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Green Energy Markets: Towards an Internal Rate of Return and ESG Factors

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Abstract

The contemporary green transformation of the economy is a strategic imperative for businesses, especially small and medium-sized enterprises (SMEs) operating in the energy market, forcing the integration of sustainable practices in decision-making processes, including investment efficiency assessment. Classic financial tools, such as the internal rate of return (IRR) and net present value (NPV), commonly used in the SME sector, do not always adequately account for environmental, regulatory, and social risks associated with green transformation, as—particularly in the case of IRR—they rely on the assumption of stable cash flows and do not incorporate regulatory uncertainty, environmental externalities, or ESG-related risks into discounting parameters. The aim of the study was to determine the impact of nominal and real discount rates, adjusted for a synthetic measure of green transformation, on investment decisions. The research methodology combines advanced multi-criteria decision-making techniques, specifically TOPSIS and CRITIC, with sustainable finance concepts, offering an innovative approach to investment decision-making in the SME sector. The study shows that integrating environmental factors, when treated as a risk component, increases the cost of capital and reduces the net present value, while maintaining the profitability of the analysed projects. Incorporating green components into the discount rate enhances valuation appropriateness and improves investment risk management, particularly under macroeconomic uncertainty. The main contribution of the study lies in linking a synthetic green transformation indicator with dynamic discount rate adjustment within a multicriteria framework, extending existing ESG-adjusted valuation models by enabling a more structured and data-driven incorporation of environmental transition risk.

Keywords: sustainable development; environmental economics; green energy market; internal rate of return

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1. Introduction

Contemporary management paradigms indicate that green transformation is no longer optional. It has become a strategic imperative, especially for small- and medium-sized

enterprises operating in the energy market. SMEs operate in an environment of growing regulatory requirements and heightened stakeholder expectations [1,2]. In this context, traditional methods of evaluating investment effectiveness have proven insufficient. They do not fully account for the environmental and social factors characteristic of pro-ecological projects [3,4]. ESG factors (environmental, social, and governance) play an increasingly important role in shaping firms' financing conditions and cost of capital; however, their impact is not uniform. The direction and magnitude of this effect depend on firm-specific characteristics, the quality of ESG information, and the extent to which transition risk is incorporated into investment valuation processes [5,6]. The literature suggests that ESG can both improve financing conditions by reducing perceived risk and increase uncertainty when ESG assessments are inconsistent or incomplete [7]. At the same time, this impact appears more pronounced under heightened regulatory pressure and rising stakeholder expectations [8,9].

The Internal Rate of Return (IRR) remains one of the keys and most frequently used measures of the profitability of investment projects, especially in the SME sector, where capital constraints and high economic uncertainty necessitate quick, relatively simple decision-making. The IRR determines the discount rate at which the net present value of the project's cash flows equals zero, enabling one to assess whether the expected financial benefits exceed the cost of the capital invested. This makes the indicator a useful comparative tool when choosing among alternative investment options under limited allocation constraints. At the same time, the current IRR approach does not always adequately reflect the specifics of pro-ecological projects. Green investments, including those in the energy sector, often have long time horizons, typical cash flow profiles, and strong dependence on regulatory and market factors. As a result, traditional methodologies may systematically underestimate their actual value or overlook the risks of failing to adapt to the requirements of energy transformation. This problem is particularly evident in the SME sector, where green innovations are often implemented in a fragmented manner, and entrepreneurs struggle to translate environmental goals into coherent and advanced analytical tools [10–13]. Although the literature on IRR is extensive, studies indicate that its application in complex transformation projects still requires further investigation, particularly regarding the incorporation of green transformation-related risk into investment evaluation frameworks. The application of IRR to complex transformation projects, including green transition investments, is documented in the literature but remains insufficiently explored, particularly regarding integration with advanced risk assessment tools. Proposed approaches combine IRR with Monte Carlo simulations and cost–benefit analyses that incorporate environmental and social effects, as well as elements of sustainability certification [3,14]. At the same time, it is emphasised that effective evaluation of complex green transformation projects requires integrating IRR with advanced risk modelling and environmental valuation techniques.

From research and practical perspectives, the development of expanded investment evaluation models that integrate conventional financial measures with environmental and social factors is gaining importance. Incorporating ESG (Environmental, Social, Governance) factors into the cash flow statement enables their monetisation through adjustments to operating and investment cash flows, reflecting effects such as energy savings, CO_2 emissions reductions, changes in regulatory costs, and improved company market reputation [15]. This approach enables the determination of an adjusted return rate that more accurately reflects the effectiveness of green projects, while also promoting SMEs' positioning in sustainable supply chains and strengthening their long-term competitive stability [16].

The evolution of investment evaluation methods towards integrated models is driven by both Porter's hypothesis, which posits that environmental regulations stimulate innovation and thereby influence firms' risk profile and cost of capital within the proposed valuation framework, and the need for precise modelling of the cost of capital in the context of energy transformation [17]. The expanded IRR calculation, which considers not only direct cash flow but also operational benefits, reputation, and reduced regulatory risks, is becoming a key element of modern capital budgeting in the SME sector. Proper quantification of these factors helps bridge the gap between financial orthodoxy and the requirements of sustainable development, supporting rational investment decisions and the sustainable integration of SMEs into the economy's green transformation.

The purpose of this paper is to analyse the impact of using nominal and real discount rates, and of adjusting them with a synthetic measure of green transformation, on the valuation of investment project efficiency. The study aims to determine how considering environmental, regulatory, and social risks within the framework of sustainable development and ESG policies affects the net present value (NPV) and the internal rate of return (IRR) of investments. Furthermore, the goal is to assess whether integrating these factors into the cost of capital translates into the sustainability and resilience of projects under changing macroeconomic conditions and increasing ecological requirements.

Considering the above objective, the paper formulates the following research questions: How do nominal and real discount rates affect the evaluation of the economic efficiency of investment projects? What are the implications of using green transformation-adjusted discount rates for project valuation, investment attractiveness, and investment risk? How do changes in discount rates driven by the green transformation influence investment decisions and the economic resilience of regions?

The novelty of the presented research lies in the comprehensive combination of classical methods of evaluating investment effectiveness with a modern approach to assessing the risks associated with green transformation, which not only expands the discounting model to include ESG factors by directly embedding them into both nominal and real interest rates, rather than treating them as separate risk adjustments, but also integrates them into authentic and nominal interest rates. The work goes beyond the traditional framework of financial analysis, considering the growing importance of environmental policies and their impact on the cost of capital. This area remains insufficiently structured in the existing ESG finance literature, particularly regarding the direct linkage between transition-related risk and discount rate dynamics. Furthermore, the study broadens the analysis to longer time horizons, accounting for the significant impact of later cash flows, thereby improving the model's predictive quality.

2. Literature Review

A systematic literature review conducted in accordance with established methodological guidelines [18,19] showed that the internal rate of return (IRR) is one of the most widely used measures of investment efficiency, especially in the SME sector. The review was based on a structured search of peer-reviewed literature in major scientific databases, using predefined keywords related to IRR, investment appraisal, and SME decision-making, and applying inclusion criteria focused on empirical and conceptual studies relevant to financial evaluation methods. Empirical studies consistently report that IRR plays a dominant role as a primary decision criterion in MSME investment appraisal, particularly under conditions of limited access to advanced analytical tools and constrained capital resources. This widespread use is further confirmed across studies documenting its continued prevalence in investment decision-making frameworks, despite the growing availability of more advanced valuation methods [20–40]. These findings indicate that IRR remains a dominant,

primarily financially oriented tool in SME decision-making, with limited incorporation of broader investment-context factors.

Despite its widespread use, the literature points to significant methodological limitations of the classical IRR approach. These problems are especially evident in projects characterised by non-standard cash flow structures, leading to multiple solutions to the IRR equation or its absence, making it impossible to interpret the results unequivocally. This phenomenon has been extensively documented in studies of projects with variable cash flows. Additionally, the classical IRR formula assumes that financial surpluses are reinvested at the IRR, which is often unrealistic in practice and can lead to overestimation of the return on investment [23–25,30–32]. These limitations suggest that IRR may not fully reflect project value under changing cost-of-capital conditions, implying that incorporating additional structural adjustments into discount-rate mechanisms may significantly influence valuation outcomes.

A significant drawback of the IRR method is its potential conflict with the NPV criterion, particularly for mutually exclusive projects or projects that differ in scale or time horizon. In such situations, IRR may lead to the selection of projects that generate lower value for the firm, which contradicts the fundamental principle of value maximisation [33]. These limitations undermine the validity of using IRR as a standalone decision-making criterion, especially in long-term investment analysis [34,35]. In the proposed approach, this inconsistency is mitigated by linking the discount rate to a synthetic indicator of green transformation (ZT = risk premium vs efficiency effect), which aggregates ESG-related factors using a multi-criteria framework (TOPSIS). As a result, IRR-based project evaluation incorporates adjusted capital cost conditions, thereby improving the comparability of IRR and NPV results when assessing environmentally oriented investments.

H1. *This leads to the hypothesis that incorporating a synthetic measure of green transformation into the nominal discount rate significantly reduces the net present value (NPV) of investment projects but does not eliminate their profitability.*

In response to these challenges, the literature calls for the development of multidimensional analytical frameworks that integrate IRR, NPV, and cost–benefit analysis (CBA) with the valuation of environmental externalities, such as energy savings or CO_2 emissions reductions [36]. Monetising environmental effects enables a more accurate representation of the actual economic efficiency of green investments. In this study, ESG-related effects are operationalised through a synthetic green transformation indicator (ZT), constructed via a weighted aggregation of selected environmental variables and incorporated into the discount-rate adjustment mechanism. Green transformation and the implementation of energy-efficiency and circular-economy practices significantly impact the competitiveness of the SME sector. Empirical research indicates that companies with high ESG maturity achieve better financial results, which justifies the inclusion of reputational benefits and regulatory risks in investment analyses [37]. At the same time, the implementation of green innovations in the SME sector is fragmented, due to difficulties in translating strategic environmental goals into systematic management processes, such as Green BPM or KEI indicators [38].

H2. *These findings support the view that ESG-related factors influence not only risk perception but also the stability and resilience of investment outcomes, which underpins the hypothesis that investment projects evaluated using a real discount rate adjusted for green transformation factors show greater resilience to macroeconomic variability and environmental risks than projects valued at traditional rates.*

In the context of low-carbon investments, a deterministic approach to IRR is particularly problematic given the high volatility of energy and emission permit prices [39]. In sectors such as sustainable forestry, IRR only reflects the timing of capital flows, disregarding the marginal environmental and social costs [40]. Recent studies also highlight that macroeconomic information and risk transmission are inherently dynamic and may evolve across different regimes. For instance, research using hidden Markov models shows that commodity markets operate under distinct high- and low-volatility regimes, with latent macroeconomic information flows acting as leading indicators of broader economic conditions. Such findings indicate that market behaviour and risk exposure are not constant over time but depend on underlying structural and informational dynamics. This perspective is directly relevant to investment appraisal, as it suggests that discount rates and risk assessments should account for time-varying and regime-dependent uncertainty rather than relying solely on static assumptions [41]. Recent research shows that financial markets exhibit regime-dependent dynamics, in which interdependencies and risk transmission mechanisms differ significantly between calm and high-volatility periods, implying that risk is not constant over time but is structurally variable [42]. In response to these limitations, models that integrate ESG factors with financial accounting are being developed, enabling better risk management and improving access to capital focused on sustainable development. Recent approaches extend this perspective by incorporating uncertainty into investment appraisal through stochastic or scenario-based frameworks, allowing for the modelling of variability in energy prices, regulatory changes, and emission costs, rather than relying on single-point deterministic estimates. Expanded approaches to calculating IRR also include operational savings, reputational effects, and life cycle analysis of investments [43–47].

H3. *These considerations imply that incorporating dynamic and uncertainty-sensitive discount rate adjustments improves the alignment between theoretical valuation and real-world investment performance, which supports the hypothesis that the use of adjusted discount rates results in more accurate investment decisions, as measured by a higher correlation between financial evaluations and actual project outcomes and long-term economic stability.*

The regional dimension, encompassing regional resilience and spillover development effects, constitutes an extension of the proposed analytical framework rather than a separate analytical layer. In this study, regional heterogeneity is reflected in the synthetic green transformation indicator (ZT), which captures differences in environmental performance, innovation capacity, and infrastructure development across regions. The green transformation encourages the concentration of innovation in specialised growth centres, thereby increasing patent activity and employment in high-tech sectors. At the same time, investments in decarbonization and energy infrastructure strengthen regional resilience, but they require the integration of financial indicators with measures of regional sustainable development [48–50]. According to Porter's hypothesis, stricter environmental regulations can stimulate innovation in companies [51,52], but without appropriately modified evaluation tools, such as extended IRR models, a reliable assessment of the profitability of pro-environmental projects remains difficult. The literature indicates that classical tools, such as IRR, are inadequate under conditions of increased investment risk complexity and spatial heterogeneity [53–55].

Despite numerous studies on the valuation of investment projects and the use of discount rates, there is a significant gap in the literature regarding the formal incorporation of green transformation into the cost of capital and its impact on discounting methodology and risk assessment. Previous analyses often limit themselves to nominal or real interest rates, failing to fully integrate environmental risks and thereby underestimating

the actual financing costs of projects subject to increasingly stringent regulatory and social requirements. Furthermore, there is a lack of comprehensive research analysing how such adjustments affect long-term investment decisions and regional economic resilience, especially in the context of implementing sustainable development policies.

In the face of growing climate challenges and increasingly stringent environmental regulations, businesses (especially small and medium-sized ones) must consider ecological aspects in their investment processes. Traditional financial performance evaluation tools, such as the internal rate of return (IRR), need to be adapted to better support green transformation. The study proposed integrating a synthetic measure of green transformation into the classic IRR model to consider the impact of environmental factors on investment profitability. The methodology presented combines advanced multi-criteria analysis techniques with sustainable finance concepts, offering an innovative approach to investment decision-making in the SME sector.

3. Materials and Methods

The proposed research design integrates a systematic literature review with a structured quantitative modelling framework to evaluate the impact of green transformation on investment appraisal. The process begins with identifying a research gap: the absence of an integrated mechanism that links ESG-related transformation to traditional financial evaluation tools such as IRR and NPV. Subsequently, a synthetic Green Transformation index (ZT) is constructed using min–max normalization, the CRITIC weighting method, and TOPSIS aggregation. The resulting ZT index is incorporated into the discount rate and IRR framework, enabling empirical testing of the proposed hypotheses regarding investment performance, risk sensitivity, and decision quality under green transition conditions (Figure 1).

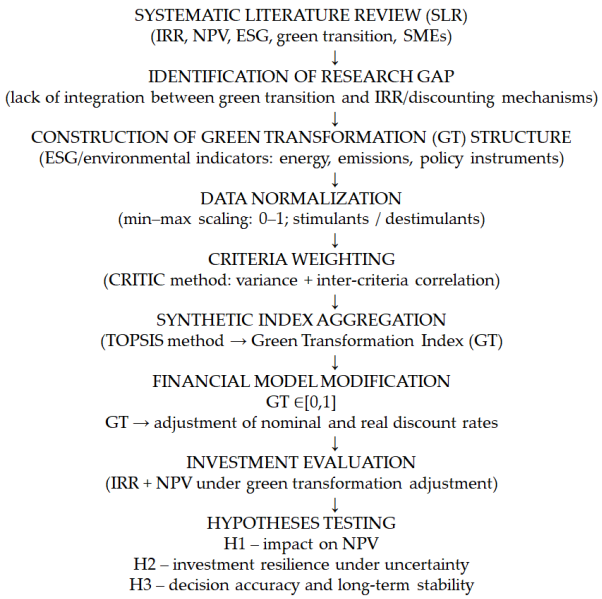


Figure 1. Methodological framework for constructing the Green Transformation (GT) index and its integration into IRR/NPV analysis. IRR—Internal Rate of Return (internal rate of return), NPV—Net Present Value (net present value), ESG—Environmental, Social and Governance (environmental, social and governance), GT—Grey Theory (grey theory), SMEs—Small and Medium-sized Enterprises (small and medium-sized enterprises), CRITIC method—Criteria Importance Through Intercriteria Correlation (method for determining criteria weights based on inter-criteria correlation), TOPSIS method—Technique for Order Preference by Similarity to Ideal Solution (method for ranking alternatives based on similarity to the ideal solution).

To conduct the study comprehensively and avoid unreliable results, the analysis process was divided into several key stages: selecting criteria and data sources, normalising variables, determining criterion weights, aggregating data using the TOPSIS method, and adjusting the return rate to account for the impact of green transformation. Each of these stages was conducted in accordance with recognised research methods, ensuring the consistency and reliability of the results obtained.

(1) Selection of criteria and data sources. A synthetic measure of green transformation (GT) was constructed from a set of ESG indicators, with particular focus on the environmental component. The selection of these indicators is grounded in both the relevant literature on measuring green transformation and their ability to capture its key multidimensional aspects. The chosen criteria reflect major dimensions of the transition process, including energy transition (share of renewable energy sources), improvements in energy and resource efficiency (energy efficiency), the level of investment commitment to environmental protection (investment outlays for ecological protection), and actual environmental pressure (pollutant emissions). Additionally, regional-level environmental policy instruments were included to account for institutional and regulatory support for the transformation process. Together, these variables provide a comprehensive and internally consistent framework for measuring green transformation at the regional level. Quantitative data for a decision matrix:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nm} \end{bmatrix} \quad (1)$$

where X_{ij}—the values of the diagnostic variables under study of the *j*-th variable (j = 1, 2,. . ., m) for the *i*-th object (i = 1, 2,. . ., n).

Model data were used for the analysis because they allow for a controlled, comparable depiction of the impact of the internal rate of return on investment decision-making in SMEs in the context of green transformation. Empirical data on actual investments in the SME sector are often limited, heterogeneous, or subject to commercial secrecy, making them difficult to obtain and compare. Using model data allows one to focus on the IRR method itself and its sensitivity to key investment parameters, which is particularly important for long-term and uncertain green projects.

(2) Data normalisation (zero-based unification). Due to the diversity of measurement units, zero-based unification was used to normalise all variables to the [0, 1] range. This method is characterised by simplicity of interpretation and high usefulness in linear or ordering analyses. Unification was performed using the min–max normalization procedure. For stimulants, the following transformation was applied:

$$Z_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}, j \in S \quad (2)$$

For destimulants, the transformation takes the form:

$$Z_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}, j \in D \quad (3)$$

where S is the stimulant, D is the destimulant, Z_{ij} is the value of the i-th unit for the j-th criterion, $\max(x_{ij})$ is the maximum value of the j-th criterion, $\min(x_{ij})$ is the minimum value of the j-th criterion, and n_{ij} is the normalised value [56,57].

(3) Determining the weights of criteria–the CRITIC method. The CRITIC (CRiteria Importance Through Intercriteria Correlation) method was used to objectively determine

the criterion weights. This method accounts for both the variability of characteristics and their mutual correlations, assigning greater importance to criteria that provide unique information. The steps include: calculating the standard deviation σ_j, determining the correlation matrix r_{jk}, and calculating the information measure:

$$\begin{gathered} C_j = \sigma_j R_j \\ \sigma_j = \sqrt{\frac{1}{m}\sum_{i=1}^{m}\left(n_{ij} - \overline{n}_j\right)^2} \\ R_j = \sum_{t=1}^{n}\left(1 - r_{jk}\right) \\ W_j = \frac{C_j}{\sum_{k=1}^{n} C_k} \end{gathered} \tag{4}$$

where σ_j is the standard deviation for the j_{th} criterion, $\overline{n}$ is the normalized mean value for the j_{th} criterion, r_{jk} is the correlation coefficient between the j_{th} and kth criteria, R_j is the sum of the distance coefficients (1 minus correlation) between the j_{th} criterion and all other criteria, C_j is the information content measure for the j_{th} criterion, w_j is the weight of the j_{th} criterion, m is the number of units (rows), and n is the number of criteria (columns) [58].

In this study, the CRITIC method (CRiteria Importance Through Intercriteria Correlation) was applied to determine the weights of criteria. This method allows for an objective, data-driven assignment of weights, taking into account both the variability of each criterion and the correlations between them. Unlike subjective methods such as AHP, CRITIC does not require expert judgments, reducing the risk of arbitrariness. Moreover, the method assigns higher weights to criteria that provide unique information and lower weights to highly correlated criteria, ensuring a more reliable, multidimensional weighting.

(4) Synthetic measure aggregation–TOPSIS. The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method was used to determine the synthetic measure of green transformation, which assumes that the best alternative is both closest to the ideal solution and farthest from the anti-ideal solution. The following are determined: the ideal object $A^+(=1)$, the anti-ideal object A^-(=0), and the distance of the object from:

$$pattern;\ \mathrm{d_i^+} = \sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{j}=1}^{\mathrm{m}} w_j\left(\mathrm{Z_{ij}} - \mathrm{Z_j^+}\right)^2} \tag{5}$$

$$anti\text{-}pattern;\ \mathrm{d_i^-} = \sqrt{\frac{1}{\mathrm{n}}\sum_{\mathrm{j}=1}^{\mathrm{m}} w_j\left(\mathrm{Z_{ij}} - \mathrm{Z_j^-}\right)^2} \tag{6}$$

where w_j—weight of the j-th criterion $\left(w_j \geq 0, \sum_{j=1}^{m} w_j = 1\right)$, Z_{ij}—is the normalised value of the j-th variable of the i-th object multiplied by the corresponding weighting factor, Z_j^+ / Z_j^-—is the reference or anti-reference object, m is the number of criteria, and n is the number of objects. A synthetic measure aggregates multidimensional data across various criteria into a single value, making it easier to compare and classify. This measure was calculated according to the formula:

$$q_i = \frac{d_i^-}{d_i^- + d_i^+},\ gdzie\ 0 \leq q_i \leq 1,\ i = 1,\ 2,\ \ldots,\ n \tag{7}$$

where $q_i \in [0, 1]$; d_i^-—denotes the distance of the object from the anti-pattern (from 0), d_i^+—denotes the distance of the object from the pattern (from 1) [56–62].

The choice of the TOPSIS method was made due to its ability to perform a multi-criteria evaluation of alternatives based on their simultaneous closeness to the ideal solution and distance from the anti-ideal solution. This approach enables a comprehensive assessment of the analyzed units by considering both positive and negative reference points. Compared to simpler aggregation methods, TOPSIS allows for more precise differentiation between

alternatives, as it accounts for their relative positions with respect to the ideal and anti-ideal solutions. Furthermore, the method is widely used in multi-criteria decision-making studies, which ensures its high methodological acceptance and comparability of results with other research.

(5) Modification of the IRR return. The internal rate of return (IRR) is the discount rate for which the net present value of cash flows is zero:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1 + IRR)^t} = 0 \quad (8)$$

The nominal rate of return is treated as a variable dependent on the level of green transformation, according to the relationship:

$$\mathrm{r_n^{ZT}} = \mathrm{r_n} \cdot (1 + \mathrm{ZT}), \mathrm{ZT} \in [0, 1] \quad (9)$$

where ZT is a synthetic measure of the green transformation of a territorial unit or industry; $\mathrm{r_n}$ is the base nominal rate of return, ZT is the synthetic measure of green transformation. The real rate of return is similarly adjusted to account for inflation.

The relationship between the nominal rate of return and the level of green transformation is grounded in the literature, suggesting that environmental transition processes may affect investment profitability through several channels. These include improvements in energy efficiency, reductions in environmental compliance costs, and enhanced access to green financing instruments and policy support mechanisms. As a result, entities with a higher level of green transformation may experience changes in expected returns due to more favourable operating conditions and lower long-term risk exposure. This functional form assumes a proportional effect of the green transformation level on the base rate of return, preserving its economic interpretability while ensuring that the adjustment remains positive and scalable. The use of a bounded synthetic index $ZT \in [0, 1]$ guarantees a gradual scaling effect, where higher levels of green transformation correspond to higher adjusted returns. The real rate of return is adjusted analogously to account for inflation. This specification is consistent with evidence suggesting heterogeneous effects of environmental transformation on firm profitability and investor perceptions across different contexts [63,64]. A positive relationship between environmental transformation and financial eco-efficiency suggests that improved environmental practices may enhance overall financial performance [65]. Moreover, green assets such as green bonds and equities have recently exhibited higher returns, driven not necessarily by fundamentally higher expected returns but by rising environmental concerns and shifting investor sentiment, highlighting the role of market-based green premia [66].

The record $r_n^{ZT} = r_n \cdot (1 + ZT)$ is based on the assumption that the green transformation is a factor that increases the effective return on investment by generating additional economic benefits, such as reducing operating costs, access to public support instruments, and improving the competitiveness of the enterprise. The variable ZT is interpreted as a positive bonus reflecting the level of advancement of pro-ecological actions and their positive impact on effective return on investment. The use of the "+" symbol is justified when the long-term benefits of green transformation—such as cost savings, access to preferential financing, or increased competitiveness—outweigh the short-term costs of implementation. The assumption is based on the interpretation that the green transformation increases the effective return on investment, rather than decreasing it.

Green transformation is considered a growth factor, generating additional economic benefits, such as cost savings, access to subsidies, and improved competitiveness of the enterprise, which is why $ZT > 0$ will play the role of a premium added to the nominal

return rate. The notation $r_n^{ZT} = r_n \cdot (1 + ZT)$ means that the level of green transformation acts as a multiplier that increases the rate of return, similar to the premium for innovation or public support. The "–ZT" symbol would only be applicable if the green transformation was seen as a source of additional costs or risk, whereas the adopted interval ZT ∈ [0, 1] provides a moderate and realistic scale of correction. Proportional scaling of nominal and real return rates using the 1 + ZT multiplier integrates the environmental dimension with classical financial tools, thereby enhancing the adequacy of investment assessment in the face of contemporary market and institutional challenges. Such an adjustment more accurately reflects the actual costs of capital and the investment risks associated with the ecological transformation, thereby strengthening the accuracy of decisions, especially in the SME sector. This method accounts for regulatory risk, the cost of failing to meet environmental standards, and bonuses for access to green finance, thereby increasing the consistency of investment assessment with the sustainable development paradigm.

Proportional scaling of nominal and real rates of return using the (1 + ZT) multiplier enables the integration of the environmental dimension with classical financial tools, thereby increasing the adequacy of investment assessment in the context of regulatory risks and costs associated with ecological transformation. This approach better reflects the actual cost of capital and investment risks, which is particularly relevant in the SME sector, while also accounting for benefits from green financing and compliance with environmental standards. The literature indicates that investment appraisal methods increasingly integrate ESG criteria with traditional financial indicators, thereby reducing information asymmetry and improving the accuracy of investment decisions [67,68]. In this context, multi-criteria decision-making methods such as fuzzy AHP and WASPAS are also applied, enabling the incorporation of uncertainty and heterogeneous environmental priorities into the decision-making process [69,70]. Furthermore, the integration of Life Cycle Assessment (LCA) with Life Cycle Cost Analysis (LCCA) enables a comprehensive evaluation of investment projects in both economic and environmental terms, supporting decision-making aligned with circular economy principles [71,72]. Finally, transparency of environmental data and standardization of ESG reporting are crucial for the effective integration of such information into investor decision-making processes [73].

In the face of global climate challenges, traditional investment assessment tools need to be redefined. In the SME sector, characterised by limited resources, it is crucial to incorporate ESG factors precisely into economic calculations. The study assumed that the internal rate of return (IRR) and the discount rate should be functions of green transformation (ZT). The proposed model assumes that the green transformation affects the risk profile and the cost of capital in a proportional manner. The adjustment of returns (nominal and real) is made through a multiplier (1/ZT), which reflects the endogenous impact of institutional-technological changes on investment profitability.

4. Results

The study analyzes the impact of different discount rate variants on the assessment of the profitability of the same investment project (initial investment-PLN 300,000) over a 5-year and 10-year horizon, using four approaches to the cost of capital: (1) nominal discount rate of 4%, (2) nominal discount rate adjusted for a synthetic measure of green transformation (ZT = 0.4) according to the formula $r_n^{ZT} = r_n \cdot (1 + ZT)$, which gives 5.60%, (3) real discount rate of 0.97% (derived from the nominal 4% at an inflation of 3%), and (4) real discount rate adjusted for a synthetic measure of green transformation according to the analogous formula $r_r^{ZT} = r_r \cdot (1 + ZT)$, which gives 1.36%. A synthetic measure of green transformation at 0.4 (at the national or regional level) reflects the additional regulatory, environmental, and technological risks associated with green transformation

and serves to internalise ESG factors through a multiplicative adjustment of the cost of capital.

The results in Table 1 show that the project generates a positive net present value (NPV) of 98,919 PLN, meaning that expected cash inflows exceed the cost of capital and create a measurable economic surplus. The IRR of 14.60% is substantially higher than the assumed discount rate, which indicates a significant margin of safety against potential increases in financing costs. This suggests that the investment remains robust under baseline financial conditions and is not highly sensitive to precise cost-of-capital estimates. However, the relatively moderate NPV level implies that the project's value creation is sensitive to changes in discount rate assumptions, which should be considered in further risk analysis.

Table 1. Cash flow analysis and evaluation of the investment project's profitability using the NPV and IRR methods.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	4%	1.0000	−300,000.00	-
flow 1	1	80,000.00	4%	0.9615	76,923.08	-
flow 2	2	85,000.00	4%	0.9246	78,587.28	-
flow 3	3	90,000.00	4%	0.8890	80,009.67	-
flow 4	4	95,000.00	4%	0.8548	81,206.40	-
flow 5	5	100,000.00	4%	0.8219	82,192.71	-
-	-	-	-	NPV=	98,919.14	a profitable
-	-	-	-	IRR=	14.60%	perform

Source: own elaboration based on model data.

Table 2 illustrates the investment project's cash flows over 10 years, discounted at a 4% rate. The initial investment is PLN −300,000, and the annual cash flows range from PLN 80,000 to PLN 35,000, with corresponding discount rates. The sum of discounted cash flows yields a positive NPV of 268,963.17 PLN, indicating the creation of economic value. The IRR of 22.39% significantly exceeds the cost of capital, indicating not only profitability but also a strong buffer against adverse macroeconomic changes. Compared to the 5-year horizon, the higher NPV reflects the increasing importance of later cash flows, suggesting that the project's value creation is driven by long-term operational stability rather than short-term gains. This structure implies sensitivity to discount rate assumptions, particularly in the terminal years of the project.

Table 2. Evaluation of the profitability of an investment project based on the NPV and IRR analysis over a 10-year horizon.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	4%	1.0000	−300,000.00	-
flow 1	1	80,000.00	4%	0.9615	76,923.08	-
flow 2	2	85,000.00	4%	0.9246	78,587.28	-
flow 3	3	90,000.00	4%	0.8890	80,009.67	-
flow 4	4	95,000.00	4%	0.8548	81,206.40	-
flow 5	5	100,000.00	4%	0.8219	82,192.71	-
flow 6	6	60,000.00	4%	0.7903	47,418.87	-

Table 2. *Cont.*

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
flow 7	7	50,000.00	4%	0.7599	37,995.89	-
flow 8	8	45,000.00	4%	0.7307	32,881.06	-
flow 9	9	40,000.00	4%	0.7026	28,103.47	-
flow 10	10	35,000.00	4%	0.6756	23,644.75	-
-	-	-	-	NPV=	268,963.17	a profitable
-	-	-	-	IRR=	22.39%	perform

Source: own elaboration based on model data.

The positive NPV and high IRR results clearly justify the project's implementation, indicating its ability to generate economic value. An analysis based on the standard discounting method ensures comparability with other projects, and the long time horizon emphasises the importance of later cash flows to the final NPV. Given the low discount rate used, the analysis is sensitive to changes in macroeconomic conditions; therefore, it is recommended to conduct sensitivity and scenario tests. In the context of green transformation, it is worth considering green risk measures in the cost of capital to better assess the project's profitability and account for environmental factors. Such an approach will increase the accuracy of investment decisions in a changing regulatory and market environment. The summary of nominal and discounted cash flows illustrates the impact of the time value of money: although nominal inflows stabilise after the 5th year, their real contribution to the NPV structure gradually decreases as the discount rate declines. The small difference between the bars in the graph (especially in the initial phase) confirms the observation of a low discount rate, which makes the project attractive but also sensitive to changes in the cost of capital (Figure 2).

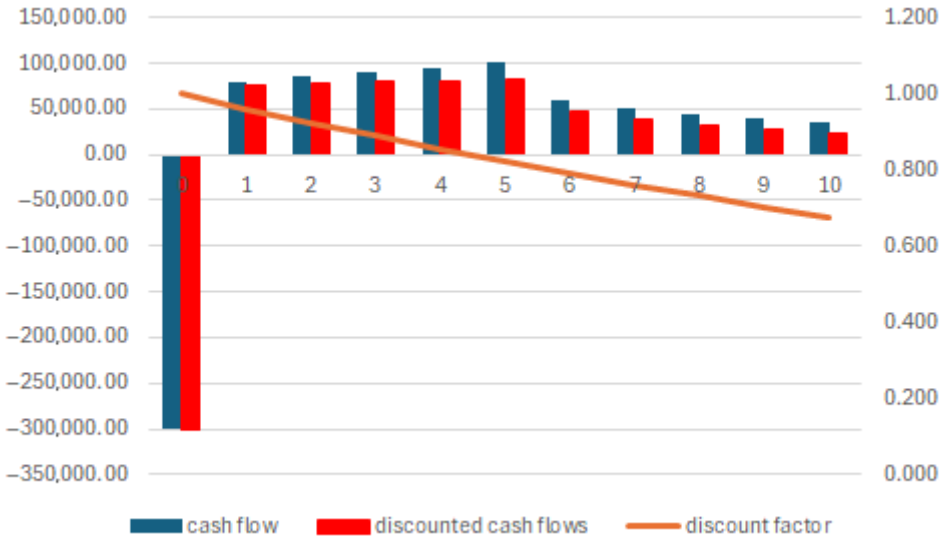


Figure 2. The time distribution of cash flows and the progression of discount factors. Source: own elaboration based on model data.

Using a higher discount rate of 5.60%, which accounts for the risks associated with the green transformation, results in greater discounting of future cash flows (Table 3). Despite the higher cost of capital, increased to 5.6%, the project continues to generate a positive net present value of 80,956.52 PLN. This indicates that the expected cash inflows still exceed the risk-adjusted discount rate, meaning the project retains its capacity to create value

even under stricter financing conditions. However, the reduction in NPV compared to the baseline scenario suggests that the project is moderately sensitive to changes in the cost of capital. Cash flows from 80,000 PLN to 100,000 PLN over the next five years, discounted at the appropriate rates, confirm the economic viability of the investment. The internal rate of return (IRR) of 14.60% significantly exceeds the adjusted discount rate, further confirming the project's attractiveness despite the inclusion of additional risk factors. Such a result testifies to the effectiveness of the investment even in conditions of increased environmental and regulatory risk.

Table 3. Evaluation of the profitability of the investment project using the NPV and IRR methods at a discount rate of 5.6%.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	5.60%	1.0000	−300,000.00	-
flow 1	1	80,000.00	5.60%	0.9470	75,757.58	-
flow 2	2	85,000.00	5.60%	0.8968	76,223.89	-
flow 3	3	90,000.00	5.60%	0.8492	76,427.69	-
flow 4	4	95,000.00	5.60%	0.8042	76,395.53	-
flow 5	5	100,000.00	5.60%	0.7615	76,151.84	-
-	-	-	-	NPV=	80,956.52	a profitable
-	-	-	-	IRR=	14.60%	perform

Source: own elaboration based on model data.

Table 4 shows the discounting of the project's ten-year cash flows at an adjusted nominal discount rate of 5.60%, reflecting the impact of green transformation. The initial investment is PLN 300,000, and the annual cash flows of PLN 80,000 to PLN 35,000 were discounted by the appropriate factors, decreasing from 1.0000 to 0.5799. The sum of the discounted cash flows yields a positive NPV of 232,262.08 PLN, indicating the project's economic viability. The internal rate of return (IRR) of 22.39% is significantly above the cost of capital, confirming the investment's attractiveness. These results indicate that the project generates added value despite the additional environmental and regulatory risks considered.

Table 4. An analysis of the profitability of the investment project, taking into account the green transformation, at a discount rate of 5.60%.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	5.60%	1.0000	−300,000.00	-
flow 1	1	80,000.00	5.60%	0.9470	75,757.58	-
flow 2	2	85,000.00	5.60%	0.8968	76,223.89	-
flow 3	3	90,000.00	5.60%	0.8492	76,427.69	-
flow 4	4	95,000.00	5.60%	0.8042	76,395.53	-
flow 5	5	100,000.00	5.60%	0.7615	76,151.84	-
flow 6	6	60,000.00	5.60%	0.7211	43,268.09	-
flow 7	7	50,000.00	5.60%	0.6829	34,144.64	-

Table 4. *Cont.*

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
flow 8	8	45,000.00	5.60%	0.6467	29,100.55	-
flow 9	9	40,000.00	5.60%	0.6124	24,495.41	-
flow 10	10	35,000.00	5.60%	0.5799	20,296.86	-
-	-	-	-	NPV=	232,262.08	a profitable
-	-	-	-	IRR=	22.39%	perform

Source: own elaboration based on model data.

Introducing a green transformation factor into the discount rate reflects the growing importance of ESG factors in assessing risk and expected returns. Despite the increased cost of capital, the project still yields a positive NPV and a high IRR, confirming its profitability and financial resilience. The increased discount rate reflects the impact of environmental policies on valuation, raising the discount rate for future benefits without eliminating the project's profitability. The long-term analysis horizon emphasises the importance of later flows, which is why it is recommended to conduct sensitivity and scenario tests to assess the resilience of the decision to changes in parameters. In summary, integrating environmental factors into the cost of capital improves the accuracy and sustainability of investment decisions in the context of green transformation. The visualisation presented confirms that, despite using a higher discount rate that accounts for the green transformation, the financial surpluses (cash flow) generated over the entire 10-year period are sufficient to more than cover the initial investment outlay of over 300,000 units. A clear downward trend in the discounting factor line illustrates the mechanism of increased discounting of future benefits, as evidenced by the growing difference between the nominal and red bars of discounted cash flows in the later stages of the project (Figure 3).

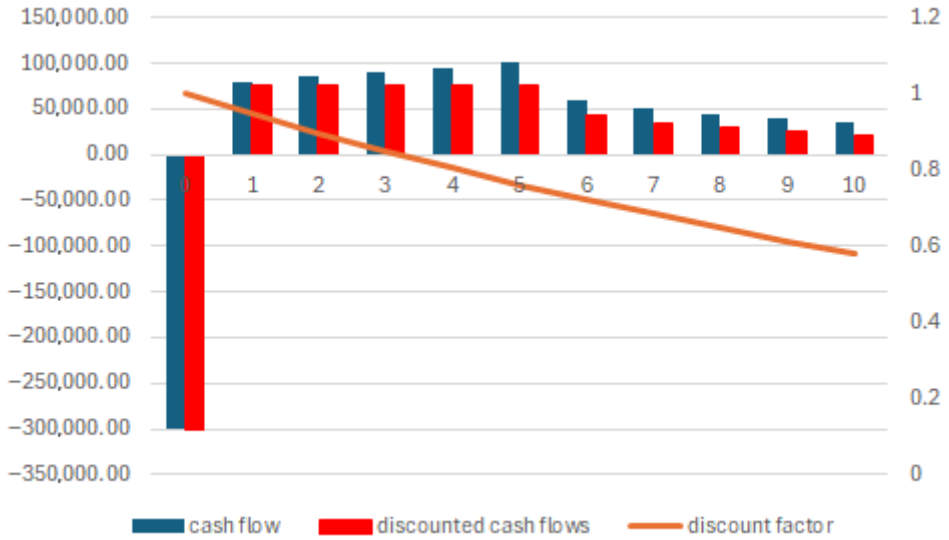


Figure 3. Nominal and discounted cash flow structure for the "Green Transformation" scenario. Source: own elaboration based on model data.

The analysis is based on a real discount rate of 0.97%, which accounts for inflation and separates nominal price effects from the real value of money over time. The initial investment cost is −300,000 PLN, and the cash flow in the next five years increases from 80,000 PLN to 100,000 PLN. A low real return rate results in a high discounted cash flow, yielding a positive NPV of 136,715.14 PLN, confirming the project's profitability (Table 5). The IRR significantly exceeds the real discount rate, which indicates that the

project generates substantial real value even after adjusting for inflation. This implies that inflation does not erode the project's profitability, and that its economic performance is driven primarily by real productivity gains rather than nominal price effects. As a result, the project demonstrates stability in real terms and low exposure to inflationary distortions. This project generates a real, inflation-adjusted increase in economic value.

Table 5. Cash flow analysis and evaluation of the profitability of the investment project using the NPV and IRR methods.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	0.97%	1.0000	−300,000.00	-
flow 1	1	80,000.00	0.97%	0.9904	79,230.77	-
flow 2	2	85,000.00	0.97%	0.9809	83,373.24	-
flow 3	3	90,000.00	0.97%	0.9714	87,428.73	-
flow 4	4	95,000.00	0.97%	0.9621	91,398.52	-
flow 5	5	100,000.00	0.97%	0.9528	95,283.88	-
-	-	-	-	NPV=	136,715.14	a profitable
-	-	-	-	IRR=	14.60%	perform

Source: own elaboration based on model data.

The financial analysis uses a real discount rate of 0.97%, which eliminates the effect of inflation and precisely reflects the value of money over time (Table 6). The project requires an initial investment of PLN 300,000 and generates a flow of PLN 80,000 to PLN 35,000 over the next ten years. The discount factors decrease gradually from 1.0000 to 0.9079, resulting in discounted cash flow values of PLN 79,230.77 in the first year and PLN 31,776.56 in the tenth year. The sum of discounted cash flows gives a positive NPV of 350,163.86 PLN, confirming the project's profitability. The IRR of 22.39% significantly exceeds the discount rate, which justifies the investment.

Table 6. Cash flow analysis and evaluation of the investment project profitability under a 0.97% cost of capital using NPV and IRR methods.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	0.97%	1.0000	−300,000.00	-
flow 1	1	80,000.00	0.97%	0.9904	79,230.77	-
flow 2	2	85,000.00	0.97%	0.9809	83,373.24	-
flow 3	3	90,000.00	0.97%	0.9714	87,428.73	-
flow 4	4	95,000.00	0.97%	0.9621	91,398.52	-
flow 5	5	100,000.00	0.97%	0.9528	95,283.88	-
flow 6	6	60,000.00	0.97%	0.9437	56,620.61	-
flow 7	7	50,000.00	0.97%	0.9346	46,730.15	-
flow 8	8	45,000.00	0.97%	0.9256	41,652.74	-
flow 9	9	40,000.00	0.97%	0.9167	36,668.65	-
flow 10	10	35,000.00	0.97%	0.9079	31,776.56	-
-	-	-	-	NPV=	350,163.86	a profitable
-	-	-	-	IRR=	22.39%	perform

Source: own elaboration based on model data.

Comparing the IRR to the real capital rate reveals a significant excess of real profitability over the cost of financing, especially for long-term, moderate-risk investments. The analysis indicates that, taking the real interest rate into account, the project is highly resistant to price changes, and its real effectiveness remains stable and unequivocally positive. As a result, the project not only creates value but also does so in a way that is resistant to inflationary pressures, which is particularly important in decision-making processes concerning strategic or pro-development investments. Furthermore, the long-term time horizon and the systematic consideration of discounted cash flows emphasise the importance of precise modelling and reliable valuation in investment decision-making. Even when accounting for the real interest rate, the financial surplus generated significantly exceeds the discounted capital costs, confirming the project's high resilience to market volatility. The slope of the discount factor line and relatively small differences between nominal and discounted cash flows illustrate the stability of the real investment efficiency over the entire 10-year time horizon (Figure 4).

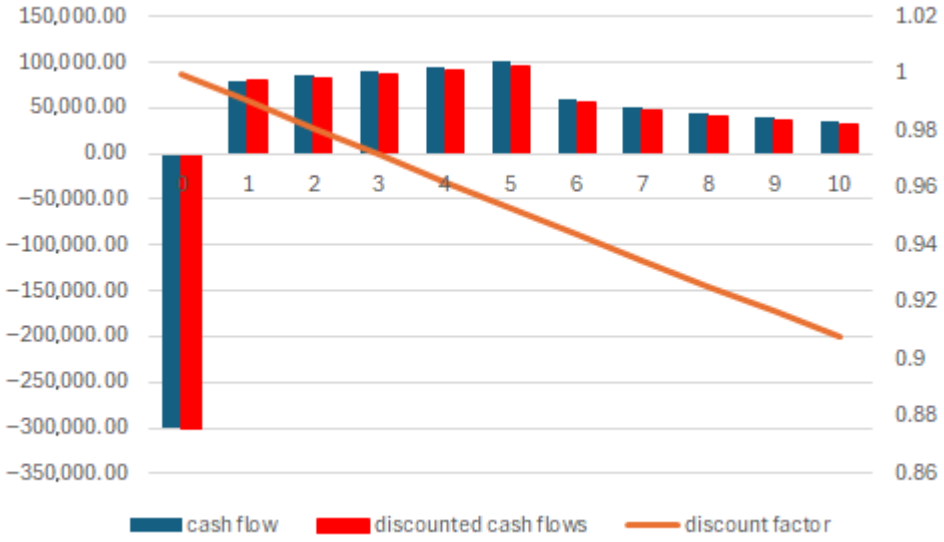


Figure 4. A summary of nominal and discounted cash flows in relation to the discounting factor. Source: own elaboration based on model data.

The analysis uses a real discount rate adjusted for the green transformation factor, yielding a value of 1.36% (Table 7). This considers both the real value of money and the additional risks associated with the green transformation, which affect the cost of capital. The project requires an initial investment of PLN 300,000 and generates positive cash flows of PLN 80,000 to PLN 100,000 over five years. Discounting at the allowed rate yielded an NPV of PLN 131,568.70, confirming the investment's profitability. The IRR of 14.60% significantly exceeds the adjusted cost of capital, justifying the project's implementation.

Table 7. Cash flow analysis and evaluation of the investment project profitability under a 1.36% cost of capital (base case scenario) using NPV and IRR methods.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	1.36%	1.0000	−300,000.00	-
flow 1	1	80,000.00	1.36%	0.9866	78,927.20	-
flow 2	2	85,000.00	1.36%	0.9734	82,735.59	-
flow 3	3	90,000.00	1.36%	0.9603	86,427.65	-
flow 4	4	95,000.00	1.36%	0.9474	90,005.80	-

Table 7. *Cont.*

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
flow 5	5	100,000.00	1.36%	0.9347	93,472.45	-
-	-	-	-	NPV=	131,568.70	a profitable
-	-	-	-	IRR=	14.60%	perform

Source: own elaboration based on model data.

The analysis is based on a real discount rate adjusted for the green transformation factor of 1.36%, which accounts for both the real value of money and additional environmental risks (Table 8). The project requires an outlay of PLN 300,000 and generates positive cash flows of PLN 80,000 to PLN 35,000 over ten years. Discounting at the adjusted rate yields a net present value of PLN 338,787.55, confirming the investment's profitability. The IRR of 22.39% significantly exceeds the cost of capital, reinforcing the decision to implement the project. The results indicate a stable and attractive return that accounts for green transformation factors.

Table 8. Cash flow analysis and evaluation of the investment project profitability under a 1.36% cost of capital with extended cash flow horizon using NPV and IRR methods.

Size	n (Period)	Cash Flow	r (Discount Rate) Cost of Capital	Discount Factor	Discounted Cash Flows	-
Initial investment	0	−300,000.00	1.36%	1.0000	−300,000.00	-
flow 1	1	80,000.00	1.36%	0.9866	78,927.20	-
flow 2	2	85,000.00	1.36%	0.9734	82,735.59	-
flow 3	3	90,000.00	1.36%	0.9603	86,427.65	-
flow 4	4	95,000.00	1.36%	0.9474	90,005.80	-
flow 5	5	100,000.00	1.36%	0.9347	93,472.45	-
flow 6	6	60,000.00	1.36%	0.9222	55,331.39	-
flow 7	7	50,000.00	1.36%	0.9098	45,491.17	-
flow 8	8	45,000.00	1.36%	0.8976	40,393.02	-
flow 9	9	40,000.00	1.36%	0.8856	35,423.42	-
flow 10	10	35,000.00	1.36%	0.8737	30,579.85	-
-	-	-	-	NPV=	338,787.55	a profitable
-	-	-	-	IRR=	22.39%	perform

Source: own elaboration based on model data.

Incorporating the green transformation metric into the discount rate increases the cost of capital, reflecting the higher return-on-investment requirements associated with environmental and social risks. Despite this, the project remains highly financially attractive, a testament to its ability to generate value amid the complex challenges of green transformation. The analysis proves the economic feasibility of the green development paradigm. The project is not only profitable in light of traditional economics but also effective when evaluated through the lens of environmental economics. This is the argument that environmental and financial goals can converge, which underpins the "Green Growth" theory. The summary of nominal and discounted cash flows shows that even with tightened profitability criteria arising from ESG risks or green transformation, the financial surplus generated (as indicated by the positive bars after year zero) permanently exceeds the cost of the capital invested. The clear slope of the discount factor line confirms the inclusion

of a higher premium for environmental risk, which does not eliminate the positive result, thus confirming the economic validity of the green growth paradigm (Figure 5).

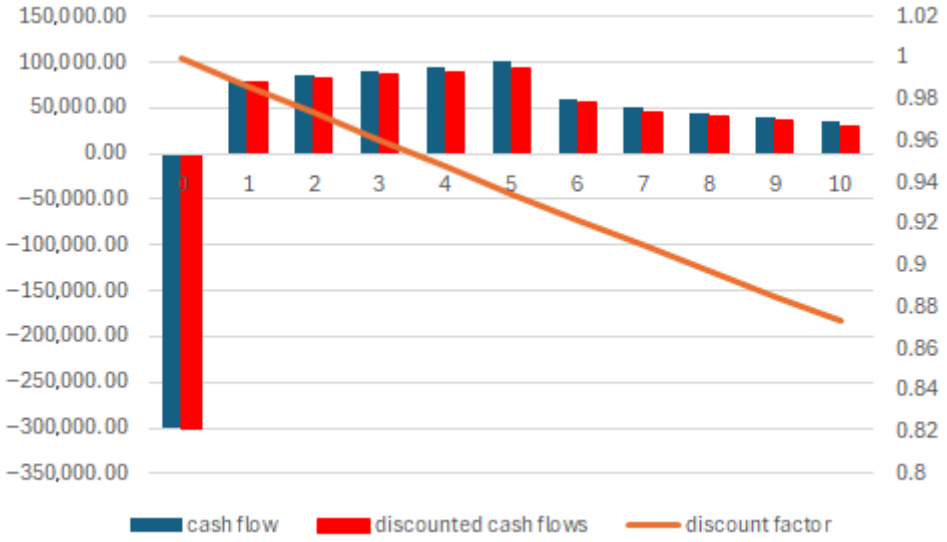


Figure 5. Nominal and discounted cash flow projections over a 5- and 10-year horizon. Source: own elaboration based on model data.

The results of the financial analysis, which take into account the theory of the time value of money and Fisher's equation by separating nominal and real terms, confirm that using real discount rates enables a precise assessment of the real growth of the investor's assets. In light of the investment theory and the NPV model, positive NPV values and stable IRR across variants indicate a high margin of safety and the project's resistance to changes in the cost of capital, driven by its technological characteristics. Adjusting the discount rate by a synthetic measure of green transformation (ZT), in line with the assumptions of modern portfolio theory, reflects the premium for systemic risk associated with energy transformation and environmental regulations, forcing investors to consider the additional cost of capital. The analysis also points to the importance of the legal and institutional environment, which relates to institutional economics—the discount rate serves as a signal of the quality of norms and regulations, such as the EU Taxonomy, that affect asset valuation.

From the perspective of environmental economics and sustainable development, introducing the ZT adjustment shifts project assessment towards strong sustainability, where a positive NPV, even under stricter criteria, indicates the investment's ability to generate profits without overburdening the ecosystem. Through the internalisation of external effects, the project accounts for the financial burden of potential negative environmental impacts, and the application of climate risk and ESG (Environmental, Social, Governance) theory enables reliable asset valuation by balancing transition risk with profitability. A long, ten-year analysis horizon emphasises that the stability of cash flows and discounted values is crucial for sustainable economic resilience, consistent with the concepts of intergenerational justice and time horizon.

In a regional context, integrating green transformation into the cost of capital supports the spike model of development, enabling the creation of growth centres that are resilient to environmental and economic risks. At the same time, it points to the need for mechanisms to diffuse benefits, counteract the negative effects of polarisation, and strengthen the resilience of entire regional systems. The results indicate that the project remains financially viable across all tested discount-rate scenarios, although the magnitude of value creation varies significantly depending on cost-of-capital assumptions. The introduction of green

transformation adjustments lowers valuation levels but does not eliminate investment attractiveness, suggesting that ESG factors operate primarily as risk premiums rather than as viability constraints. This implies that sustainability and financial performance are not inherently conflicting objectives, but their trade-off depends on how environmental risk is priced into the discount rate.

5. Discussion

Research contributes to both theory and practice by extending the analytical framework of environmental economics toward integrating ESG factors into investment appraisal. The proposed approach, combining nominal and real discount rates with a synthetic measure of green transformation, shows that ESG inclusion systematically affects project valuation. Increasing the discount rate through ESG adjustments reduces NPV across all variants but does not eliminate value creation, indicating that ESG primarily serves as a risk-pricing mechanism rather than a determinant of infeasibility. The choice between nominal and real discount rates remains crucial, as real rates tend to yield higher and more stable NPVs, underscoring the importance of inflation and sensitivity to long-term cash flows. Additionally, investor demand for ESG-compliant assets may influence discount rates independently of fundamental risk. Overall, ESG integration enhances valuation frameworks but remains sensitive to data quality and methodological assumptions [74].

The comparison of nominal and real discount-rate scenarios highlights that the discounting method significantly influences the interpretation of investment efficiency. The use of real discount rates yields higher NPVs and a more stable assessment of long-term value, suggesting that nominal approaches may underestimate real economic performance under inflationary conditions. At the same time, the higher NPVs observed over the 10-year horizon confirm that project value is strongly driven by later cash flows, thereby increasing sensitivity to discount rate assumptions and emphasising the importance of long-term stability in investment performance.

The choice between nominal and real discount rates significantly affects investment valuation, with real discount rates generally yielding higher net present values (NPVs) and more stable long-term assessments, particularly under inflationary conditions, thereby emphasising the importance of long-term cash flows and sensitivity to discount-rate assumptions. Incorporating ESG factors into discount rates—such as by introducing a green transformation factor—provides additional insight into how environmental and regulatory risks are internalised in financial analysis. The resulting decrease in NPV under adjusted discount rates confirms that ESG-related risk premiums reduce the present value of future cash flows; however, the persistence of positive NPVs across scenarios indicates that projects often retain their value creation potential even under stricter risk assumptions. This suggests that ESG considerations are quantitatively significant but not decisive for investment acceptance and should be interpreted within a nuanced risk-pricing framework rather than as binary criteria. Accordingly, adjusting discount rates for ESG risks has become a common practice among financial professionals, supported by tools such as scoring models and expert assessments that enhance valuation precision. Empirical evidence shows that integrating ESG factors into discounted cash flow models aligns valuations more closely with market realities [75,76].

The verification of research hypotheses confirms that incorporating the synthetic green transformation measure reduces NPV while maintaining positive investment outcomes (H1). Furthermore, the results show that projects evaluated using real discount rates adjusted for ESG factors exhibit greater resilience to macroeconomic variability, as reflected in consistently high IRRs that exceed the cost of capital (H2). The consistency of results across scenarios supports the conclusion that adjusted discount rates improve the reliability

of investment appraisal by aligning financial evaluation with broader risk considerations (H3). At the same time, the relatively stable IRR across variants suggests that IRR alone may be less sensitive to ESG adjustments, reinforcing its role as a complementary rather than primary decision criterion.

From a policy perspective, the findings indicate that incorporating green transformation into the cost of capital can influence investment selection by favouring projects that are more resilient to environmental and regulatory risks. The reduction in NPV observed under ESG-adjusted scenarios may lead to stricter capital allocation, but does not prevent economically viable projects from being implemented. This supports the argument that integrating ESG considerations into investment appraisal can enhance decision-making quality without fundamentally constraining economic activity. Moreover, the long-term perspective highlights the importance of aligning investment strategies with sustainability objectives to strengthen regional economic resilience.

From a business perspective, the results suggest that integrating ESG-adjusted discount rates into financial analysis improves risk awareness and supports more informed investment decisions. This is particularly relevant for small and medium-sized enterprises, where simplified evaluation methods may overlook the long-term implications of environmental risks. The findings indicate that even a relatively simple adjustment mechanism, such as a synthetic green transformation factor, can significantly alter valuation outcomes and provide a more comprehensive view of investment performance. As a result, the adoption of ESG-adjusted discounting approaches may contribute to more robust and forward-looking investment strategies.

Empirical evidence shows that strong ESG performance reduces financing costs, improves investment efficiency, and enhances corporate resilience, thereby positively influencing firm value and financial stability during market turmoil. Studies also highlight that ESG investments tend to exhibit lower volatility during crises and contribute to sustainable financial performance by aligning investment strategies with long-term sustainability objectives. Policy reforms in green finance have been shown to promote ESG performance by easing financing constraints and increasing managerial environmental awareness, further supporting sustainable development goals. Overall, integrating ESG considerations into financial analysis fosters robust economic resilience and quality decision-making without fundamentally constraining economic activity [77–79].

In summary, the results demonstrate that investment projects remain financially viable across all tested discount rate variants, although the scale of value creation is highly dependent on cost-of-capital assumptions. The integration of ESG factors into the discount rate reduces valuation levels but does not eliminate profitability, confirming that environmental and financial objectives can be aligned. This supports the view that ESG considerations should be treated as an integral component of modern investment appraisal frameworks, influencing not only risk assessment but also the strategic allocation of capital.

The results indicate that incorporating ESG-related risk into the discount rate increases the cost of capital and reduces NPV, without eliminating project feasibility. This suggests that policies aimed at internalising environmental risk may influence investment valuation and selection rather than constrain investment activity. At the same time, the findings highlight the importance of supporting long-term, resilient projects, particularly in the context of the green transition and regional economic stability.

The findings are consistent with investment theory, confirming that higher discount rates reduce NPV while reflecting increased risk. The ESG adjustment functions as a risk premium, aligning with risk-based valuation approaches. At the same time, the relative stability of IRR across scenarios suggests it is less sensitive to such adjustments, supporting

its role as a complementary decision metric. The higher valuations under real discount rates further confirm the importance of distinguishing between nominal and real analysis.

Incorporating ESG-related risks into investment valuation typically increases the cost of capital and reduces NPV, reflecting higher perceived risk, but it does not eliminate project feasibility. This aligns with financial theory, where ESG functions as a risk premium that affects discount rates, while IRR remains relatively stable. At the same time, firms with strong ESG profiles benefit from lower costs of capital and higher valuations due to reduced systematic and idiosyncratic risks 1. Although climate risks negatively impact firm value, ESG investments can mitigate these effects and support valuation growth. In sectors such as energy, resource efficiency and innovation are more significant drivers of market value than emission control or governance alone, while higher ESG risks tend to increase operational and financing costs, potentially reducing short-term cash flows but enhancing long-term resilience and sustainable growth [80,81].

6. Conclusions

The study is based on modelled cash flows and assumptions regarding nominal and real discount rates, which may limit the generalisability of the results to other economic sectors or changing market conditions. While the scenario-based approach allows for capturing key valuation differences, it remains a simplified representation of real-world investment environments.

Furthermore, the synthetic green transformation measure used in the analysis serves as an aggregated proxy for ESG-related risk. As such, it does not fully reflect the heterogeneity and sector-specific nature of environmental risks. This simplification may affect the precision of the estimated impact of ESG adjustments on project valuation, particularly in industries with highly differentiated regulatory exposure.

In addition, the analysis does not explicitly model the full dynamics of regulatory policy changes and potential external spillover effects, which may influence investment performance in practice. As a result, the observed impact of ESG adjustments should be interpreted as a stylised representation of risk internalisation rather than a comprehensive simulation of policy-driven market dynamics.

Future research could extend the model by incorporating sector-specific parameters, allowing for a more granular assessment of ESG risk differentiation across industries. It would also be valuable to include dynamic macroeconomic variables, such as inflation and interest rate variability, to improve the realism of valuation outcomes under changing economic conditions. Moreover, further studies could focus on developing more advanced quantitative frameworks for integrating ESG factors into investment appraisal, enhancing decision-support tools aligned with sustainable finance and climate policy objectives.

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