sustainable mineral governance, circular resource management, and consideration of energy accessibility and affordability. Ultimately, the article argues that renewable energy should be understood as a pathway toward sustainability rather than sustainability itself. A genuinely green energy transition must simultaneously reduce lifecycle environmental impacts, preserve ecological

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integrity, ensure responsible resource use, and maintain reliable and equitable energy services.

Keywords: ecological energy transition, renewable energy, green transition, biodiversity conservation, critical minerals, ecological integrity, energy sustainability.

1. Introduction

The global energy system is currently undergoing a fundamental transformation driven by the dual challenges of climate change mitigation and increasing energy demand. Global primary energy consumption has continued to rise alongside economic growth, industrialization, and population expansion [1]. According to the Energy Institute Statistical Review of World Energy 2024, global primary energy consumption reached approximately 620 exajoules (EJ) in 2023, representing an increase of around 2% compared with 2022 and the highest level recorded in modern history [2]. Despite the rapid development of low-carbon technologies, fossil fuels continue to dominate the global energy structure. In 2023, coal, oil, and natural gas collectively accounted for approximately 81% of global primary energy consumption, demonstrating that the world economy remains structurally dependent on carbon-intensive energy sources.

This dependence has significant implications for global climate stability [3]. The International Energy Agency (IEA) reported that energy-related carbon dioxide (CO_2) emissions reached a record level of approximately 37.2 gigatonnes ($GtCO_2$) in 2023, representing an increase of 1.1% compared with 2022 [4]. The energy sector remains the largest contributor to anthropogenic greenhouse gas emissions, accounting for approximately 73% of global greenhouse gas emissions when emissions from electricity and heat generation, transport, industry, buildings, and fuel production are combined [5]. Furthermore, the Intergovernmental Panel on Climate Change (IPCC) emphasizes that limiting global warming to 1.5°C above pre-industrial levels requires global greenhouse gas emissions to decline by approximately 43% by 2030 compared with 2019 levels, creating substantial pressure for rapid transformation of the global energy system [6]. Under these circumstances, renewable energy has become a central strategy in achieving climate mitigation targets and advancing global net-zero emission commitments.

The transition toward renewable energy has accelerated significantly over the last decade. According to the International Renewable Energy Agency (IRENA), global renewable energy capacity reached approximately 4,448 GW by the end of 2024, representing an annual addition of around 585 GW, the largest yearly increase ever recorded [7]. Solar photovoltaic (PV) technology has become the dominant contributor to renewable expansion, accounting for approximately 75% of newly installed renewable capacity in 2024 [8]. In parallel, investment flows toward clean energy technologies have expanded rapidly. The IEA World Energy Investment 2024 reported that global clean energy investment exceeded USD 2 trillion in 2024, representing almost two-thirds of total global energy investment and approximately double the investment allocated to fossil fuel supply [9]. These developments indicate that renewable energy has moved from an alternative technology toward a central component of global energy strategies.

However, the rapid expansion of renewable energy infrastructure introduces a critical sustainability challenge that extends beyond carbon reduction. Although renewable technologies generally produce substantially lower operational emissions compared with fossil fuels, their deployment requires extensive material resources, land availability, and industrial supply chains. For example, the lifecycle greenhouse gas emissions of solar photovoltaic systems remain significantly lower than fossil fuel technologies, with median values of approximately 40–50 gCO_2-equivalent/kWh, compared with approximately 820 gCO_2-equivalent/kWh for coal-fired electricity generation based on lifecycle assessments compiled by the IPCC [10]. Nevertheless, carbon performance alone does not fully represent environmental sustainability because renewable infrastructure can generate other ecological pressures, including land-use change, biodiversity disturbance, and increasing demand for critical minerals.

The emerging contradiction is particularly evident in the material requirements of the green transition. According to the IEA Critical Minerals Market Review 2024, clean energy technologies require substantially higher mineral inputs than conventional energy systems [11]. For instance, electric vehicles require approximately six times more mineral resources than conventional vehicles, while offshore wind projects require significantly larger quantities of copper, nickel, rare earth elements, and other critical materials compared with fossil-based electricity generation [12]. The IEA further projects that demand for lithium could increase by more than fivefold by 2030 under current policy scenarios, driven primarily by battery storage and electric mobility expansion [13]. This growing mineral dependency raises concerns regarding mining-related deforestation, water contamination, ecosystem degradation, and social conflicts in resource-producing regions.

Therefore, the dominant measurement of energy transition success based primarily on carbon reduction presents a conceptual limitation. Existing assessments commonly emphasize indicators such as renewable energy share, emission reduction rates, and energy efficiency improvements, but ecological indicators such as biodiversity loss, ecosystem integrity, land transformation, and resource sustainability remain comparatively underrepresented. The United Nations

Environment Programme (UNEP) reported that approximately one million species are currently threatened with extinction due to human activities, with land-use change and resource extraction identified among the major drivers of biodiversity decline [14]. Consequently, a fundamental question emerges: can an energy transition be considered truly sustainable if carbon emissions decline while ecological degradation increases?

2. Renewable Energy Expansion and the Hidden Ecological Cost

The global acceleration of renewable energy deployment represents a critical milestone in addressing climate change. Renewable technologies have demonstrated substantially lower operational greenhouse gas emissions compared with fossil-based energy systems, making them central to global decarbonization strategies [15]. However, the rapid expansion of renewable infrastructure introduces a less discussed dimension of sustainability: the ecological footprint associated with land transformation, material extraction, and ecosystem disturbance. The assumption that renewable energy is inherently environmentally harmless reflects a narrow interpretation of sustainability based primarily on carbon reduction. In reality, renewable energy systems require extensive physical infrastructure, including solar farms, wind turbines, hydropower facilities, transmission networks, and battery storage systems, all of which depend on land availability and mineral resources [16]. Therefore, the transition toward renewable energy creates a new sustainability challenge: reducing carbon emissions while preventing ecological degradation.

Table 1 summarizes lifecycle greenhouse gas emissions from major electricity generation technologies.

Energy Technology	Median Lifecycle Emissions (gCO_2-eq/kWh)	Main Environmental Concern
Coal power	~820	CO_2 emissions, air pollution, mining impacts
Natural gas	~490	Methane leakage, fossil dependency
Biomass	~230	Land competition, deforestation risk
Hydropower	~24	River ecosystem alteration
Solar photovoltaic	~48	Land occupation, material demand, waste
Wind power	~11	Land use, material extraction, biodiversity risks

Source: IPCC AR6 Working Group III (2022) [10]

2.1 Renewable Energy Is Not Impact-Free

Although renewable energy technologies produce significantly lower lifecycle emissions than fossil fuel systems, they are not environmentally impact-free. The environmental performance of energy technologies must be assessed through a life-cycle perspective, considering raw material extraction, manufacturing, construction, operation, and end-of-life management [17]. According to the IPCC Sixth Assessment Report, lifecycle greenhouse gas emissions from renewable technologies remain considerably lower than fossil fuel-based electricity generation [6], [18].

However, the difference between renewable and fossil technologies does not eliminate environmental impacts associated with material consumption and infrastructure development, as shown in **Table 1**.

The data demonstrate that renewable technologies provide substantial carbon advantages. Solar PV produces approximately 94% lower lifecycle emissions than coal, while wind energy produces approximately 99% lower emissions than coal-based electricity generation. However, carbon performance represents only one environmental dimension. For example, solar photovoltaic deployment requires large-scale material inputs including silicon, silver, aluminum, glass, and copper [19]. The expansion of utility-scale solar farms also requires significant land areas, creating potential conflicts with agricultural production and natural ecosystems [20]. Similarly, wind energy requires steel, concrete, copper, and rare earth elements, particularly for offshore wind turbine components. According to the International Energy Agency (IEA), clean energy technologies require substantially higher quantities of mineral resources compared with conventional energy technologies [9], [21]. An electric vehicle, for example, requires approximately six times more mineral inputs than a conventional internal combustion engine vehicle, while renewable power systems require extensive quantities of copper, lithium, nickel, and rare earth elements [22]. This indicates that the environmental challenge of renewable energy is shifting from carbon emissions during operation toward material intensity and ecological pressure throughout the supply chain.

2.2 Land Use and Biodiversity Conflict

One of the most significant ecological challenges associated with renewable energy expansion is competition for land resources. Unlike fossil fuel plants that often have concentrated infrastructure footprints, renewable energy systems such as solar and wind farms require extensive spatial distribution because energy generation depends on natural conditions. Solar photovoltaic systems represent a clear example of this challenge. Although solar technology has among the lowest lifecycle emissions, large-scale deployment may require substantial land conversion. Estimates indicate that utility-scale solar PV generally requires approximately 1–10 hectares per MW of installed capacity, depending on technology type, geographical location, and project design. The global expansion of solar capacity has increased this concern. According to IRENA, global solar PV capacity exceeded 1,400 GW by 2024, making solar the largest contributor to renewable capacity growth [7], [23]. While this expansion contributes significantly to emission reduction, inappropriate site selection may result in habitat fragmentation and biodiversity decline.

The biodiversity implications are particularly important because land-use change remains one of the dominant drivers of global ecosystem degradation. The United Nations Environment Programme (UNEP) reported that approximately one million species are currently threatened with extinction, with land-use change identified as one of the primary causes of biodiversity loss [14], [24]. The ecological trade-off can be summarized as seen in **Table 2**. The implication is not that renewable energy should be restricted, but rather that renewable deployment requires ecological planning. A renewable energy project constructed on degraded land, industrial areas, rooftops, or low ecological-value areas produces a fundamentally different environmental outcome compared with projects located in forests, wetlands, or biodiversity hotspots [25]. Therefore, the central question is not whether renewable energy is environmentally beneficial, but whether renewable energy expansion occurs under ecological governance principles.

Table 2. Potential Environmental Trade-offs of Renewable Energy Expansion

Renewable Technology	Climate Benefit	Potential Ecological Impact
Solar PV	Reduces fossil electricity emissions by >90% compared with coal	Habitat conversion, land competition, photovoltaic waste.
Wind Energy	Lifecycle emissions ~11 gCO_2-eq/kWh	Bird and bat collision risks, landscape fragmentation.
Hydropower	Low operational emissions	River fragmentation, biodiversity disruption, ecosystem alteration.
Biomass	Renewable carbon cycle potential	Deforestation risk, food-energy competition.
Battery Storage	Enables renewable integration	Increased mineral extraction pressure.

Sources: IRENA (2025) [7]; IPCC (2022) [10]; UNEP (2022) [14]

2.3 Critical Mineral Dependency

Beyond land-use conflicts, renewable energy expansion creates a growing dependency on critical minerals. Modern clean energy technologies require significant quantities of minerals that were previously less important in conventional energy systems. The IEA Global Critical Minerals Outlook 2024 highlights that mineral demand for clean energy technologies is increasing rapidly [11], [26], as shown in **Table 3**. Under the Net Zero Emissions by 2050 scenario, demand for critical minerals is projected to increase substantially, with lithium experiencing the fastest growth due to electric vehicle and energy storage demand. Lithium demand could increase approximately nine times by 2040 compared with current levels under the IEA's Net Zero Scenario. The environmental challenge emerges because mineral extraction frequently occurs in ecologically sensitive regions. Lithium extraction in South America, nickel mining in Indonesia, and cobalt mining in the Democratic Republic of Congo demonstrate that the green transition may generate new environmental and social pressures if mineral governance is weak. The IEA also highlights that critical mineral supply chains remain geographically concentrated. For lithium, approximately 85% of refining capacity in

2030 is expected to remain concentrated in the top three refining countries, creating both geopolitical and sustainability risks [9].

Table 3. presents projected mineral demand growth associated with the energy transition.

Mineral	Main Application	Projected Demand Trend
Lithium	Battery storage and electric vehicles	Increase ~9 times by 2040 (NZE scenario)
Graphite	Battery anodes	Nearly 4 times increase by 2040
Nickel	Battery cathodes	Approximately double by 2040
Cobalt	Battery materials	Approximately double by 2040
Copper	Electricity networks and electrification	Largest absolute volume growth

Source: International Energy Agency (IEA) [9], Global Critical Minerals Outlook 2024 [11]

3. The Fossil Energy Paradox and Environmental Management

The global transition toward renewable energy is often framed as a straightforward replacement of fossil fuels with cleaner alternatives. However, this perspective overlooks the complex reality that fossil energy remains deeply embedded within global economic systems, particularly in emerging economies where energy demand continues to increase. Although fossil fuels represent the primary source of greenhouse gas emissions, their continued utilization reflects challenges related to energy security, affordability, infrastructure dependency, and industrial development [27]. Therefore, the central challenge of energy transition is not simply eliminating fossil fuels immediately, but managing a gradual transformation while minimizing environmental damage during the transition period.

The fossil energy paradox emerges from this contradiction: fossil fuels are environmentally harmful due to their contribution to climate change, yet they continue to provide energy reliability, economic stability, and industrial capacity for billions of people [28]. Consequently, sustainability should not be evaluated solely based on the type of energy source, but also on the governance systems, technological controls, and environmental management practices applied throughout the energy lifecycle.

Table 4. Global Primary Energy Consumption by Source (2023)

Energy Source	Share of Global Primary Energy Consumption	Approximate Energy Contribution
Oil	31.7%	~197 EJ
Coal	26.5%	~164 EJ
Natural Gas	23.3%	~145 EJ
Renewable Energy	~14%	~87 EJ
Nuclear Energy	~4%	~25 EJ

Source: Energy Institute Statistical Review of World Energy (2024) [2]

3.1 Fossil Energy Remains a Reality

Despite unprecedented growth in renewable energy deployment, fossil fuels continue to dominate the global energy system. According to the Energy Institute Statistical Review of World Energy 2024, as shown in **Table 4**, [2], [29], fossil fuels accounted for approximately 81% of global primary energy consumption in 2023, consisting of oil (31.7%), coal (26.5%), and natural gas (23.3%). Meanwhile, renewable energy sources, including wind, solar, hydro, geothermal, and biomass, accounted for approximately 14% of global primary energy consumption. This dependency is particularly significant because global energy demand continues to increase. In 2023, global primary energy consumption reached approximately 620 exajoules (EJ), representing the highest level ever recorded. The increase was driven primarily by economic growth, industrial expansion, population growth, and rising electricity demand, especially in developing economies.

Table 5. Global Electricity Generation Mix (2023)

Electricity Source	Share of Global Electricity Generation
Coal	~35%
Natural Gas	~22%
Hydropower	~14%
Nuclear	~9%
Solar PV	~6%
Wind	~7%
Other Renewables	~3%

Source: International Energy Agency (IEA) [9]

The continued role of fossil fuels is particularly evident in electricity generation. According to the International Energy Agency (IEA), as shown in **Table 5**, fossil fuels generated approximately 60% of global electricity in 2023, while renewable sources generated around 30% [9], [30]. Coal remained the largest source of electricity generation globally, contributing approximately 35% of global electricity production. The persistence of fossil energy is especially pronounced in developing economies. Many countries continue to rely on coal, oil, and natural gas because these resources provide dispatchable electricity, industrial fuel supply, and relatively established infrastructure. For example, according to the IEA World Energy Outlook 2023, energy demand growth until 2030 is expected to come primarily from emerging and developing economies, where affordability and energy access remain major policy priorities [9], [31]. This reality creates a policy dilemma. Rapid fossil fuel elimination without sufficient alternatives may threaten energy security and economic development, while continued fossil dependence increases climate risks. Therefore, the transition pathway requires a balance between reducing emissions and maintaining reliable energy systems.

3.2 Comparing Energy Source and Environmental Governance

The conventional debate regarding energy transition often assumes that renewable energy is automatically sustainable while fossil energy is inherently unsustainable. However, this perspective does not fully consider the role of environmental governance, technological improvement, and lifecycle management. Environmental impacts are determined not only by the energy source but also by how energy systems are planned, regulated, and managed. For example, uncontrolled fossil fuel exploitation generates severe environmental consequences through carbon emissions, air pollution, and ecosystem destruction [32]. However, renewable energy projects developed without ecological considerations may also generate environmental conflicts through land conversion, mineral extraction, and biodiversity impacts. The relationship between energy source and sustainability can therefore be represented through an integrated governance perspective.

Table 6. Comparison Between Energy Sources and Environmental Governance

Energy System	Carbon Impact	Ecological Impact	Governance Challenge
Conventional fossil energy without environmental control	Very high emissions (~820 gCO_2/kWh for coal)	Air pollution, mining damage, ecosystem degradation	Emission reduction and pollution control
Fossil energy with advanced environmental management	Reduced but still significant emissions	Lower local pollution through technology improvement	Carbon capture, efficiency improvement, methane reduction
Renewable energy without ecological planning	Very low operational emissions	Land conversion, biodiversity disturbance, mineral pressure	Site selection and lifecycle management
Renewable energy with ecological governance	Very low emissions	Reduced ecosystem impact	Circular economy, biodiversity protection, responsible mining

Sources: IEA (2024) [9]; IPCC AR6 WGIII (2022) [10]; UNEP (2022) [14]

The importance of governance is particularly evident in fossil energy management. According to the IEA Global Methane Tracker 2024, as shown in **Table 6**, the fossil fuel sector contributes approximately 40% of anthropogenic methane emissions, with oil and gas operations representing a major source [9], [33]. However, methane emissions can be significantly reduced through improved monitoring, leak detection, and operational management. The IEA estimates that approximately 75% of methane emissions from fossil fuel operations could be reduced using existing technologies, demonstrating that governance and technology significantly influence environmental outcomes. Similarly, carbon capture, utilization, and storage (CCUS) represents another pathway for reducing fossil fuel emissions. According to the Global CCS Institute 2024, global operational carbon capture capacity reached approximately 50 million tonnes of CO_2 per year, although this remains small compared with global energy-sector emissions exceeding 37 billion tonnes of CO_2 annually [9], [34]. This indicates that technological solutions can contribute to emission reduction but cannot replace the fundamental need for energy system transformation. The comparison demonstrates that sustainability cannot be defined exclusively by whether an energy source is renewable or fossil-based. Instead, sustainability depends on the interaction between energy characteristics, environmental governance, technological innovation, and ecological responsibility.

4. Toward an Ecological Energy Transition Framework

4.1 Redefining Green Energy Beyond Energy Source Classification

The current global energy transition has largely been shaped by a source-based classification, where renewable energy is considered environmentally preferable while fossil energy is regarded as inherently unsustainable [35]. This classification has accelerated renewable energy deployment and contributed significantly to global decarbonization efforts. However, such a perspective provides an incomplete understanding of sustainability because the environmental performance of an energy system cannot be determined solely by whether the energy source is renewable or non-renewable. Renewable energy technologies demonstrate significant advantages in reducing greenhouse gas emissions. However, their environmental performance depends on multiple factors, including land requirements, material intensity, ecosystem impacts, and end-of-life management. Similarly, fossil energy systems remain major contributors to global emissions, but technological improvements such as higher efficiency, methane leakage reduction, carbon capture and storage (CCS), and stricter environmental governance can reduce their environmental footprint compared with conventional fossil energy practices [1]. Therefore, this article proposes that the definition of green energy should move beyond a categorical approach toward a performance-based environmental framework. Under this perspective, energy should not be classified as green solely because it originates from renewable sources, but because it demonstrates the ability to minimize environmental impacts throughout its lifecycle while maintaining energy reliability and social benefits [36]. The fundamental question is no longer: "Is this energy renewable or fossil-based?" but rather: "How effectively can this energy system provide human energy needs while maintaining ecological integrity?"

4.2 The Ecological Energy Transition Framework

The limitations of the conventional energy transition paradigm indicate the need for a broader framework that evaluates energy systems beyond their source classification. The proposed Ecological Energy Transition Framework is based on the assumption that sustainability cannot be determined solely by whether an energy source is renewable or fossil-based, but by how effectively the entire energy system minimizes environmental impacts while fulfilling human energy needs. Under this framework, renewable energy remains a fundamental component of climate mitigation; however, its deployment must be integrated with ecological protection, responsible resource management, and social considerations. The framework consists of four interconnected dimensions: carbon performance, ecological integrity, resource sustainability, and energy security with social responsibility. These dimensions represent a transition from a technology-centered approach, which prioritizes replacing fossil fuels with renewable technologies, toward an ecosystem-centered approach, where energy systems are evaluated based on their total environmental performance throughout the lifecycle. This perspective recognizes that every energy pathway involves environmental trade-offs, and therefore the objective of sustainability is not to identify an absolutely impact-free energy source, but to develop energy systems that achieve the lowest possible environmental burden while maintaining reliability and accessibility.

4.3 Four Dimensions of Ecological Energy Transition Framework

A. Carbon Performance: Beyond Emission Reduction

The first dimension of the Ecological Energy Transition Framework is carbon performance, which remains a fundamental component of sustainable energy development due to the urgent need to mitigate climate change. However, carbon performance should not be interpreted solely through direct operational emissions, but through a comprehensive lifecycle perspective that considers emissions generated from resource extraction, manufacturing, transportation, operation, and end-of-life management [37]. Renewable energy technologies generally provide significant advantages in reducing greenhouse gas emissions compared with conventional fossil fuel systems. Nevertheless, their total environmental performance depends on the entire supply chain. For example, solar photovoltaic systems produce substantially lower lifecycle emissions than coal-based electricity generation, but their environmental footprint is influenced by the energy intensity of manufacturing processes, material extraction, and waste management [38]. Similarly, fossil energy systems may reduce their environmental impact through technological improvements such as higher efficiency, methane emission control, carbon capture and storage (CCS), and improved environmental governance, although their long-term sustainability remains constrained by carbon dependency [39]. Therefore, carbon performance within this framework does not seek to classify energy sources as inherently clean or dirty, but evaluates how effectively an energy system reduces environmental pressure relative to the energy services it provides.

The key indicators include lifecycle greenhouse gas emissions, methane leakage intensity, carbon intensity, and overall energy efficiency.

B. Ecological Integrity: Making Nature a Core Parameter

The second dimension emphasizes that environmental protection should become a central criterion in energy decision-making rather than a secondary consideration. The conventional transition paradigm often evaluates energy systems primarily through their contribution to emission reduction, while ecological consequences such as biodiversity loss, land transformation, and ecosystem disruption receive comparatively less attention [40]. However, the expansion of energy infrastructure inevitably interacts with natural systems. Large-scale renewable energy projects, including solar farms, wind farms, and hydropower facilities, require significant spatial resources and may generate ecological consequences when developed without appropriate planning [1]. Therefore, an energy system cannot be considered fully sustainable if it reduces carbon emissions while simultaneously accelerating ecosystem degradation. Within the Ecological Energy Transition Framework, nature conservation becomes an essential decision parameter through the integration of ecological impact assessments, biodiversity protection strategies, and environmentally sensitive spatial planning. Energy development should prioritize areas with lower ecological value, such as degraded land, industrial areas, and previously disturbed landscapes, while avoiding ecosystems with high conservation importance. The fundamental principle of this dimension is that energy systems must operate within ecological boundaries rather than assuming that natural resources and ecosystems can continuously absorb environmental pressures generated by human development [1].

C. Resource Sustainability: Managing the Material Foundation of Energy Transition

The third dimension addresses the increasing importance of resource sustainability in the global energy transition. Unlike conventional energy discussions that focus primarily on fuel availability, modern low-carbon energy systems are increasingly dependent on mineral resources required for renewable technologies, energy storage systems, and electrification infrastructure [41]. The transition toward clean energy has significantly increased demand for critical minerals, including lithium, nickel, cobalt, copper, and rare earth elements [42]. While these materials are essential for accelerating decarbonization, their extraction may generate environmental challenges such as land degradation, water consumption, mining waste generation, and ecosystem disturbance. Consequently, replacing fossil fuel dependency with unmanaged mineral dependency would represent a shift in environmental pressure rather than a complete solution. Therefore, ecological energy transition requires responsible resource governance through sustainable mining practices, mineral recycling, circular economy implementation, and transparent supply chains [43]. The objective is not only to secure sufficient material supply for energy technologies but also to ensure that the extraction and utilization of these resources remain compatible with environmental protection principles.

D. Energy Security and Social Responsibility

The fourth dimension recognizes that sustainability is not exclusively an environmental concept but also includes social and economic considerations. An energy transition that reduces emissions but creates energy insecurity, unaffordable electricity prices, or social inequality cannot be considered a successful transformation [1]. Energy systems must continue to provide reliable, affordable, and accessible energy while reducing environmental impacts. This requires balancing climate objectives with energy security, particularly in developing countries where increasing energy demand remains closely associated with economic growth and social development. Within this framework, energy transition policies should consider indicators such as electricity accessibility, energy affordability, employment opportunities, community participation, and social acceptance of energy projects. Large-scale energy developments, whether renewable or fossil-based, must incorporate mechanisms that ensure local communities benefit from energy transformation rather than experiencing disproportionate environmental and social costs [44]. Therefore, the concept of green energy should include not only environmental performance but also the ability of energy systems to support equitable human development.

4.4 Implication: From Renewable Expansion to Sustainable Energy Optimization

The Ecological Energy Transition Framework fundamentally changes the objective of global energy transformation. The primary goal of energy transition should no longer be interpreted as maximizing renewable energy deployment or eliminating specific energy categories, but rather as optimizing energy systems according to their overall environmental and social performance. Under this framework, renewable energy remains a crucial pathway because of its ability to reduce carbon emissions; however, renewable deployment must be guided by ecological considerations and responsible resource management. Conversely, fossil energy remains associated with significant environmental limitations due to its carbon intensity, but its environmental performance should be evaluated based on actual impacts and mitigation efforts rather than solely on categorical classification [45]. This perspective suggests that the future of sustainable energy should move beyond the simplified distinction between renewable and fossil energy. Instead, energy sustainability should be defined by the ability of an energy system to provide reliable energy services while minimizing lifecycle environmental impacts and maintaining ecological integrity.

5. Conclusion

The global energy transition should not be understood merely as a process of replacing fossil fuels with renewable energy, but as an effort to develop energy systems that achieve environmental sustainability in a broader sense. Although renewable energy plays a crucial role in reducing carbon emissions, its expansion must be accompanied by ecological protection, responsible resource management, and social considerations. Similarly, the environmental performance of energy systems should not be determined solely by whether they are renewable or fossil-based, but by how effectively their impacts are managed throughout the lifecycle.

Therefore, this editorial argues that green energy should be defined not by energy source classification, but by its ability to minimize environmental impacts while maintaining energy security and human well-being. The ultimate objective of energy transition is not merely to replace fossil fuels with renewable technologies, but to establish energy systems that maintain harmony between human development and ecological sustainability. Renewable energy should be considered a pathway toward sustainability, not the definition of sustainability itself.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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