Research Article

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ANALYSIS OF INVESTMENT TRADE-OFFS AND THE COST OF POLICY INACTION IN THE GREEN ENERGY TRANSITION

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Background. The intensification of climate, energy and geopolitical risks contributes to the formation of a fundamentally new paradigm of strategic economic planning. For countries characterised by institutional fragility and increased geopolitical vulnerability, postponing the green energy transition is associated with a potentially non-linear escalation of economic losses due to the cumulative and mutually reinforcing impact of systemic risks.

Purpose. The study aims to conduct an analysis of green energy transition, with an emphasis on the economic interpretation of the "cost of choice", and on identifying barriers that may hinder the large-scale implementation of renewable energy sources.

Findings. The methodological basis is a discounted expected cost model that accounts for direct investment, probabilistic estimates of energy shocks, and related macroeconomic losses. The analytical horizon was 10 years, with a 5% discount rate. The cumulative discounted "opportunity cost" of the active green transition scenario in Ukraine is USD 28.12 billion, while the status quo scenario reaches USD 75.06 billion. The total costs, adjusted for energy shocks, under the green transition scenario are estimated at USD 1.7 billion, compared to USD 9.2 billion under the status quo scenario. The risk of disruption in the energy sector under the green transition scenario is estimated at approximately 15%. However, the current energy balance relies heavily on traditional energy sources, significantly increasing risks and raising the probability of system failure to 40%. The cumulative costs of inaction are projected to reach a staggering USD 47 billion over the next decade of planning. Consequently, the initial capital outlays required for green initiatives are effectively offset by the mitigation of these long-term financial liabilities.

Implications. Delaying the green transition leads to a non-linear increase in macroeconomic losses, with the "cost of inaction" significantly exceeding the costs of active transformation. In this context, accelerating decarbonisation is crucial not only as a goal to combat climate change but also as a key strategy to reduce systemic risks and enhance the resilience of the energy sector. Furthermore, the opportunity cost methodology proposed in this paper represents an effective tool for addressing the challenges of modern energy management and strategic planning.

Keywords: Cost of Inaction, Economic Risks, Energy Policy, Green Transition, Renewable Energy.

1. Introduction.

The global economy operates in a highly volatile and uncertain environment. Climate change, energy price volatility, and escalating geopolitical tensions are interconnected and overlapping. In this context, the development of green technologies has ceased to be simply a matter of environmental protection; it has become a critical factor in energy security, the transition to carbon neutrality, and long-term economic sustainability. This study takes a broader look at the concept of "costs of inaction" examining not only the direct financial costs of additional carbon reductions but also the future economic losses countries will incur if energy reforms are delayed. This study focuses on the balance between short-term benefits and long-term stability, as well as the relationship between risk reduction, increased energy independence, and sustainable economic growth.

Investments in renewable energy, energy efficiency, and eco-innovation are inherently capital-intensive and require not only institutional stability but also the availability of long-term financial instruments (Halldén et al., 2025; Beloeva et al., 2025). In contrast, continued reliance on traditional energy sources contributes to the accumulation of macroeconomic imbalances, amplifies the impact of external shocks, and exacerbates the negative consequences of climate change (Iorember et al., 2025; Wen et al., 2025).

This study examines the need for a systematic, integrated assessment of the determinants shaping the investment environment for green technologies in Ukraine amid economic, energy, and political uncertainty.

Regarding its scholarly novelty, this study establishes the "cost of inaction" (CoI) as a precise, quantifiable derivative of systemic risk. Unlike traditional models, our approach integrates the probability of energy-sector disruptions into the fiscal architecture of investment modelling. Furthermore, a non-linear scenario-based methodology is deployed to adjudicate the inherent tensions between immediate liquidity constraints and long-term macroeconomic durability. This analytical lens is particularly relevant to emerging or threatened economies, where geopolitical instability is a primary determinant of energy security.

2. Literature Review.

2.1. Drivers of Green Technology Development.

The literature has demonstrated that "green" technologies and investments are shaped by complex combinations of economic, environmental, and social factors (Niu et al., 2023). Green investment activities include projects in renewable energy, energy efficiency, clean technologies, and related areas (Adamowicz, 2021).

There is lack of a single, universally accepted definition due to the diversity of approaches and application contexts (Milindi & Inglesi-Lotz, 2022).

Green investment, as a broader concept, encompasses ESG investments, socially responsible investments, and sustainable finance instruments, highlighting its dynamic and context-dependent nature (Eyraud et al., 2013; Iliev et al., 2023; Shopova et al., 2023).

Recent studies have identified several key drivers of green technology implementation and investment.

1. Regulatory and policy pressures (Young et al., 2011). Environmental regulations and government incentives (tax benefits, subsidies, and grants) strongly encourage enterprises to pursue green innovation, thereby supporting the transformation of production processes and technology.

2. Market factors and consumer demand. The formation of a "clean" technology market and stakeholder requirements force companies to adapt to environmental standards, stimulating innovation (Fu et al., 2020).

3. Financial instruments and financing innovations. The development of sustainable finance is considered an important driver that facilitates access to capital and reduces barriers to the implementation of technological innovations (Kumar et al., 2023).

The literature confirms that the development of green technologies is influenced by regulatory, market, and financial factors. For Ukraine, an active green transition is strategically important, as it helps reduce systemic economic and energy risks, increase energy resilience, and integrate into global clean technology markets.

2.2. Theoretical Perspectives on Barriers to the Green Transition.

The set of barriers and constraints that hinder the widespread implementation of green technologies and investments is widely represented in the literature.

1. Financial constraints related to the high capital intensity of green projects, limited access to financing for small businesses, and immature financial markets significantly restrain the development of clean technologies (Ozcelik et al., 2025).

2. Policy uncertainty and regulatory risks determine the instability of environmental legislation, and uncertainty regarding subsidies and regulatory frameworks reduces the attractiveness of investments in green projects (Kodua et al., 2022).

3. Organisational and technological constraints include low levels of IT and innovation competencies, and high R&D costs, which are significant barriers in certain sectors and the economy as a whole (Mojumder et al., 2022).

This study proposes an approach to analysing the "cost of choice", which combines scenario modelling of economic and financial costs with an assessment of national institutional and geopolitical risks. It considers the investment trade-off between short-term costs and long-term benefits for both the state and businesses. The literature proposes various theoretical approaches to understanding investments in green technologies.

– Drivers–barriers approach within innovation diffusion theory, combining institutional theory, resource-based view, and diffusion of innovation theory to explain how internal and external factors influence the adoption of green technologies (Tan et al., 2022). In this framework, drivers reduce long-term costs, while barriers increase the "cost of inaction".

– Behavioural factors approach, where the implementation of green technologies depends not only on economic incentives but also on the behavioural characteristics of agents (firms and investors), which may explain slow adoption even under favourable economic conditions (Zacher et al., 2023).

Du et al. (2021) highlighted the positive long-term impact of green technologies on structural economic transformation, while Mikhno et al. (2021) argued that green technology-led growth has a revolutionary impact on reducing carbon intensity, especially in high-income countries.

Demirel et al. (2025) highlighted the significant financial and institutional constraints that may slow the implementation of green growth policies, even within the EU's Green Deal. Similarly, Angelakis et al. (2025) emphasise that regulatory instability and insufficient institutional capacity can offset the potential economic benefits of green investments. Furthermore, Fathoni et al. (2025) analyse the green transition within the framework of innovation diffusion theory, highlighting the role of internal organisational resources and strategic management.

Koval et al. (2021) focused on behavioural aspects, showing that even economically beneficial green solutions may not be implemented because of cognitive and psychological barriers.

However, previous studies have not formally considered the risks associated with investment decisions, assessed the "costs of choice" or compared the economic consequences of deciding not to make one. To support future strategic investments in Ukraine's green technology sector, a model is needed that integrates economic assessments, risks, and country-specific factors. A literature review shows that, although numerous factors facilitate the adoption of green technologies, many barriers remain that must be overcome through institutional innovation, financial mechanisms, and specific regulations.

2.3. Literature Gap and Research Questions.

An analysis of the academic literature indicates a large number of studies on the drivers and barriers to green investment. The issue of a comprehensive quantitative assessment of the "cost of choice" between an active green transition and maintaining the status quo remains underdeveloped, especially in economies with heightened geopolitical vulnerability.

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The identified gaps in "cost of choice" research highlight the importance of studying the strategic green transition in Ukraine's energy sector. In this regard, the following research questions are posed:

RQ1. Does the total discounted expected cost of inaction exceed the cost of an active green transition in a risk-oriented assessment?

RQ2. To what extent do energy, political, and institutional risks affect the formation of the "cost of choice" in the medium term?

RQ3. What is the magnitude of the "cost of inaction" in an economy with increased geopolitical vulnerability?

RQ4. What investment trade-offs are critical for the formation of effective public policies for the green transition?

Thus, the formulated research questions define the logic for further modelling and serve as the basis for a quantitative scenario analysis.

3. Methodology.

3.1. Research Design and Methodological Approach.

The methodological basis of the study is the concepts of sustainable development, green economy, and investment theory, which allow considering the development of green technologies as the result of interaction between economic incentives, institutional conditions, and external risks. Particular attention is paid to the concept of the "cost of choice", which is defined as the combination of short-term costs and long-term benefits associated with the adoption or postponement of decisions regarding the green transition in the energy sector.

Within the study, a model for evaluating investment trade-offs and the "cost of choice" is proposed, combining scenario modelling, comparison of alternative investment trajectories and risk-oriented cost assessment.

3.2. Scenario Framework of the Green Transition.

In this study, a scenario-based approach was used, involving the development of two alternative trajectories for the energy sector and the economy as a whole.

1. Scenario G (Green Transition).

This scenario involves large-scale investments in renewable energy sources, modernisation of energy networks, development of energy storage systems, improvement in energy efficiency, and gradual diversification of energy consumption. High initial capital investments and a reduction in the probability of energy and macroeconomic shocks in the medium term characterise it.

2. Scenario S (Status Quo).

This scenario is characterised by maintaining the existing energy balance structure, limited investment in renewable energy sources, and high dependence on traditional energy resources. Short-term costs are lower; however, the probability of systemic risks and the scale of potential economic losses increase accordingly.

The modelling horizon is 10 years, which allows for capturing the medium-term effects of investments in green technologies while maintaining the relative predictability of macroeconomic and political parameters. A ten-year period is sufficient to assess the cumulative effects of investments, structural changes in energy consumption, and the impact of risk on economic resilience.

The comparison was based on calculating the total discounted expected cost for each scenario. The cost structure includes the following:

- Initial investment costs.
- Annual operating costs.
- Expected losses from potential energy and political shocks (adjusted by probability).
- Discounted value of future payments.

The "cost of choice" is defined as the difference between the total discounted costs of scenarios "S" and "G". If the discounted cost of scenario "S" exceeds that of scenario "G", postponing the green transition is considered economically irrational.

This approach formalises the trade-off between the short-term financial burden and long-term macroeconomic stability, accounting for the non-linear increase in the "cost of inaction" under conditions of elevated systemic risk.

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Effective scenario modelling should focus on contrasting yet internally consistent development paths to enable the identification of key decision points.

In the context of energy transformation, the use of a binary structure, "transition vs inaction", allows for the clear isolation of the effects of investment decisions and assessment of differences in long-term expected costs. This approach is consistent with scenario analysis practices in the energy sector, particularly those used by the International Energy Agency (2025), which compares a baseline scenario with a transformation scenario.

Furthermore, the risk-oriented model accounts for asymmetry in outcomes. In vulnerable economies, potential losses from negative shocks may be non-linear and significantly exceed short-term savings from reduced investment activity.

Therefore, integrating shock probabilities into discounted cost calculations is methodologically justified and is consistent with modern approaches to strategic planning under uncertainty.

This approach treats uncertainty as an integral structural element of the model, rather than as an external factor. Special attention is given to economies with high geopolitical vulnerability, where risks tend to accumulate and grow non-linearly, significantly affecting the long-term "cost of inaction".

Scenario modelling enables the quantitative assessment of the economic, social, and environmental outcomes of each development option.

The "cost of choice" is expressed as the minimisation of discounted total costs under two alternative scenarios (Table 1): G – an active green transition; and S – the status quo.

Table 1. Key Model Parameters and Assumptions.

Parameter	Symbol	Value	Description
Time Horizon	T	10 years	Evaluation period for the scenario analysis
Discount Rate	r	5%	Social discount rate applied to infrastructure investments
Probability of Energy Shock (Green Scenario)	pG	15%	Estimated probability of systemic energy disruptions under the green transition scenario
Probability of Energy Shock (Status Quo Scenario)	pS	40%	Higher probability due to continued reliance on energy imports
Loss per Shock (Green Scenario)	LG	USD 6 billion	Economic losses associated with localised disruptions in the energy system
Loss per Shock (Status Quo Scenario)	LS	USD 18 billion	Economic losses from large-scale disruptions, including significant GDP impacts

Table 2 presents a comparative cost structure for two alternative energy system development scenarios: an active green transition scenario (G) and a business-as-usual scenario (S). The cost structure is organised into four key categories, allowing for a comprehensive assessment of differences not only in direct financial costs but also in hidden economic consequences, the level of vulnerability to energy shocks, and the long-term sustainability of the energy system in each scenario.

The estimation of losses from an energy shock (L) represents another limitation of the model. In the proposed scenarios, losses are assumed at USD 6 billion for the green transition scenario ($L_{(G)}$) and USD 18 billion for the status quo scenario ($L_{(S)}$). However, the methodology for deriving these values is not fully specified. The threefold difference reflects the assumption that a more resilient and decentralised energy system significantly mitigates the scale of economic damage; however, this proportionality may raise questions regarding its empirical justification.

The estimation is based on a modelled area of 1,000 km², using data on the number of enterprises located in the Kyiv region, their economic performance indicators, and environmental impact metrics.

Table 2. Comparative Cost Structure of Energy Transition Scenarios.

Cost Category	Green Transition Scenario (G)	Status Quo Scenario (S)
Initial and Capital Costs	Investments in renewable energy (solar, wind, bioenergy); grid modernisation and digitalisation (smart grids); energy storage systems; decentralisation of generation; R&D in green technologies	Limited capital investments; maintenance of existing infrastructure; emergency repairs; partial and delayed modernisation
Operational and Current Costs	Operation and maintenance of renewable capacities; integration of renewables into the energy system; administrative costs of policy implementation	Fossil fuel imports; price compensation mechanisms; tariff subsidies; increasing operating costs of outdated infrastructure
Institutional and Macroeconomic Costs	Workforce retraining programs; policy incentives (subsidies, tax benefits); educational campaigns; improved energy independence and investment attractiveness	Losses from energy dependence; price volatility; reduced investment attractiveness; capital outflows; weak institutional support
Risk-Related Losses and System Outcomes	Local disruptions in early stages; delays in technology deployment; regulatory risks; reduced probability of systemic shocks; long-term price stabilisation and resilience	Large-scale energy shocks; infrastructure destruction; high price volatility; GDP losses due to supply disruptions; persistent systemic vulnerability

In this context, it should be clarified that the estimated losses include GDP decline, costs of emergency response and recovery, as well as losses associated with industrial disruptions. While this approach allows for an approximate macro-level assessment, it involves simplifications and may not fully capture regional heterogeneity across the country. A more precise estimation would require detailed modelling and empirical validation, including references to statistical data or prior studies, which can be considered as a direction for further research.

A key feature of scenario S is the higher probability of systemic shocks and larger scale of losses, leading to non-linear growth of expected costs.

Taking into account uncertainty, the model of expected costs can be expressed as:

$$E\,(TC_i) = I_{0,i} + \sum_{t=1}^{T} \frac{C_{i,t} + p_t L_{i,t}}{(1+r)^t} \quad (1)$$

where:

TC_i – total discounted “cost of choice” of scenario i;

T – time horizon;

$C_{i,t}$ – direct costs in period t;

$I_{0,i}$ – initial investment expenditures for scenario i;

p_t – probability of an energy shock in period t;

r – discount rate;

$L_{i,t}$ – economic losses associated with a shock in period t.

The decision criterion is based on the difference between the total costs of the status quo scenario (S) and the green transition scenario (G):

$$P_0 = TC_S - TC_G \quad (2)$$

where:

P_0 – economic effect of postponing the green transition.

$P_0 > 0$ indicates that delaying the green transition is economically irrational, as the total discounted costs of maintaining the status quo exceed those of the green transition.

The annual costs (C_i) used in the model for the 10-year analysis horizon include both operational, institutional, and risk-related expenditures as well as initial capital investments. Specifically, for the green transition scenario (G), annual operational and institutional costs are estimated at USD 0.8 billion per year, while initial investment expenditures total USD 15–28 billion (covering renewable energy capacities, grid modernisation, energy storage, decentralisation, and R&D). For the status quo scenario (S), annual operational and institutional costs are USD 2 billion per year, with initial investments of USD 4 billion.

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The total discounted costs and the "cost of inaction" already reflect the combination of upfront capital expenditures and ongoing annual expenses. The model demonstrates that the lower short-term costs of maintaining the status quo are offset by increased long-term risks and losses, forming a positive "cost of inaction".

The model incorporates uncertainties related to economic, technological, and political factors. The flowchart (Fig. 1) demonstrates that the choice between an active green transition and maintaining the status quo directly affects the expected economic costs and shapes the "cost of inaction".

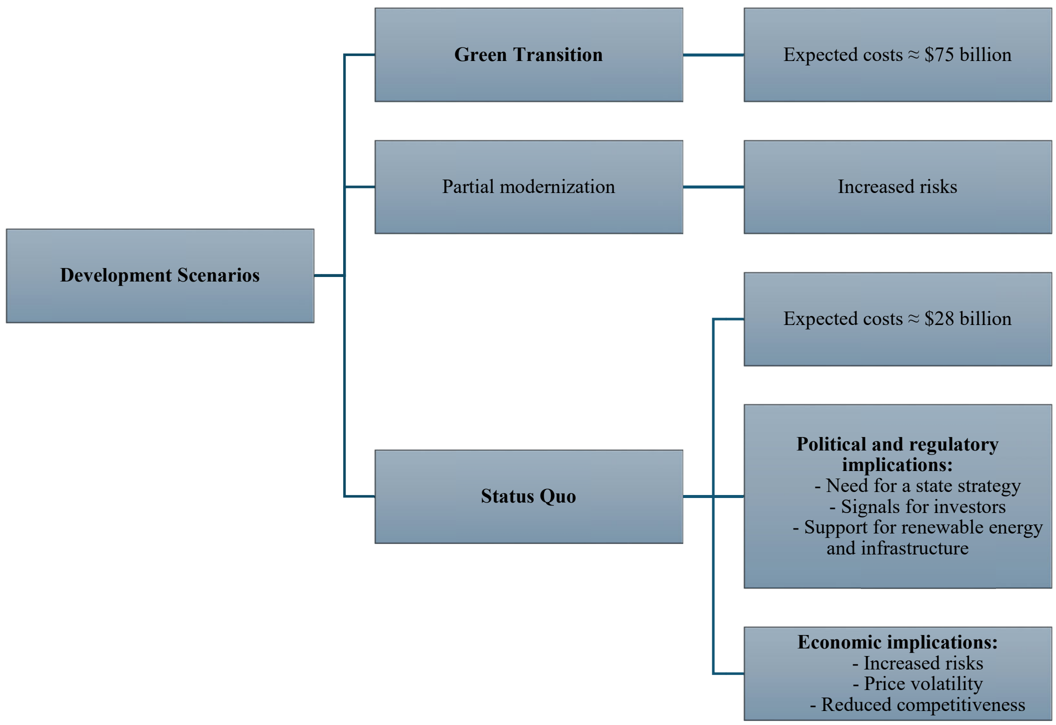

Fig. 1. Logical Framework of the Impact of Development Scenarios on Expected Costs and Economic Outcomes.

3.3. Limitations.

It should be noted that this analysis takes into account several important limitations associated with organising data over a longer period, given the ongoing military situation in Ukraine. Furthermore, the choice of binary scenarios, a fixed discount rate, and a relatively short 10-year horizon was aimed at maximising interpretability. However, this simplified approach is a deliberate but significant limitation.

Another point to consider is the limited geographic and sectoral scope. Since this analysis is based specifically on the Ukrainian energy sector, any attempt to generalise these results to other countries or different economic sectors will require careful recalibration.

Finally, the model does not include all variables and may therefore overestimate the differences between alternative scenarios. For comparison purposes, the current analysis focuses on typical extreme cases, while intermediate scenarios represent a promising direction for future research.

Adopting a 10-year time horizon allows for the identification of the economic, technological and risk implications associated with the energy transition in the medium term. However, large investments in renewable energy infrastructure typically generate returns over longer time horizons, often 15–20 years. The chosen duration may therefore result in a reduction in the overall economic benefits of the green transition.

Therefore, extending the analytical horizon further strengthens the relative effectiveness of the green scenario. The model uses a standard discount rate of 5% without fully exploring alternative methodological approaches. While the sensitivity analysis includes variations of 3% and 7%, the choice of the base rate may require additional justification, especially in the context of post-conflict economies characterised by uncertainty and risk. A higher discount rate should be used. However, the 5% discount rate chosen here reflects generally accepted methods for evaluating public infrastructure projects.

Finally, the probabilities of energy shocks used in the model (pG2 = 15% for the green transition scenario, pS2 = 40% for the status quo scenario) are based on expert assessment and reflect the current vulnerability profile of Ukraine's energy transport system under different development scenarios.

The high probability of the status quo reflects reliance on imported energy, obstacles to infrastructure development, and ongoing geopolitical risks. In contrast, the low probability under a "green" scenario reflects energy decentralisation, diversification of energy sources, and increased reliance on imports. However, the lack of formal statistical assessment is a significant limitation and a key area for future research.

4. Results.

The recent data from the International Renewable Energy Agency (IRENA, 2025) indicate that global investment in renewable energy has exceeded USD 500 billion, with clean energy now accounting for 30% of the global energy mix. This reflects a profound structural transformation of national energy systems, with green capital becoming a fundamental economic driver.

In this study, "choice cost" is considered a complex economic prism encompassing direct costs, opportunity costs, and delayed effects. Moving away from traditional models that focus solely on implementation costs this framework pits two realities against each other: an accelerated green shift versus the maintenance of the status quo.

While the transition undoubtedly carries a heavy price tag in terms of initial CAPEX and fiscal strain, the alternative is a deceptive "cost of inaction".

Traditionally, the main barriers to the development of green technologies in the academic literature are financial constraints and technological immaturity. However, under modern instability, institutional and behavioural factors are gaining importance. Policy inconsistency, frequent regulatory rule changes, and the absence of long-term signals for investors significantly reduce the effectiveness of financially attractive projects. Particular attention should be paid to the behavioural aspects of decision-making.

Even when economic incentives are present, economic agents may avoid investing in green technologies due to high uncertainty, information asymmetry, and a tendency to preserve existing business models. This suggests that barriers to the green transition are not only economic, but also institutional and psychological. To visually present the risk-oriented assessment of the "cost of choice", a flowchart is proposed that captures the main modelling stages and interconnections among scenarios, risks, and expected outcomes. First, the initial data are formed, including alternative investment trajectories (active green transition and status quo scenarios), initial capital investments, and socio-economic parameters.

At the next stage, a risk-adjusted evaluation is performed, incorporating technological, energy-related, and socio-institutional uncertainties, which allows for the correction of expected cost estimates. Subsequently, the "cost of choice" framework is applied to formalise the intertemporal trade-off between immediate expenditures and prospective benefits, with explicit consideration of the identified risk factors.

By synthesizing these variables, the model generates a set of outputs that include projected costs, a quantified "cost of inaction," and sensitivity analyses tied to specific risk parameters. This provides more than just raw data; it establishes a rigorous analytical foundation for strategic planning in green technology deployment (Figure 2).

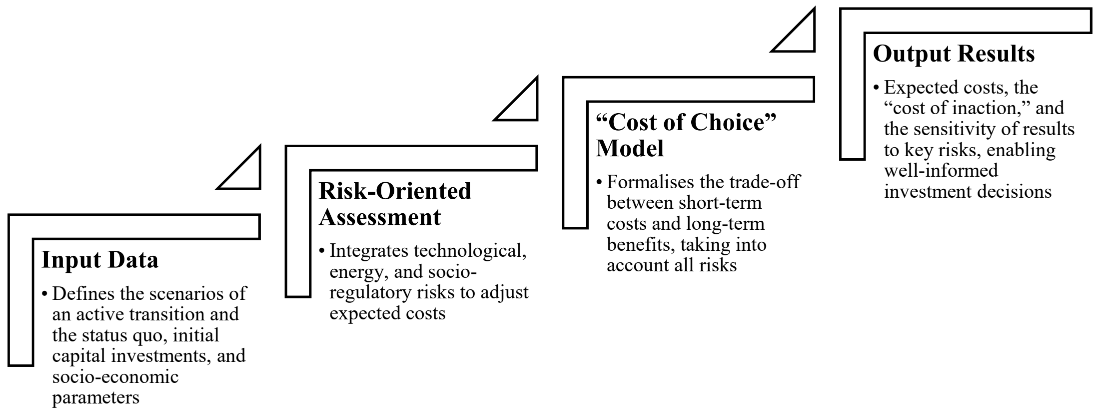

Fig. 2. Block Diagram of the Risk-Oriented Model for Assessing the "Cost of Choice" of the Green Transition.

Despite the growing risks, the current transition undoubtedly requires significant initial capital investments, but it is characterised by the emergence of new factors in the development of "green" technologies.

At the same time, the gradual decline in the cost of some green technologies has reduced the "choice costs" of a green transition. Table 3 shows that the "choice costs" of a green transition extend beyond initial investments.

Table 3. "Cost of Choice" of the Green Transition: Comparison of Alternative Development Scenarios of a Country.

Dimension of analysis	Active development of green technologies	Delay / status quo preservation
Capital expenditures (short-term)	High initial investments in renewable energy sources (RES), grids, energy storage, and energy efficiency	Lower initial costs, absence of large-scale modernisation
Fiscal burden	Temporary increase in budget expenditures (subsidies, investment support)	Hidden fiscal risks due to price shocks and energy crises
Energy security	Reduced dependence on energy imports, diversification of sources	Persistence of high external dependence and vulnerability
Price stability	Gradual stabilisation of energy prices in the long term	High volatility of energy prices
Investment attractiveness	Increased interest from international and private investors	Limited access to green finance
Technological development	Formation of new economic sectors and innovation clusters	Risk of technological lag
Social implications	Redistribution of employment, need for workforce reskilling	Preservation of traditional jobs, but without long-term prospects
Climate and environmental costs	Reduction of emissions and environmental pressure	Increase in adaptation costs to climate change
Long-term economic benefits	Enhanced economic resilience and competitiveness	Accumulation of structural and macroeconomic risks
Overall "cost of choice"	High short-term cost → lower long-term risks	Low short-term cost → high cost of inaction

Lagging in green technology development results in long-term hidden costs, including increased energy dependence. This model uses a 10-year calculation period and a 5% discount rate. A 10-year period was chosen as the optimal time frame for assessing green technology investments because it allows consideration for the medium-term impacts of renewable energy deployment and energy system modernisation to be examined. The 5% discount rate balances reducing the long-term risks of public and private investments with the current value of money in the context of the national economy.

Table 4 presents the results of the scenario analysis, summarising the expected costs of transitioning to green technologies compared to maintaining the status quo.

Table 4. Assessment of the "Cost of Choice" of the Green Transition for Ukraine Based on Scenario Calculations.

Indicator	Active Green Transition (G)	Status Quo / Deferral (S)
Initial Investments (t = 0)	USD 15 billion *	USD 4 billion *(maintenance and support of the current power system)*
Operating Expenses (OPEX), USD billion/year	0.8 *(maintenance, system support, RES integration)*	2.0 *(fuel imports, emergency repairs, compensation mechanisms)*
Probability of Energy Shock, p	15% *(lower due to decentralisation, renewable energy expansion, and reduced import dependence)*	40% *(higher due to external shocks, import dependence, and price volatility)*
Loss per Shock, *L*	USD 6 billion *(localised disruptions of the energy system)*	USD 18 billion *(large-scale blackouts, import disruptions, and GDP losses)*
Expected Risk Losses (*pL*), USD billion/year	0.9	7.2
Total Annual Costs (C + *pL*), USD billion/year	1.7	9.2
Discounted Operating and Risk Costs (10 years), USD billion	13.12	71.06
Total Expected Cost of Choice, E(TC), USD billion	28.12	75.06
Cost of Inaction (S − G), USD billion		≈ 47

Note: Baseline calculation uses USD 15 billion (phased transition). Full investment range: USD 15–28 billion; upper bound (USD 28 billion) tested in sensitivity analysis.*

The calculation is based on the expected total cost formula (Formula 1), where I_0 denotes the initial investment, C denotes the annual cost, *pL* denotes the expected annual risk-related losses, and r denotes the discount rate.

The estimated "cost of inaction" of approximately USD 47 billion, equivalent to 25–30% of Ukraine's GDP, underscores the substantial macroeconomic scale of potential losses and the critical importance of a timely green transition.

The values of USD 13.12 billion and USD 71.06 billion are obtained as the discounted sum of annual costs ($C + pL$) over a 10-year period at r = 5%, after which the initial investments are added.

The difference between the scenarios (≈ USD 47 billion) is interpreted as the "cost of inaction". The green scenario (G) demonstrates a significant reduction in expected losses from energy shocks: the pL indicator decreases from USD 7.2 billion to USD 0.9 billion per year, that is, by approximately 87.5%, indicating a sharp increase in the resilience of both the energy system and economy to crisis events.

The total annual costs, including risk (C + p·L), amount to USD 1.7 billion in the green scenario versus USD 9.2 billion in the baseline, representing a reduction of approximately 81.5%. This indicates that, even when accounting for the investment component, the green transition is economically more efficient in the medium term.

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The discounted difference in costs between the scenarios amounts to approximately USD 47 billion, which is interpreted as the "cost of inaction", the additional costs the economy will incur if the energy transition is delayed. Maintaining the status quo incurs a significant "cost of inaction" that exceeds USD 47 billion and is driven by the high probability of large-scale energy shocks. To assess the impact of the key directions on the success of the green transition, an expert analytical approach with weighted evaluation was applied. The methodology is based on determining the relative importance of each direction and the balance between positive factors and barriers (Table 5).

In the first stage, the main directions determining the effectiveness of the green transition were identified, including policy and regulation, investment and finance, technologies and infrastructure, the social dimension, risks and system resilience, and external political influence.

In the second stage, a qualitative assessment was performed for each direction.

• The level of potential positive impact of the proposed recommendations

• The strength and scale of existing barriers that may hinder implementation.

These assessments were aggregated into an integrated impact indicator that reflected the net effect of each direction, accounting for both enabling and constraining factors.

The indicator "Approximate impact on success (%)" presented in the table is interpreted as the relative weight of each direction in shaping the overall outcome of the green transition.

These values were expertly determined, considering the following: scale of economic effects; speed of implementation of changes; the impact of reducing systemic risks; criticality for energy security.

The sum of all weights equals 100%, allowing them to be considered as the contribution structure of different factors in achieving a successful transition.

Table 5. Recommendations and Potential Barriers to the Development of the Green Transition in Ukraine.

Pillar / Direction	Policy Recommendations	Potential Barriers	Estimated Impact on Success (%)
Policy and Regulation	Implementation of a national green transition strategy; ensuring a stable legislative framework and tax incentives	Frequent legislative changes; insufficient enforcement of policy measures	25% (Critical)
Investment and Financing	Establishment of dedicated funds and credit lines for renewable energy sources (RES); attraction of private investment through guarantees and incentives	High initial capital requirements; lack of long-term financial instruments	20% (High)
Technology and Infrastructure	Modernisation of energy grids for RES integration; support for research in energy storage and smart energy management	Legacy infrastructure incompatible with RES; insufficient technological and scientific capacity	20% (High)
Social Dimension and Education	Workforce upskilling for green technologies; public awareness campaigns on energy efficiency and sustainable consumption	Resistance to change in traditional sectors; low level of public awareness	15% (Medium)
Risk Management and System Resilience	Integration of risk assessment into energy planning; development of rapid response mechanisms to energy shocks	High exposure to energy and climate-related risks	20% (High)
External Political Factors	Diversification of funding sources; strengthening energy independence and international partnerships	External political influence and geopolitical instability potentially delaying implementation	10% (Moderate)

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The analysis in Table 5 shows that the successful implementation of the green transition in Ukraine depends on a comprehensive approach to political, economic, technological, and social aspects.

The most critical barriers include instability of legislation and insufficient enforcement of policies (≈25% impact on success), high initial capital investments and limited access to long-term financing (≈20%), outdated infrastructure and an insufficient scientific and technical base for integrating renewable energy sources (≈20%), resistance to change among the workforce and low public awareness (≈15%), and high risks of energy and climate change (≈20%).

Overcoming these barriers requires a coherent state strategy, a stable regulatory environment, investment support and, modernisation of energy infrastructure. If most of these measures are implemented, the share of successful integration of renewable energy sources into the country's energy balance could reach 35–45% by 2030, significantly reducing economic risks and lowering the "cost of inaction". To assess the robustness of the economic efficiency of the green transition, a sensitivity analysis of the key parameters of the "cost of choice" model was conducted. The main parameters affecting the expected costs and the "cost of inaction" are presented in Table 6.

Table 6. Key Parameters Influencing Expected Costs and the "Cost of Inaction".

Parameter	Base Value	Tested Variants	Result
Discount Rate	5%	3%, 7%	Reducing the rate to 3% decreases the expected costs of the Green Scenario by ≈8%; increasing it to 7% raises costs by ≈10%. Long-term benefits of the green transition are highly sensitive to financial parameters.
Probability of Energy Shocks (External Risks)	15%	10%, 20%	Reducing the shock probability to 10% lowers expected additional costs of the Status Quo by ≈5%; increasing it to 20% raises them by ≈12%. This underscores the importance of integrating risk assessment into strategic planning.
Initial Capital Expenditures (CAPEX) in RES	USD 28 billion	±20%	A 20% increase in CAPEX raises expected costs by ≈15%; a 20% decrease lowers them by ≈12%. Despite these fluctuations, the Green Scenario remains more economically viable than the Status Quo.
Impact of Social and Regulatory Barriers	–	–	Lack of incentives and slow workforce adaptation could reduce the overall efficiency of the green transition by ≈10–15%.

A comparison of Ukraine with Central and Eastern European countries (Poland, the Czech Republic, Romania, and Hungary) reveals significant differences in the pace of integrating renewable energy sources into the electricity grid and in the expected economic costs of inaction. Table 7 shows that the level of renewable energy integration in Ukraine is moderate. Ukraine faces high costs of inaction due to dependence on existing energy sources and inadequate infrastructure. In contrast, the experience of neighbouring countries shows that even before the share of renewable energy sources peaks, investment in technology and political stability can mitigate economic risks.

It is worth noting that, in addition to domestic political factors, Ukraine's "green" development path is significantly influenced by foreign policy factors, which hinder the achievement of long-term strategic goals and reduce the effectiveness of renewable energy projects. In this tense environment, geopolitical instability is expected to increase the "cost of inaction" by 5-10% and exacerbate economic risks.

Decarbonisation has moved from a moral choice to a strategic advantage for energy importers, while fossil fuel producers face the growing threat of "stranded assets" (Mercure et al., 2021).

Table 7. Comparison Countries on Renewable Energy Integration and the "Cost of Inaction".

Country	RES Share in Electricity Generation	Key Features / Commentary	Expected "Cost of Inaction" (USD billion)	Cost of Inaction (% of GDP)
Ukraine	15%	Low RES share; high dependence on traditional energy sources	47	29%
Poland	20%	High dependence on coal; slow energy transition	55	6.9%
Czech Republic	22%	Significant investments in solar and wind energy	38.5	11.7%
Romania	25%	Active state support for renewable energy investments	33–35	11–12%
Hungary	18%	Low energy autonomy; high vulnerability to external shocks	44	24%

As the environmental component plays an increasingly important role, the energy transition is now a means to ensure energy independence and resilience against external shocks (Genc & Kosempel, 2023).

In developing countries, renewable energy packages often produce neutral or even negative results in the short term, with significant gains achieved in the medium term (Galeazzi et al., 2024). Moreover, this shift is reflected in public support not for climate initiatives but for the possibility of achieving energy security (Ahonen et al., 2025).

5. Discussion.

In economies suffering from institutional weaknesses and geopolitical instability, the costs of inaction do not grow linearly; rather, they accumulate as systemic risks intensify. Therefore, postponing structural reforms makes no economic sense.

Future research should delve deeper into the sensitivity analysis of variables and gain a more complete understanding of the interactions among discount rates, specific probability distributions of energy shocks, and capital demand volume. Furthermore, a logical next step would be to direct macroeconomic analysis towards geospatial mapping of Ukraine's renewable energy potential. Complementary research directions may include comparative analyses of the integration of advanced technologies into energy system management, storage infrastructure, and digitalisation processes.

These findings are broadly consistent with contemporary contributions to the energy transition literature, which emphasises that the primary effect of decarbonisation extends beyond emission reduction to encompass a substantial decrease in systemic economic risks. In particular, Mercure et al. (2021) and Genc and Kosempel (2023) demonstrated that the transition to renewable energy sources is associated with reduced macroeconomic vulnerability, largely due to lower dependence on imported energy resources and a diminished price volatility. These findings indicate significantly lower expected risk-related losses in the green transition scenario. A comparison of modelling approaches within the EU Green Deal further confirms the conceptual consistency of these results.

Large-scale European models, such as PRIMES (Price-Induced Market Equilibrium System) and GEM-E3 (General Equilibrium Model), explicitly incorporate the cost of inaction, which typically manifests as higher energy import costs, increased climate adaptation costs, and measurable losses in gross domestic product. However, in contrast to the relatively stable EU economies, this effect is considerably more pronounced in Ukraine owing to the compounded influence of war-related risks, infrastructure degradation, and persistent energy dependence. Compared with the economies of Central and Eastern Europe, the estimated cost of inaction for Ukraine (approximately USD 47 billion) is comparable or even lower in absolute terms.

However, relative to GDP, particularly as a share of GDP, it is substantially higher. These findings indicate that postponing the green transition in Ukraine entails disproportionately high economic costs, thereby strengthening the strategic case for a more rapid transformation of the energy sector.

The results support the existence of an "insurance investment effect", in which a significant decline in long-term costs and systemic risks offsets the higher upfront investments required for a green transition. This interpretation is consistent with analytical approaches that conceptualise infrastructure investment as a form of risk management.

Moreover, the green transition generates a range of additional macroeconomic effects that are not fully captured within the model, including the following:

– A reduction in the balance deficit owing to decreased reliance on energy imports.

– Stimulation of investment activity and employment growth within the renewable energy sector.

– An increase in energy autonomy, accompanied by enhanced geopolitical resilience.

Thus, even under relatively conservative modelling assumptions, the results robustly confirm that delaying the green transition is economically inefficient. Simultaneously, the active transformation of the energy sector is a key determinant of long-term macroeconomic stability and national economic security.

6. Conclusions.

This study provides substantial, methodologically sound evidence that the transition to green energy in Ukraine should be viewed not only as an ecological necessity but also as an economically rational and strategically inevitable path that fully meets the stated goal of assessing the relative efficiency of alternative development trajectories in the national energy sector. In particular, the analysis of the so-called "choice cost" clearly demonstrates that any delay in integrating renewable energy sources imposes significant long-term economic burdens.

It manifests through a combination of increased external energy dependence, greater macroeconomic instability, and the systematic loss of potentially profitable investment opportunities that could otherwise support structural modernisation.

Regarding the research objective, the green transition scenario is characterised by a significantly higher level of economic efficiency than maintaining the status quo.

Over 10-years, an effective transition to a green economy would cost USD 1.7 billion per year, compared to USD 9.2 billion per year for the status quo. However, the "cost of inaction" is USD 47 billion, as delaying decisions only increases risks rather than generating savings.

When compared to its Central and Eastern European peers, Ukraine shows a moderate level of RES integration, yet the fiscal penalty for delaying this transition is disproportionately severe. This is largely because deep-seated structural rigidities continue to stifle the country's adaptive capacity.

Sensitivity analysis confirms that, regardless of whether we reset the discount rates or adjust the expected probability of energy shocks, the green energy transition trajectory consistently outperforms the baseline scenario. The green energy transition lays the foundation for long-term sustainable growth by promoting energy autonomy and mitigating the impact of external shocks.

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