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FINANCING NUCLEAR ENERGY THROUGH SOVEREIGN GREEN BONDS: POLAND'S PATHWAY TO AFFORDABLE DECARBONISATION

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Purpose: The paper analyses how sovereign green bond financing could influence the affordability of Poland's nuclear energy programme. It examines whether green-labelled debt, through reduced yields ("greenium"), can lower the cost of capital for state-backed nuclear investments consistent with EU sustainable finance regulations.

Design/methodology/approach: A desk-based scenario analysis integrates international cost benchmarks for nuclear power (OECD/IEA & NEA, 2020) with Poland's sovereign yield curve and empirically observed greenium ranges. Levelised cost of electricity (LCOE) is modelled under alternative financing conditions, assuming sovereign guarantees for the PEJ special purpose vehicle. The analysis reflects the June 2025 Sovereign Green Bond Framework, which does not explicitly include nuclear among eligible categories.

Findings: The baseline LCOE for nuclear in Poland is estimated at €60/MWh under a 4.5% real WACC (Weighted Average Cost of Capital). LCOE increases by nearly €45/MWh between 3% and 10% WACC, confirming high sensitivity to financing costs. A greenium of 3-36 basis points would reduce LCOE by ≤ €1.5/MWh but yield fiscal savings of €250-600 million for a €10 billion sovereign issue.

Research limitations/implications: Results are illustrative, not predictive. They rely on international benchmarks and assume sovereign-backed financing. Future work should link financial modelling with power-system integration and domestic regulatory factors.

Practical implications: Green bonds could modestly reduce Poland's financing costs and signal alignment with EU sustainable finance standards, but they cannot substitute for broader credit enhancement or policy stability.

Social implications: By integrating nuclear investment within sustainable finance frameworks, Poland could strengthen public credibility in its low-carbon transition while maintaining fiscal prudence.

Originality/value: The study bridges sustainable finance and nuclear economics, demonstrating how sovereign bond structures can marginally improve affordability and credibility in coal-dependent economies pursuing decarbonisation.

Keywords: nuclear finance; green bonds; levelised cost of electricity; Poland; sustainable finance taxonomy.

Category of the paper: Research paper.

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1. Introduction

Poland's energy system remains one of the most coal-dependent in the European Union. In 2017, coal accounted for about 79% of electricity generation (Helgilibrary, 2025), and although this share has since declined to 60% in 2023 (IEA, 2023b), coal still dominates the national mix. This dependence contributes to some of the highest carbon intensity levels in Europe and exposes Poland to political and economic pressures to decarbonise. In response, the government has identified nuclear power as a central element of its long-term energy strategy. The *Polish Nuclear Power Programme* (PNP), adopted in 2020 by the Ministry of Climate and Environment, sets out plans to construct 6-9 GW of nuclear capacity by 2043, with the first reactor scheduled for 2033 (PNP, 2020). Though more recent news suggests this date to be delayed by 2036 (WNA, 2025).

Financing these programmes is among the biggest challenges energy transition in the world and Poland is no different. Nuclear plants require very large upfront capital investments and long lead-times for construction, although their fuel and operating costs are relatively low once in operation[1]. *In Poland, the first nuclear power plant is currently estimated to cost PLN 150 billion (roughly €34.6 billion) with alternate figures around USD 37-40 billion, depending on supplier and scope* (bneIntellinews, 2024). Construction is expected to begin in the mid-2020s, but commissioning may not occur until 2033–2036 or even 2040 in some forecasts. Delays of several years are already flagged by OECD and independent analyses as likely, which thereby increase financing costs (Lewandowska, 2025). Operating cost estimates are lower in comparison to fossil fuel plants, especially once fuel and carbon costs are internalized, but achieving cost-competitiveness depends heavily on achieving high utilization (capacity factors near 90%) and managing regulatory, construction, and cost-overrun risks (Göke et al., 2023).

The financing of Poland's nuclear programme is widely recognised as one of the most significant challenges in the country's energy transition. Official estimates place the cost of the first plants at PLN 115-150 billion (≈ USD 25-40 billion)[2], underscoring the scale of upfront capital requirements. International benchmarks published by the OECD/IEA/NEA (2020) indicate overnight costs for nuclear construction ranging from USD 2156 to 6920 per kW, reflecting the diversity of project outcomes across countries. Once operational, nuclear plants exhibit relatively low fuel and operating costs, but the economics of new build are highly

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[1] It is agreed that "low operating cost" depends on many specific parameters: maintenance, waste management, staffing, regulatory compliance, etc. The evidence indicates that over the long term, nuclear can be cost-competitive but is not cost-free or trivial.

[2] One government-source media article quotes a cost estimate of PLN 115 billion (≈ EUR 26.5 billion) for Poland's first nuclear power plant (Olbryt, 2025; Rogers, 2024) Another source places the estimate at PLN 150 billion (≈ €34.6 billion) per an official proxy from PEJ (PNB - Polish News Bulletin, 2024). The variation arises from differences in assumed scope (plant core cost vs full infrastructure), inclusion or exclusion of financing costs, contingencies, and fluctuations in exchange and inflation rates.

sensitive to financing conditions. Illustrative data from Lazard's Levelized Cost of Energy v18 (2025), based on U.S. experience, show that nuclear LCOE increases steeply with higher discount rates—from approximately USD 115/MWh at a 4.2 WACC to over USD 240/MWh at 10% WACC. These values are derived from U.S. benchmarks (Vogtle plant)[3] and should be treated as illustrative only. In the Polish context, where financing costs reflect higher country and project risk, actual WACC values could be higher, implying even greater sensitivity of nuclear LCOE to capital costs. This highlights how financing terms exert a disproportionate influence on overall affordability, a factor particularly relevant for Poland as it seeks to mobilise capital for large-scale nuclear deployment.

Poland intends to implement its nuclear programme through a state-owned Special Purpose Vehicle (SPV), the PEJ. Initially 100% government-owned, PEJ is expected to be partially privatised to a 51% state stake as private investors are gradually introduced. This ownership model underscores the importance of sovereign-backed financing, including the potential issuance of government bonds, guarantees, and green-labelled debt instruments. The policy environment is also shaped by the European Union's sustainable finance taxonomy, which since 2022 has recognised nuclear energy as a transitional activity, thereby enabling its inclusion in sustainable finance frameworks (Commission Delegated Regulation (EU) 2022/1214, 2022). At the same time, investor perceptions under environmental, social, and governance (ESG) criteria remain divided, underscoring the importance of labelling, external verification, and market confidence.

Against this backdrop, this paper asks: To what extent can nuclear energy contribute to Poland's long-term decarbonisation goals, and how do sovereign bond yields and financing mechanisms — including the greenium[4] — shape its affordability? To answer this question, the analysis pursues three objectives: first, to evaluate nuclear cost benchmarks under standard international assumptions; second, to model financing scenarios using Poland's sovereign bond yields and empirical estimates of the greenium, defined as the yield differential between green and conventional bonds; and third, to assess the implications of these financing outcomes for the affordability of nuclear power within Poland's decarbonisation strategy.

The contribution of this paper is twofold. Conceptually, it integrates insights from sustainable finance into the debate on nuclear power, treating financing conditions as a strategic lever comparable to technology choice or vendor selection. Empirically, it applies international cost benchmarks and evidence on green bond markets to the Polish context, quantifying the

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[3] Poland's first nuclear power plant at Lubiatowo-Kopalino will be developed by Westinghouse and Bechtel in partnership with PEJ, based on the AP1000 reactor design (Westinghouse, 2022). Same technology deployed at Vogtle Unit 3 and 4 in Georgia, USA, which forms a benchmark for LCOE calculations. The Vogtle case is therefore useful for ILLUSTRATIVE purposes in showing financial sensibility and cost dynamics, but its U.S – specific context (regulations, financial structure and supply chains) means that results should not be read as directly transferable to the Polish programme.

[4] The sovereign-level greenium (i.e. a yield discount on green bonds relative to conventional sovereign bonds) has been estimated in recent studies to average about 4 basis points in advanced economies and around 11 basis points in emerging markets, which include many Central and Eastern European countries (Ando et al., 2023).

potential cost implications of alternative financing scenarios. The remainder of the paper is structured as follows: Section 2 outlines the methodology; Section 3 presents the results; Section 4 discusses financial and policy implications; and Section 5 offers conclusions.

2. Methods

2.1. Study design and scope

This study is a desk-based scenario analysis that integrates (1) international cost benchmarks for building a new nuclear power plant (OECD/IEA & NEA, 2020), (2) a financing model that maps Poland's sovereign borrowing costs to project WACC5. Under an explicit assumption of sovereign support (e.g., guarantees/capital injections) for the state-backed SPV (Wisława-Bąk, 2025), and (3) empirically observed "greenium" effects in bond markets – typically 4 bps in advanced economies and 11 bps in emerging markets (Ando et al., 2023). The method quantifies how financing terms propagate into the levelised cost of electricity (LCOE). Poland's June 2025 Sovereign Green Bond Framework (Ministry of Finance, 2025; Reuters, 2025), was updated in line with the ICMA 2021 Green Bond Principles but does not explicitly include nuclear energy among eligible categories. Therefore, green-label effects are modelled illustratively—consistent with EU taxonomy provisions that recognise nuclear as a transitional activity (Commission Delegated Regulation (EU) 2022/1214, 2022) – rather than as commitments under the present framework. Results are illustrative rather than predictive and are used to assess affordability implications within Poland's decarbonisation strategy.

2.2. Data sources and inclusion criteria

Cost benchmarks. The primary engineering-economic reference is the OECD/IEA/NEA Projected Costs of Generating Electricity from 2020, which reports overnight capital cost (OCC) ranges for large reactors of USD 2156-6920/kW (≈ EUR 2000-6440 per kW at 2025 October exchange rates), under standard evaluation settings for discount rate, capacity factor and plant life. To capture the financing gradient, the analysis applies the WACC-LCOE sensitivity for nuclear reported in LCOE v18 (2025), where nuclear costs rise from about USD115/MWh (≈ EUR 107/MWh) at a 4.2% WACC to more than USD 240/MWh (≈ EUR 223/MWh) at 10% WACC.

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[5] This assumption reflects the Polish government's decision to finance the initial stages of the nuclear programme through the state-owned SPV *PEJ.* The law of **13 July 2023** provides for PLN 60.2 billion of budget funding for 2025-2030, and the Ministry of Finance has confirmed that the State Treasury may provide guarantees or capital injections. These measures imply that project debt would be priced off the sovereign yield curve rather than purely corporate spreads.

For financing inputs, the sovereign borrowing costs are anchored in Poland's government bond yield curve (10-30-year maturities), sourced from the National Bank of Poland's auction data. The post-2018 period is used to represent current market conditions and plausible ranges. For point estimates, the 30-year tenor (e.g. 2047 bonds yielding ~5.6% in 2025 auctions) (National Bank of Poland (NBP), 2025) is taken as the baseline, consistent with the long asset life of nuclear plants, while recognising that liquidity at ultra-long maturities is limited and often requires curve interpolation.

As for the "greenium" — the yield differential between green and conventional bonds — is parameterised using ranges reported in both sovereign and corporate studies. The most comprehensive cross-country evidence remains the IMF by (Ando et al., 2023), which estimates an average premium of about 4 basis points in advanced economies and 11 basis points in emerging markets. More recent work for the euro area by the Banque de France (Descombes, Szczerbowicz, 2024) suggests that the effect may even be slightly negative (≈ -3 bps on average), indicating that the greenium is neither stable nor guaranteed. Corporate and municipal bond markets show similar variability, with most studies finding modest premia in the low single digits (Caramichael, Rapp, 2024; Malich et al., 2024), while a subset report negligible or statistically insignificant differences (Berdiev, 2025; Dragotto et al., 2025). "Dark green" bonds with strong external validation tend to capture somewhat larger but still small premia (Dorfleitner et al., 2022). Taken together, this literature justifies treating the greenium in the modelling as a range — potentially positive, negligible, or slightly negative — rather than a fixed value.

The sources are included if they (1) provide transparent methodologies that allow replication or scrutiny of assumptions; (2) report numerical ranges directly usable in constructing financing scenarios; and (3) are recognised in the literature, typically through multilateral institutions, central banks, or peer-reviewed research. Market commentary, consultancy reports, and unaudited data releases are excluded, unless they provide unique contextual information on Poland's nuclear programme, in which case they are cited descriptively but not used in the core calculations.

2.3. Cost and financing model

2.3.1. LCOE framework

This formulation follows the standard LCOE approach applied by OECD/IEA/NEA and Lazard, using a capital recovery factor to annualise capital costs and adding operating and fuel components. The contribution of this study does not lie in modifying the LCOE equation itself, but in how financing terms are parameterised: sovereign bond yields from Poland's debt market and empirically observed greenium effects are explicitly mapped into the WACC, creating scenario-based estimates tailored to the Polish nuclear programme.

For technology $LCOE_i$[6], the LCOE formula (1) is:

$$LCOE_i = \frac{CRF(r,n) \times TCC + FOM + VOM + Fuel + Backend}{CF \times 8760} \tag{1}$$

where:

$CRF(r,n) = \frac{r(1+r)^n}{(1+r)^n - 1}$ is the capital recovery factor,

r is the real weighted average cost of capital WACC,

n is plant economic life (in years),

TCC is the total capital construction cost at the commercial operation date (COD), including the overnight construction cost (OCC) plus interest during construction (IDC) and contingency allowances,

FOM/VOM are fixed/variable O&M (operations and maintenance costs) ($/kW-yr; $/MWh),

Fuel and BackEnd include front-end fuel cycle, waste, and decommissioning annualisations respectively.

CF is capacity factor (fraction of hours per year the plant operates) 8760 = hours per year.

Relation to OECD/IEA/NEA methodology

The OECD/IEA/NEA (2020) – Projected Costs of Generating Electricity defines LCOE using a full discounted-cash-flow (DCF) formulation, in which lifetime costs and electricity output are discounted year by year and expressed as present values. The above formulation (1) of CRF expression is the closed-form special case of that DCF framework under the following assumptions: (a) capital costs are aggregated into a single all-in amount at COD (TCC = OCC + IDC); (b) O&M, fuel, and backend costs remain constant in real terms; and (c) annual electricity generation is constant at the chosen capacity factor. This simplification maintains mathematical consistency with the OECD approach while allowing transparent and replicable sensitivity analysis focused on financing effects.

Treatment of capital costs

Following OECD/IEA/NEA (2020), a seven-year linear construction schedule is assumed for nuclear plants. Interest during construction is estimated as the following formula (2):

$$IDC = OCC \times r \times \frac{d}{2} \tag{2}$$

where d= construction duration (7 years) (OECD/IEA & NEA, 2020, p. 38).

Under typical nuclear financing conditions ($r = 5 - 7\%$), this yields an uplift of roughly 18-25% above OCC, consistent with OECD and NEA statements that IDC adds 15-30% to overnight costs for long-lead technologies such as nuclear. Incorporating IDC in this way produces a total capital construction cost (TCC) comparable to the "investment cost" definition used in OECD/IEA/NEA tables and to the "all-in" capital values underlying LCOE analyses.

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[6] "i" stands for Nuclear Energy

Consistency with Lazard

LCOE studies adopt the same CRF-based structure, annualising capital costs using a fixed WACC and adding operating and fuel components per unit of output (MWh). Employing this form ensures comparability with both Lazard and OECD/IEA/NEA benchmarks.

Parameter variation

Technical parameters ($CF, FOM, VOM, Fuel, Backend$) are fixed within literature median ranges (e.g., $CF = 85 - 90\ \%$, $n = 60$years), while the financing parameter r (WACC) is varied to isolate financing effects. Capital cost scenarios (low, central, high) are produced using the OECD/IEA/NEA nuclear cost range adjusted to TCC values.

2.3.2. WACC construction and mapping from yields

Project WACC is built via a standard weighted average formula (3):

$$WACC = \frac{E}{D+E}R_e + \frac{D}{D+E}R_d(1-\tau) \tag{3}$$

where:

D and E denote the market values of debt and equity, respectively,
R_d is the cost of debt,
$R_e$is the cost of equity,
τ is the corporate income tax rate.

The base case assumes a capital structure of 70% debt and 30% equity, reflecting financing practices of large, sovereign-supported or export-credit-agency (ECA)-backed nuclear projects. The assumption lies within the empirical range reported by the OECD-NEA which documents debt-to-equity ratios of 80:20 for Barakah (UAE) and Paks II (Hungary), 98:2 (expected) for Dukovany 5 (Czechia), and 75:25 for Olkiluoto 3 (Finland) (OECD & NEA, 2024).

These projects share common features with Poland's PEJ programme: sovereign ownership of the project company, reliance on government or ECA-backed debt, and limited private equity exposure.

For the SPV model adopted in Poland, the cost of debt R_d is anchored in the yield of long-dated Polish government bonds, adjusted for two possible effects:

1. a greenium, representing yield reductions on labelled green or sustainability bonds (Section 2.4); and
2. ECA concessionality, where Export Credit Agencies such as U.S. EXIM or KEXIM provide loans, guarantees, or insurance for nuclear export projects. Their sovereign backing allows borrowers to access credit at below-market spreads—effectively a concessional reduction in the cost of debt.

The cost of equity R_e is modelled as a spread of +200-400 basis points over R_d, consistent with returns typically required by regulated or contracted utility assets (IEA, 2023b). This is a modelling assumption, not a fixed empirical constant, but it aligns with observed patterns across power-sector projects in the IEA Cost of Capital Observatory (IEA, 2023a), which shows equity returns generally exceeding debt by several percentage points in both advanced and emerging markets. Comparable differentials are found in regulated or sovereign-backed infrastructure finance, including the Hinkley Point C (UK) and Barakah (UAE) projects. The corporate tax rate is fixed at $\tau = 19\%$, Poland's statutory rate, and applied only to the debt component.

2.3.3. Mapping yields to real WACC

Because sovereign yields are quoted in nominal terms while levelised-cost models operate in real prices, nominal rates are converted using the Fisher relation equation (4):

$$r_{real} = \frac{1+r_{nominal}}{1+\pi} - 1 \tag{4}$$

where:

π is the long-term inflation anchor.

The National Bank of Poland's inflation target of 2.5 % is adopted as π.

the exact formulation is used rather than the approximation $r_{real} \approx r_{nominal} - \pi$ to maintain consistency with OECD, IMF and IEA practice.

All WACC and LCOE results are expressed in real €/MWh, allowing direct comparison with the Projected Costs of Generating Electricity (2020) and with the IEA Cost of Capital Observatory (2023a), which reports capital costs and LCOEs in constant-price terms. The Observatory further shows that financing costs account for roughly 25-30% of LCOE in advanced economies and around 50% in many emerging markets—underscoring the sensitivity of capital-intensive technologies such as nuclear power to financing conditions.

2.4. Scenario design

Scenarios are constructed along three independent axes to quantify how capital intensity, financing conditions and operational performance interact in determining LCOE outcomes.

a. Capital cost (OCC) – Three cost levels are taken from the OECD/IEA/NEA Projected Costs of Generating Electricity (2020) database:
    1. Low – lower-quartile overnight capital cost (fleet or replication case).
    2. Central – median benchmark.
    3. High – upper-quartile cost reflecting first-of-a-kind (FOAK) or schedule-risk premiums.
b. Financing (WACC) – Each case maps Poland's long-term sovereign yield (30-year point) to the cost of debt (R_d), with a capital structure of D/E = 70/30 and an equity spread of +300 bps in the base case. Alternative financing scenarios introduce green-label effects as yield reductions on R_d ("greenium"), drawn from recent empirical studies:
    1. 3 bps – conservative market average.
    2. 5 bps – externally verified "dark green" bonds.

3. 15-20 bps – typical range in broad bond-market samples.
4. 24-36 bps – labelled vs unlabeled spreads reported in selected studies (Ando et al., 2023; IEA, 2024).

For each differential, R_d and hence WACC are recomputed, and the resulting LCOE is evaluated. In addition, a sensitivity grid spanning real discount rates from 3 % to 10 % in 1-percentage-point steps reproduces the gradient approach used in LCOE v18 and earlier editions.

c. Operating performance (CF) – Capacity-factor assumptions follow international practice for baseload technologies: 85% and 90%, consistent with OECD/IEA/NEA conventions. Each $(OCC, WACC, CF)$ combination yields a distinct LCOE point. Scenario matrices are presented in Section 3 as heat-maps and tables, highlighting financing-driven cost deltas and the relative magnitude of green-label effects.

2.5. Sovereign green bond savings arithmetic

For an illustrative €10 billion 30-year sovereign issue dedicated to nuclear CAPEX (consistent with large-unit tranche sizing), annual interest-cost savings formula (5) from a greenium g (in basis points (bp)) is:

$$Annual\ Savings\ (€m) = \frac{g}{10{,}000} \times N_m \tag{5}$$

where $N_m$is the notional amount in € million.

For $N_m = 10{,}000$(€ 10 billion), this simplifies to formula:

$$Annual\ Savings\ (€m) = g \tag{6}$$

(e.g., 5 bps ⇒ €5 m/yr).

A simple undiscounted lifetime saving is 30 × g (€m). Where a present value is reported, as in the formula (7):

$$PV\ Savings = \sum_{t=1}^{T} \frac{\frac{g}{10{,}000} N_m}{(1+r_{disc})^t} \tag{7}$$

with r_{disc} set to the corresponding sovereign yield (consistency with issuer funding costs) and $T$is the maturity in years[7].

For a 30-year bond discounted at $r_{\mathrm{disc}} = 4.5\%$, the implied annuity factor is approximately 16.27, which reproduces all PV values reported in Table 5.

These bond-level savings are then propagated into the WACC (Section 2.3.2) and hence the LCOE via the CRF, allowing a direct link: greenium → cheaper debt → lower WACC → lower LCOE.

Contextually as the formula explains (8):

$$greenium \Rightarrow R_d \downarrow \Rightarrow WACC \downarrow \Rightarrow CRF \downarrow \Rightarrow LCOE \downarrow \tag{8}$$

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[7] In numerical illustrations N_m = €10,000million (€10 billion), T = 30years, and $r_{\mathrm{disc}}$is the real sovereign yield. The summation index t runs from 1 to T. The summation and annuity-factor forms of equation (6) are algebraically identical.

2.6. Consistency checks and validation

To ensure the robustness and internal coherence of the modelling framework, the results were subjected to a series of validation and consistency checks consistent with international methodological guidance. The approach follows the validation principles outlined in the OECD/IEA/NEA "Projected Costs of Generating Electricity" (2020), which emphasises benchmarking of levelised cost estimates across countries and technologies to ensure methodological comparability and transparency. In this study, model outputs were cross-checked against the reference LCOE ranges reported for nuclear power under comparable discount-rate and capacity-factor assumptions, confirming that the baseline values remain within the internationally observed cost bands.

Gradient and sensitivity checks were further applied to verify the expected monotonic relationship between the WACC and the LCOE, ensuring that the magnitude of change (ΔLCOE/ΔWACC) was consistent with both the direction and scale reported in the OECD/IEA/NEA analysis (2020). In addition, a back-solving test was performed using the CRF to confirm that the implied cost differentials correspond to the observed WACC variations.

Finally, the results were compared against independent methodological standards established in "A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies" (Short et al., 1995), which stress that economic evaluation of energy systems must incorporate verification of parameter sensitivity and alignment of base-case assumptions with recognised financing norms. This multi-stage validation procedure ensures that the model not only maintains internal numerical consistency but also conforms to accepted international practice in LCOE analysis.

2.7. Limitations

Several limitations should be acknowledged regarding the interpretation and transferability of the results. First, while the OECD/IEA/NEA OCC ranges and Lazard-derived WACC sensitivities provide internationally recognised benchmarks, their direct application to the Polish context may be constrained by domestic supply-chain characteristics, regulatory factors, and project-specific schedule risks. Second, the assumed greenium values are inherently sample and period dependent, implying that realised yield differentials for Polish sovereign green issuance could vary above or below the illustrative ranges applied here.

Third, the financing framework assumes full sovereign backing through guarantees or export credit agency (ECA) wraps; any deviation from this assumption would increase the effective cost of debt (R_e). Fourth, non-capital cost components, such as operations, maintenance, and fuel costs, were held constant to isolate the marginal impact of financing conditions. Consequently, the analysis does not capture future variability in back-end or fuel-cycle costs. Finally, the nominal programme size of €10 billion was adopted as an illustrative scaling convention; in practice, national nuclear financing is expected to proceed through multiple tranches and heterogeneous instruments.

2.8. Replicability statement

All equations are provided; inputs are standard (yield points, OCC ranges, operating parameters). A reader can reproduce every table by applying Sections 2.3-2.5 with the same parameter values. Where ranges are reported (e.g., 15-20 bps), both endpoints are calculated and shown.

3. Results

3.1. Baseline LCOE levels

Table 1 presents LCOE values for nuclear power in Poland under the central overnight capital cost (OCC) case and capacity factor of 90%. The baseline financing scenario assumes a real WACC of 4.5%, corresponding to Poland's long-term sovereign yield without greenium adjustment. For comparison, results are also shown across the sensitivity range of 3-10% WACC.

Table 1.
Baseline LCOE for central OCC and CF = 90% (real €/MWh)

Real WACC %	LCOE (€/MWh)
3.0	51.4
4.0	57.1
4.5 (base)	60.0
5.0	63.1
6.0	69.4
7.0	75.9
8.0	82.6
10.0	96.2

Note. Values in real € /MWh.

The results show that the baseline cost of nuclear electricity in Poland—about €60/MWh at a 4.5% real WACC—falls within the range of international benchmarks reported by OECD/IEA/NEA (2020). The steep increase from €51/MWh at 3% WACC to €96/MWh at 10% WACC underscores the dominant role of financing terms in determining overall affordability. This gradient is further analysed in Section 3.2.

3.2. Sensitivity to financing costs (WACC gradient)

The relationship between financing conditions and nuclear generation costs is summarised in Table 2, which presents the sensitivity of the LCOE to changes in the WACC under alternative OCC scenarios. The results show how even moderate increases in WACC produce substantial rises in LCOE, reflecting the capital-intensive nature of nuclear power.

Table 2.
LCOE sensitivity to WACC for OCC scenarios (CF = 90%; real €/MWh)

Real WACC %	3	4	5	6	7	8	10
OCC: Low	46.8	51.5	56.4	61.5	66.9	72.3	83.5
OCC: Central	51.4	57.1	63.1	69.4	75.9	82.6	96.2
OCC: High	56.0	62.7	69.8	77.2	84.9	92.8	108.9

Note: (for both tables 2&3). Inputs: plant life 60 years; FOM €120/kW·yr; VOM €2/MWh; fuel €7/MWh; backend €2/MWh. OCC sets: Low €4500/kW; Central €5500 /kW; High €6500/kW. Values are in real €/MWh.

Across all OCC scenarios, the results confirm a near-linear relationship between WACC and LCOE. Each one-percentage-point increase in the real discount rate raises the LCOE by roughly €6-8/MWh in the central cost case, underscoring the high financial leverage of nuclear investments.

Figure 1 visualises these results as a two-dimensional heat map, highlighting the steep gradient of LCOE with respect to WACC across the low, central, and high OCC cases.

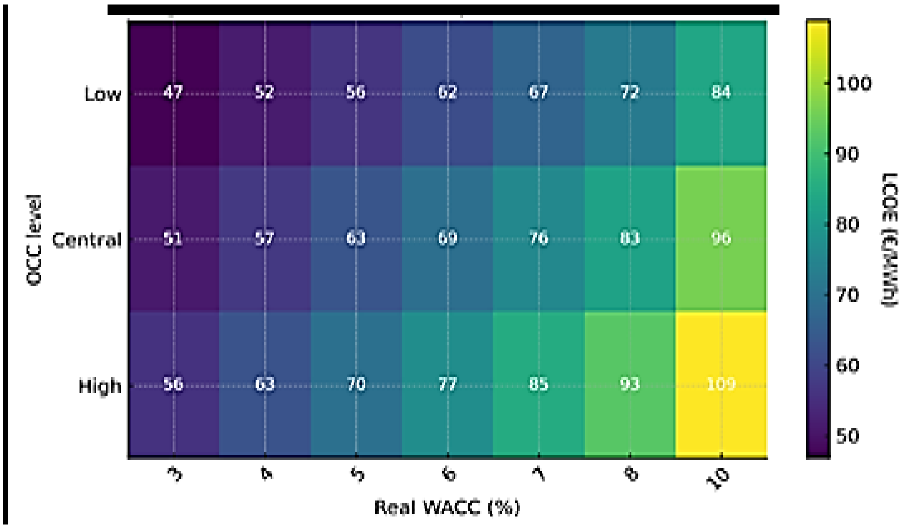


Figure 1. Heatmap of LCOE vs WACC and OCC (CF = 90%).

The heat map in Figure 1 confirms the steep cost gradient observed numerically in Table 2. Nuclear LCOE rises sharply once the real WACC exceeds about 6%, while cost differences between the low and high capital-cost cases remain roughly parallel across the financing range. This consistency supports the robustness of the model and provides the baseline against which the impact of green-label financing is examined in Section 3.3.

To test the influence of operating performance, Table 3 extends the analysis to a lower capacity factor of 85 %, illustrating how reduced utilisation amplifies the cost impact of higher WACC.

Table 3.
LCOE sensitivity to WACC for OCC scenarios (CF = 85 %; real € /MWh).

Real WACC %	3	4	5	6	7	8	10
OCC: Low	49.0	53.8	59.0	64.5	70.2	75.9	87.8
OCC: Central	53.8	59.8	66.1	72.8	79.7	86.8	101.2
OCC: High	58.7	65.7	73.2	81.1	89.3	97.6	114.7

Note: (for both tables 2&3). Inputs: plant life 60 years; FOM €120/kW·yr; VOM €2/MWh; fuel €7/MWh; backend €2/MWh. OCC sets: Low €4500/kW; Central €5500 /kW; High €6500/kW. Values are in real €/MWh.

The 5-percentage-point reduction in capacity factor increases LCOE by about €3-5/MWh across all WACC values, confirming that while financing dominates total cost, operational efficiency remains an important secondary driver. This completes the base-case sensitivity analysis and provides the reference point for assessing the impact of green-label financing in Section 3.3.

3.3. Greenium Scenarios (central OCC, CF = 90%)

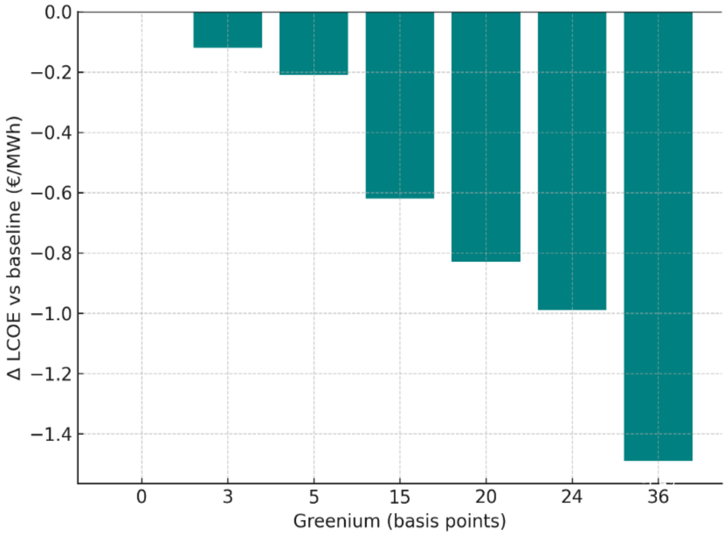
The potential impact of green-label financing on nuclear affordability is illustrated in Table 4, which quantifies LCOE reductions arising from various *greenium* levels. Each scenario converts a yield differential into an adjusted real WACC, showing the marginal—but measurable—effect of cheaper debt on generation cost.

Table 4.
LCOE impact of greenium via WACC mapping (real terms) Greenium scenarios (central OCC, CF = 90%)

Greenium (bps)	Δ Rd (bps)	Real WACC (%)	LCOE (€/MWh)	Δ LCOE vs baseline (€/MWh)
0	0	4.500	60.00	0.00
3	-2.1	4.479	59.88	-0.12
5	-3.5	4.465	59.79	-0.21
15	-10.5	4.395	59.38	-0.62
20	-14.0	4.360	59.17	-0.83
24	-16.8	4.332	59.01	-0.99
36	-25.2	4.248	58.51	-1.49

Note: WACC reduction ≈ (D/(D+E))×g = 0.70×g bps. Baseline (no greenium) equals the 3.1 central case: €60.00/MWh at 4.5% real WACC. Values rounded to 0.01 €/MWh.

As shown in Figure 2 below, the relationship between LCOE and greenium is nearly linear at small yield differentials but flattens for larger values, indicating diminishing marginal cost benefits from additional greenium gains.



Note: Sovereign green bond savings (€10bn, 30-year, real).

Figure 2. *LCOE reductions under alternative greenium assumptions (central OCC, CF = 90%).*

The patterns in Figure 2 provide the empirical bridge to Section 3.4, which assesses these same financing differentials from the perspective of the sovereign issuer rather than the project company.

3.4. Sovereign green bong savings (€10 bn, 30 year, real)

Building on the project-level results in Section 3.3, this subsection evaluates the same financing differentials from the perspective of the sovereign issuer. The fiscal implications of green-labelled issuance are summarised in Table 5, which converts each assumed *greenium* into annual, undiscounted, and present-value interest-cost savings for a notional € 10 billion 30-year bond, directly linked to the financing assumptions outlined in Section 2.5.

Table 5.
Interest-cost savings from greenium (issuer perspective) as Sovereign green bond savings (€10bn, 30-year, real)

Greenium (bps)	Annual saving (€m/yr)	Lifetime undiscounted (€m)	PV saving at r_{disc} = 4.5% (€m)
3	3	90	48.8
5	5	150	81.3
15	15	450	243.9
20	20	600	325.2
24	24	720	390.2
36	36	1,080	585.3

Note. Annual saving = g (€m/yr) on €10bn notional. PV uses annuity factor for 30 years at 4.5% (~16.27).

These results indicate that even modest *greenium* levels can yield meaningful fiscal benefits at the sovereign scale: a 15-20 bp differential corresponds to discounted savings of roughly €250-325 million, while the most optimistic 36 bp case exceeds €580 million. The next subsection (Section 3.5) verifies the internal consistency of these calculations.

3.5. Model validation and consistency checks

The results were subjected to internal validation following the procedures described in Methods (§2.6). The gradient check confirmed that the relationship between WACC and LCOE behaves as expected and is consistent with international benchmarks. In the central OCC case, the LCOE increases from €51/MWh at a 3% WACC to €96/MWh at 10% WACC, corresponding to a difference of approximately €45/MWh. This gradient aligns closely with the range reported in Lazard (2025), where nuclear LCOE rises by roughly 60-100 USD/MWh between comparable financing assumptions (4-10% WACC).

A back-solve validation was also conducted: for selected scenarios, the implied WACC differences reverse-calculated from the CRF reproduced the input deltas to within rounding error, confirming internal numerical consistency of the model. Moreover, the absolute LCOE values across OCC and capacity factor cases remain within the benchmark ranges documented by the OECD/IEA/NEA (2020) when evaluated at their standard discount rates, supporting the external validity of the results.

4. Discussion

4.1. Baseline cost position

The baseline estimate of €60/MWh for nuclear electricity in Poland, derived under central overnight capital cost assumptions and a real WACC of 4.5%, places nuclear broadly within the competitive range of low-carbon generation technologies. While this value is higher than the short-run marginal cost of existing coal assets, it is comparable to the projected costs of new renewable and gas-fired generation once system integration and carbon pricing are accounted for. The result underscores the central role of financing conditions in shaping nuclear competitiveness: with technical parameters held constant, the baseline outcome reflects primarily the sovereign cost of capital. This indicates that nuclear deployment in Poland is not constrained by intrinsic technology costs but rather by the ability to secure favourable financing. Importantly, the baseline scenario provides a reference against which the impact of financing innovations, such as green bond issuance, can be assessed.

4.2. Financing sensitivity and WACC gradient

The results highlight the exceptional sensitivity of nuclear costs to the weighted average cost of capital. Across the central overnight capital cost scenario, LCOE increases by approximately €45/MWh between 3% and 10% WACC, a gradient fully consistent with international benchmarks such as Lazard's estimates (2025) and the OECD/IEA/NEA (2020) cost ranges. This steep profile illustrates that financing terms exert a far greater influence on project viability than variations in operating or fuel costs, which remain relatively minor contributors to total generation cost. For policymakers, this reinforces the notion that nuclear energy is uniquely exposed to sovereign credit conditions and risk perceptions in capital markets. In practical terms, even modest changes in the discount rate translate into double-digit changes in the delivered cost of electricity, implying that financial structuring is as decisive as technological efficiency in determining overall competitiveness.

4.3. Effect of greenium on project economics

The introduction of a greenium produces only modest reductions in LCOE at the plant level, with the most optimistic scenario yielding a saving of just under €1.5/MWh relative to the baseline (Section 3.3). While this appears limited when viewed in isolation, the effect scales with system size. Applied across several gigawatts of capacity, even a €1/MWh reduction corresponds to hundreds of millions of euros in avoided lifetime costs for the Polish nuclear fleet.

These magnitudes are consistent with empirical evidence on green-labelled bonds, which typically report yield premia in the range of 3-5 basis points, with larger spreads being exceptional and context-dependent (Ando et al., 2023). The findings therefore suggest that while the greenium alone will not transform project-level economics, it can nonetheless deliver non-trivial system-wide savings and contribute to lowering perceived financial risk in capital markets, an effect that may indirectly improve financing access and cost over time.

4.4. Sovereign green bond implications

From the perspective of the sovereign issuer, the interest-cost savings from green-labelled debt are more pronounced than the marginal LCOE effects. A €10 billion 30-year bond could generate discounted savings of roughly €250-600 million under plausible greenium ranges (Section 3.4). Although this represents only a small share of total programme expenditure—expected to exceed €60 billion (PNP, 2020; bne Intellinews, 2024)—the fiscal significance remains substantial.

Reduced financing charges directly ease budgetary pressure, improve debt sustainability, and can enhance investor confidence in long-term transition instruments. In addition, sovereign issuance of nuclear-linked green bonds would carry a signalling effect: it would demonstrate compliance with EU sustainable finance taxonomy provisions that recognise nuclear energy as a transitional activity (Commission Delegated Regulation (EU) 2022/1214, 2022) and reinforce perceptions of policy stability. In this sense, the sovereign benefit extends beyond numerical savings, positioning nuclear as an investable component of Poland's decarbonisation strategy and aligning public-sector finance with broader ESG market expectations.

4.5. Policy and strategic relevance

Taken together, the results indicate that green bond financing offers meaningful—but not transformative—benefits for nuclear deployment in Poland. The dominant driver of competitiveness remains the overall cost of capital, which depends on sovereign creditworthiness, market risk perception, and the institutional design of the financing framework. Within this context, green-labelled instruments should be regarded as a complementary tool, not a substitute for comprehensive financing reforms or sovereign credit enhancement.

Again, it must be highlighted that Poland's principal value lies in signalling compliance with the EU Sustainable Finance Taxonomy (Commission Delegated Regulation (EU) 2022/1214, 2022), broadening the investor base, and marginally reducing borrowing costs when deployed at scale. For Poland—a country seeking simultaneously to exit coal dependence and strengthen energy security—these characteristics carry significant strategic relevance. By integrating nuclear investment within sustainable finance frameworks, policymakers can enhance both the credibility and the affordability of the programme while setting a precedent for other carbon-intensive economies pursuing nuclear power as part of their decarbonisation pathways.

4.6. Limitations and future research

The analysis presented here is based on standardised international cost benchmarks and stylised financing assumptions rather than project-specific Polish data. While this ensures comparability with OECD and IEA studies, it necessarily abstracts from domestic construction risks, regulatory features, and market conditions that could materially influence realised costs.

A further limitation concerns the stability of the greenium itself: empirical evidence indicates that the yield differential varies across issuers, market cycles, and regulatory environments, raising uncertainty over its persistence across a multi-decade investment horizon.

Moreover, the analysis isolates financing effects from broader system-integration dynamics, including grid reinforcement, balancing requirements, and interactions with variable renewables. Future research should therefore link financial modelling with power-system simulations to capture the full implications of nuclear deployment under alternative financing structures. Comparative work across Central and Eastern European economies would also help assess the general applicability of sovereign and green-bond mechanisms in coal-dependent transition contexts.

5. Summary

This paper has examined the cost implications of financing Poland’s planned nuclear programme through sovereign green bonds. Drawing on OECD/IEA/NEA benchmarks, the baseline LCOE for nuclear power was estimated at € 60/MWh under central capital cost assumptions and a 4.5% real WACC, broadly consistent with international ranges. The results confirm the exceptional sensitivity of nuclear costs to financing conditions, with LCOE increasing by almost €45/MWh between 3% and 10% WACC.

The analysis of greenium effects indicates that while reductions in project-level LCOE are modest (≤ €1.5/MWh), the scale of national investment amplifies their fiscal significance, generating system-level savings of several hundred million euros. From a sovereign perspective, the issuance of a € 10 billion green bond could yield discounted savings of €250-600 million, while simultaneously signalling compliance with the EU sustainable finance taxonomy.

Overall, green bonds should be viewed as a complementary tool within a broader nuclear financing strategy. Their value lies not in transforming nuclear economics but in marginally improving affordability, diversifying the investor base, and enhancing policy credibility. Future research should link financial modelling with system-level energy analysis to capture the wider implications of green-labelled financing for decarbonisation pathways in coal-dependent economies.

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