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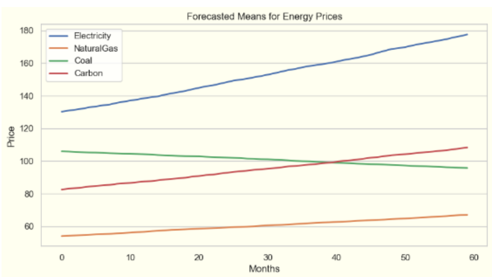
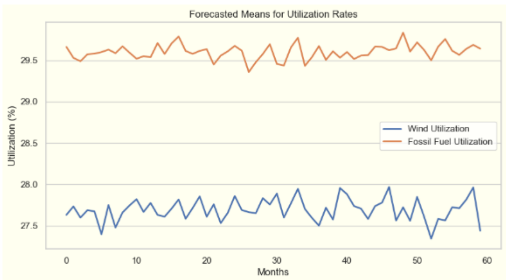
Dutch Investment Firm: Energy Investment Analysis

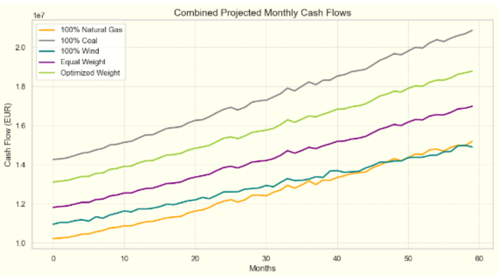
This report evaluates three energy sector investment options—natural gas, coal, and wind energy—for a Netherlands-based investment firm. It highlights key risks, including fluctuating commodity prices, regulatory uncertainties, and geopolitical instability. Leveraging a robust analytical framework that incorporates Monte Carlo simulations and a copula-based approach, our analysis suggests that natural gas investments should be avoided due to their high default risks and potential exposure to regulatory changes.

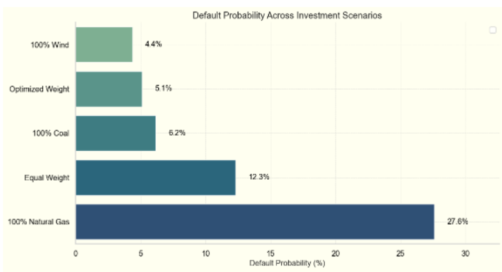
Instead, we recommend a diversified portfolio with 65% allocated to wind energy and 35% to coal. This balanced strategy maximises returns while recognizing a 5,1% default risk. The approach minimizes exposure to sector-specific volatility and aligns with sustainable investment principles, ensuring optimal returns under varying market conditions.

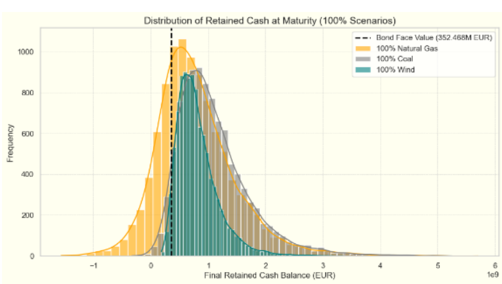
To further enhance risk management, we propose implementing customized hedging strategies to address commodity price fluctuations, alongside proactive debt management to improve the financial stability of the selected assets.

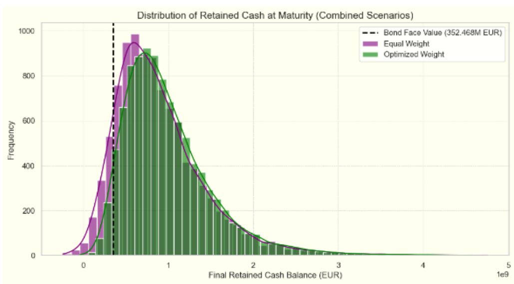












Recommendation:

Invest 65% in Wind and 35% in Coal.

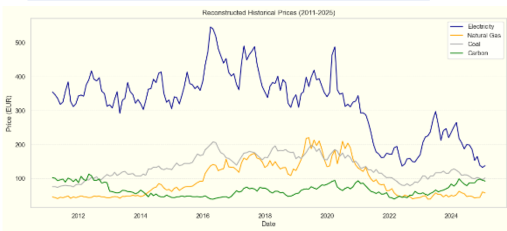
Financial Instrument Overview

Investment Scenario	Estimated Derivative Value (€M)
100% Wind	0
Optimized Weight	0.4
100% Coal	1.46
Equal Weight	2.87
100% Natural Gas	33.58

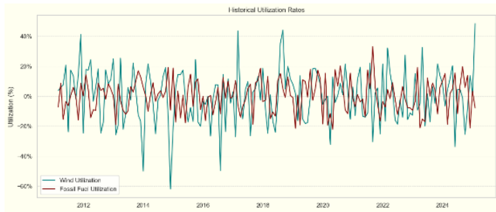
Current Bond Face Value	342
Expected Annual Yield	12%

Investment Scenario	Optimized Bond Face Value (€M)
100% Wind	353.89
Optimized Weight	355.75
100% Coal	358.44
Equal Weight	367.91
100% Natural Gas	432.49

Historical Overview (2011-2025)



Historical Energy Prices



Historical Utilization Rates

Analysts

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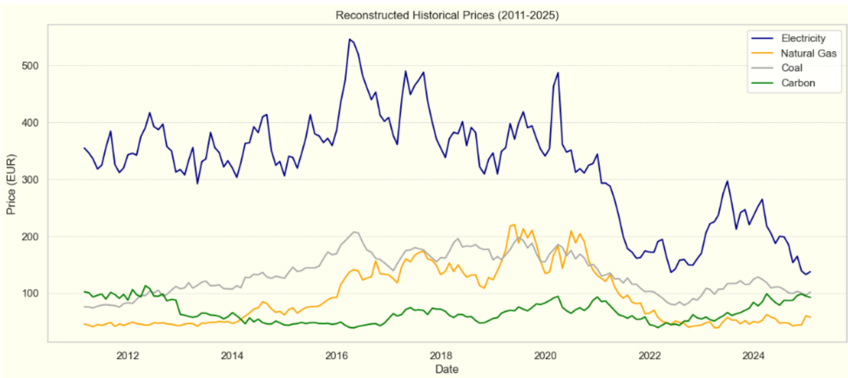
Context & Objective

Our team strives to evaluate investments into projects involving natural gas, coal, and wind energy production. The firm is considering funding their 200 million EUR investment via a zero-coupon bond – with a face value of 352.468 million EUR: at an expected annual yield of ~12% over a five-year horizon. Given the inherent uncertainty in energy prices, utilization rates, and operational costs, our objective is to develop a robust simulation framework to forecast monthly cash flows under various investment scenarios. By doing so, we assess the default risk associated with each project, determine the optimal mix of investments to support this transaction, and recommend appropriate adjustments to bond pricing if deemed suitable. Ultimately, our analysis strives to provide insights for the investment firm to take tangible steps on, enhancing their risk management strategy whilst aligning with target returns.

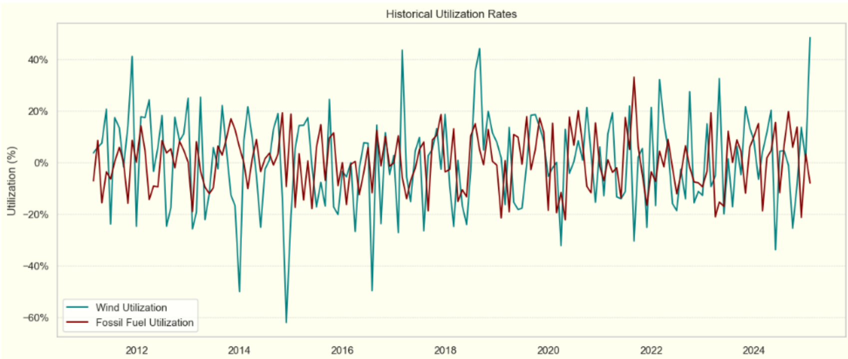
Model Estimation

Energy markets are characterized by extreme volatility, driven by geopolitical events, regulatory changes, and imbalances in supply and demand. These fluctuations create significant challenges in forecasting price movements and utilization rates, making traditional econometric approaches insufficient for capturing the full range of risks. Many conventional models assume normal distributions, which systematically underestimate the probability of extreme price swings. To address this limitation, we developed a Bootstrapping with Copula-based simulation model that effectively integrates tail risks, nonlinear dependencies, and interdependent market behaviours. This model provides a more accurate and comprehensive framework for energy investment decision-making, offering better insights into future market scenarios.



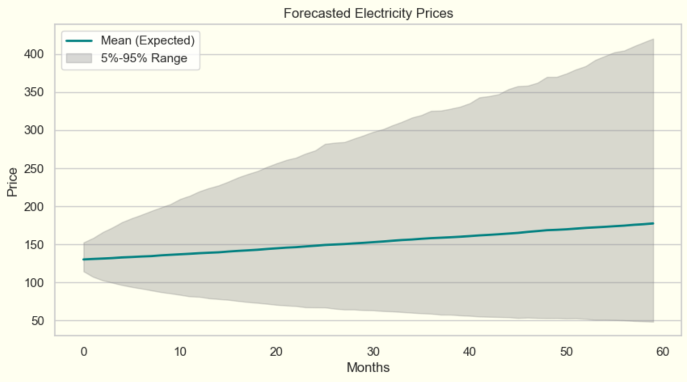
Our model incorporates key energy market variables, all of which play a significant role in shaping energy price fluctuations. The primary inputs include:

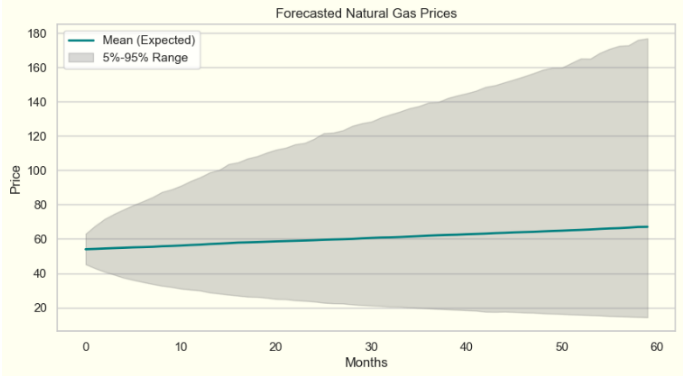
- Electricity Prices (EUR/MWh)
- Natural Gas Prices (EUR/MWh)
- Coal Prices (EUR/ton)
- Carbon Offset Prices (EUR/ton of CO_2)
- Wind Power Utilization (% of Capacity)
- Fossil Fuel Utilization (% of Capacity)

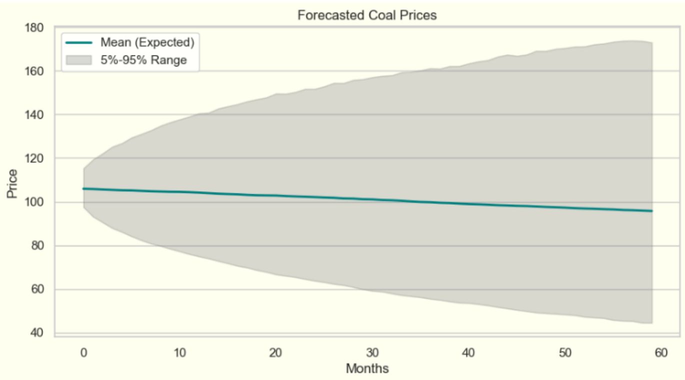


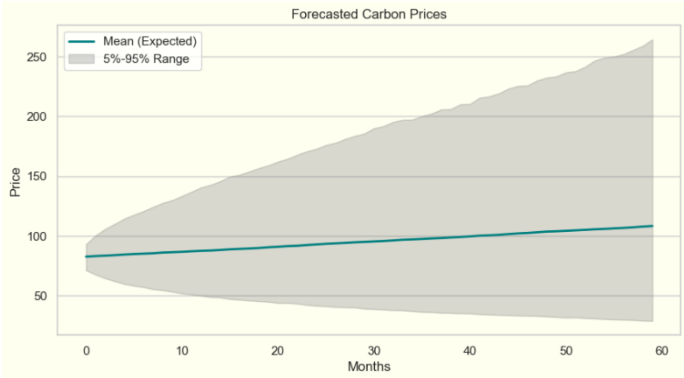
We use historical monthly price data from 2011 to 2025, which captures periods of high volatility. Additionally, historical utilization rates for wind energy and fossil fuel generation are incorporated to account for variability in power production. These utilization trends help model how energy production responds to market shocks and seasonal fluctuations.

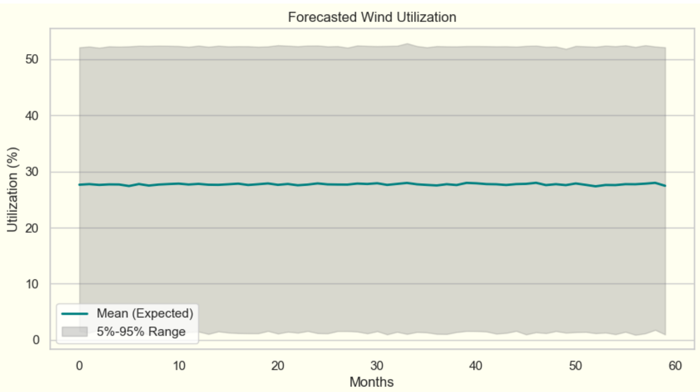
To simulate future price movements, we generate monthly returns for each energy type based on historical data. The Bootstrapping with Copula modelling approach was selected over traditional time-series models such as ARMA (Autoregressive Moving Average) and GARCH (Generalized Autoregressive Conditional Heteroskedasticity) due to its ability to better capture market dependencies and extreme price fluctuations. One key advantage of this method is that it does not impose a specific parametric distribution on returns. Instead, it preserves the empirical return distribution while allowing for flexible dependency structures through copula modelling.

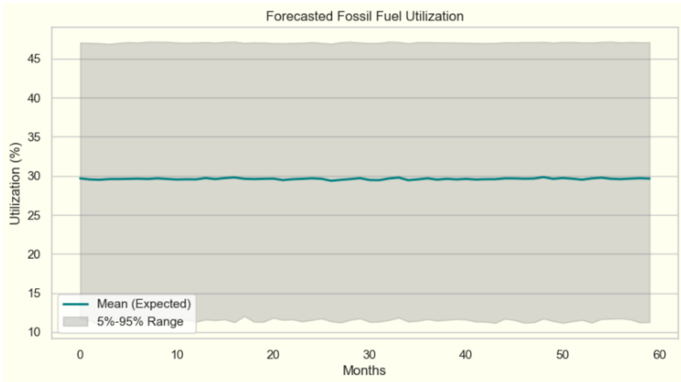












A major limitation of ARMA/GARCH models is their reliance on conditional normality assumptions, which tend to underestimate fat-tailed risks and fail to account for extreme price fluctuations observed in commodity markets. Our approach retains these extreme events by using a t-copula, which better preserves joint tail dependencies across different energy prices. This is particularly important because energy markets exhibit strong interdependencies, where price fluctuations in one commodity, such as natural gas, can directly influence electricity prices and carbon offset costs. Traditional time-series models assume linear dependencies, whereas the copula-based approach captures these relationships even during market stress conditions.

By applying a bootstrapping technique to historical returns, we ensure that the full range of market behaviour—including high volatility periods—is reflected in our forecasts. To further enhance our model, we use a Monte Carlo simulation framework, running 10,000 simulations over a 60-month forecast horizon. This allows for the generation of a wide range of potential market conditions, which is essential for stress-testing investment scenarios under extreme conditions.

One of the most critical challenges in modelling energy prices is dealing with volatility. Instead of relying on ARMA/GARCH-based volatility estimates, which may smooth out tail events, we incorporate historical volatility directly into our bootstrapped samples. Additionally, to prevent statistical anomalies while preserving tail risks, we apply a clipping-based winsorization process. The top 0.1% and bottom 0.1% of returns are adjusted to mitigate the impact of extreme outliers while ensuring that realistic downside risks remain. Further, to prevent unrealistic pricing distortions, we impose a lower price floor of EUR 0.1.

For utilization rates, an additional adjustment is necessary, as they must remain within a logical range of 0% to 100%. Without constraints, extreme values in the simulated dataset could lead to unrealistic utilization rates. To prevent this, we apply a clipping process that ensures wind and fossil fuel utilization remain within their expected operational ranges. This step ensures that projected electricity generation remains consistent with industry constraints.

To assess the sensitivity of our model, we examine how variations in key parameters influence forecasted outcomes. One major sensitivity factor is the choice of degrees of freedom in the t-copula. A lower degrees-of-freedom setting (e.g., df = 3) increases tail dependence, leading to stronger co-movements during extreme price fluctuations. Conversely, setting the degrees of freedom too high (approaching a Gaussian copula) reduces the model's ability to capture extreme joint movements. We selected df = 10 to strike a balance between capturing tail risk and maintaining reasonable dependencies between energy prices (Luo & Shevchenko, 2009, p. 19).

Another sensitivity factor is the winsorization threshold. If the threshold is set too high, volatility estimates become artificially smoothed, potentially underestimating real-world risks. On the other hand, if the winsorization is too lenient, model outcomes may be skewed by extreme statistical anomalies. By conducting a series of back-tests and stress scenarios, we found that the selected 0.1% winsorization level provides a reasonable trade-off between stability and risk preservation (Welch, 2017, p. 9).

The reliability of our model is validated by comparing forecasted correlation structures against both historical data and actual out-of-sample correlations. This ensures that our model is not simply reproducing past market trends but effectively capturing evolving market dynamics. To achieve this, we compute the Kendall's Tau distance between three correlation matrices: (1) historical correlation (training data), (2) actual out-of-sample correlation (most recent 12 months), and (3) bootstrapped forecasted correlation. If the bootstrapped correlation structure aligns more closely with the actual out-of-sample data than the historical correlation matrix, it confirms that our approach successfully adapts to changing market conditions.

The results of this validation suggest that the bootstrapped forecast closely mirrors real-world market dependencies, supporting the validity of our methodology. The estimated return distributions align with historical market behaviour, and the joint dependencies captured by the t-copula allow for a more robust assessment of systemic risk in the energy sector. By implementing a model that accounts for extreme price movements and nonlinear dependencies, we ensure that investment decisions are based on stress-tested, data-driven forecasts.

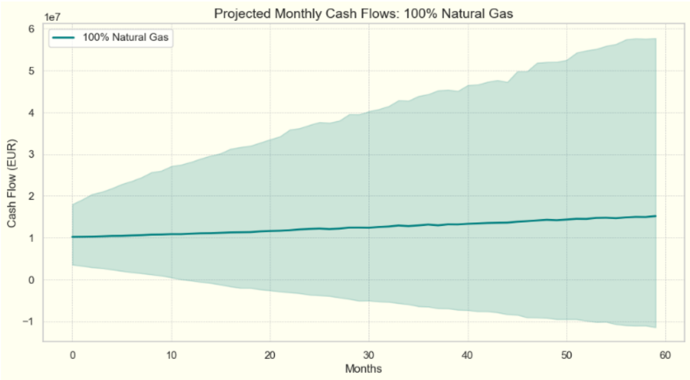
Through the integration of Bootstrapping with Copula methodology, selective winsorization, robust sensitivity analysis, and validation through correlation comparisons, our model provides a more comprehensive representation of energy price risks than traditional forecasting techniques. The inclusion of tail risks, joint dependency structures, and extreme price fluctuations ensures that investment decisions are based on realistic and stress-tested projections. In an environment where energy markets remain highly volatile and susceptible to geopolitical and regulatory disruptions, having a forecasting framework that accurately represents extreme market conditions is essential for making informed, risk-aware investment decisions.

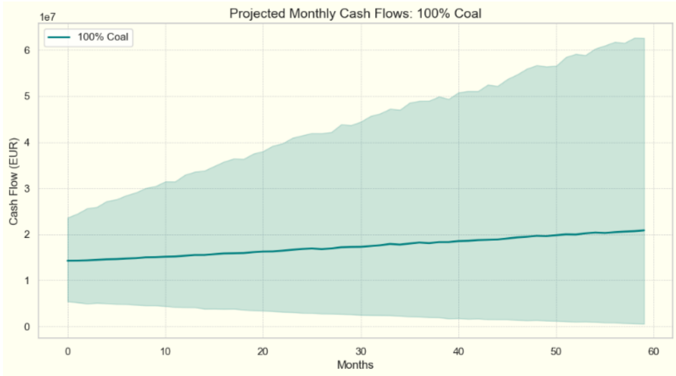
Investment Scenarios

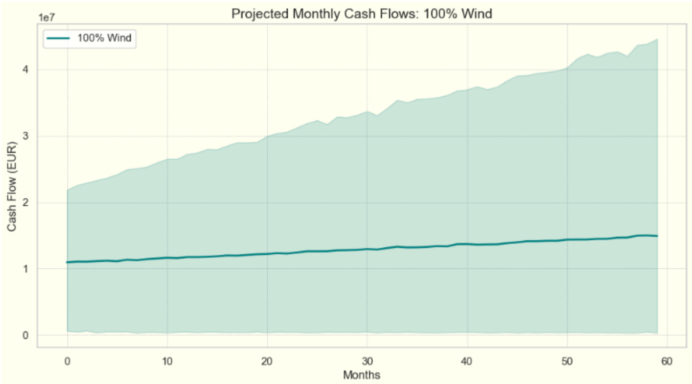
From our model, we have simulated the expected monthly cash flows over the next five years across 10,000 Monte Carlo simulations for each investment scenario. These cash flows are critical in assessing the firm's liquidity and financial stability, as they determine the ability to meet financial obligations, such as bond repayments at maturity. If management proceeds with a project that generates negative cash flows, they must ensure sufficient liquidity to cover potential shortfalls. Strategies such as increasing cash reserves or securing additional funding could be implemented to mitigate financial risk over the project's duration. However, these options may not always be favourable to management, highlighting the importance of analysing not only projected cash flows but also the risk profile and volatility of each investment scenario.

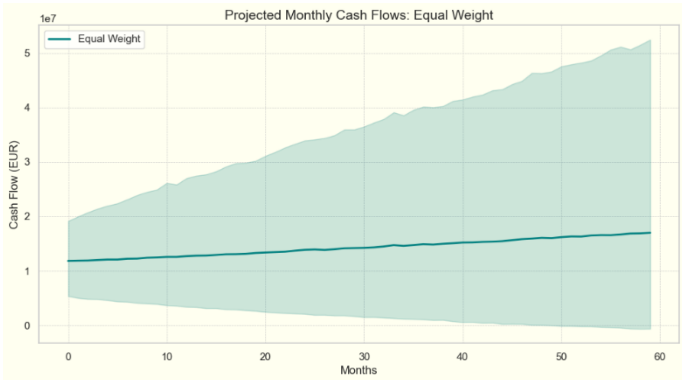
Beyond the cash flows, we evaluate the projects under traditional Modigliani & Miller (M&M) assumptions, while also considering real-world deviations such as bankruptcy costs and financing constraints. Raising equity or debt in times of financial distress is often costly, as investors demand additional risk premiums, and equity issuance may lead to dilution of existing shareholders' stakes. Given this, understanding the probability of default and maximum potential losses under adverse conditions becomes crucial for investment decision-making.

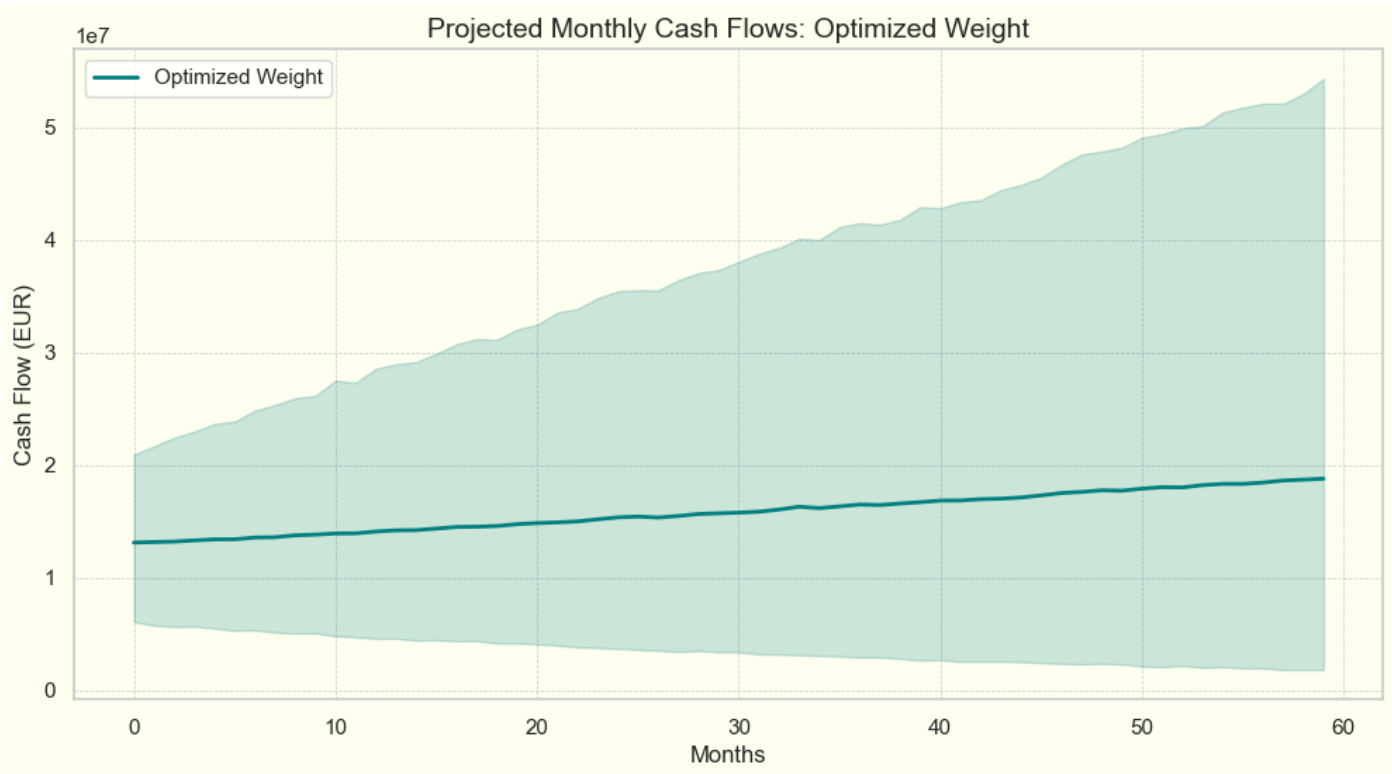
Cash Flow Observations











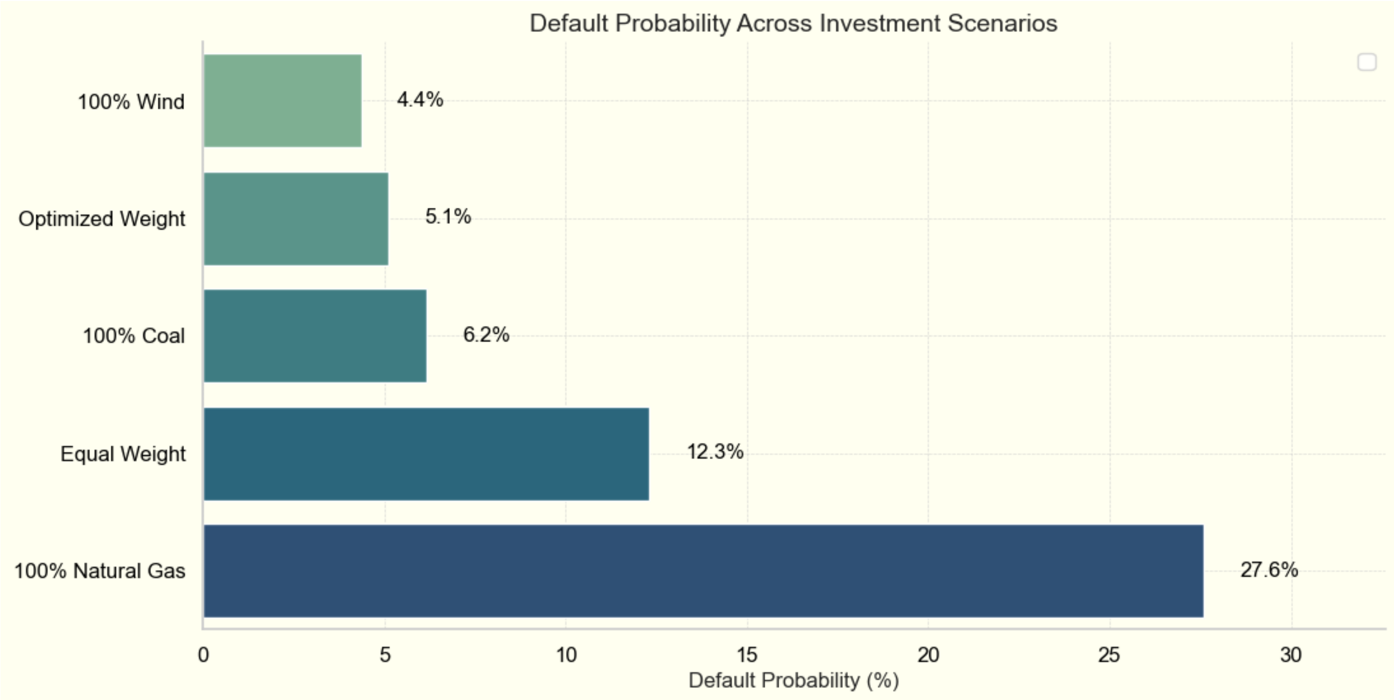
From our simulations, we observe that both the Coal and Wind Energy projects generate positive cash flows throughout their lifespan, even at the 5th percentile, indicating relative financial stability under most conditions. The Wind Project's constant profitability is largely due to its zero fuel costs and exemption from carbon emission offsets, making it the least sensitive to fluctuations in operating expenses.

The Natural Gas project, while yielding returns in some scenarios, exhibits the highest financial risk due to its exposure to negative monthly cash flows, volatile costs, and sensitivity to price fluctuations. All projects involving Natural Gas exhibit potential for negative monthly cash flows through their life cycles, increasing the likelihood of financial distress.

The Coal project generates high returns on cash flows but carries a higher default risk due to its exposure to fuel price volatility, carbon pricing, and operational expenses.

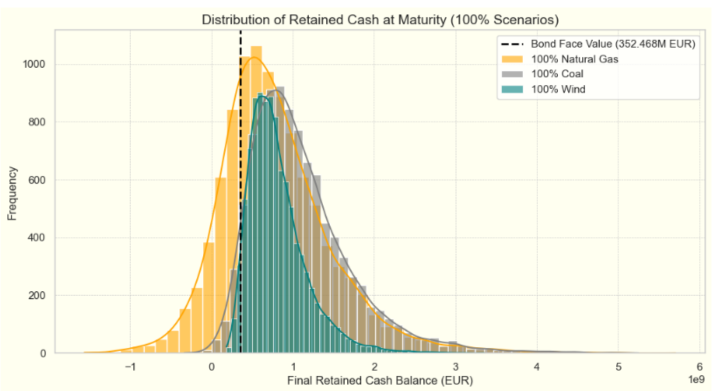
To fully capture risk exposure, we estimate the expected monthly cash flows for each month over the 60-month period, computing the mean, 5th percentile (P5), and 95th percentile (P95) for each scenario. This allows for a complete assessment of cash flow variability across time, ensuring that the firm's financial stability is evaluated under both normal and extreme conditions.

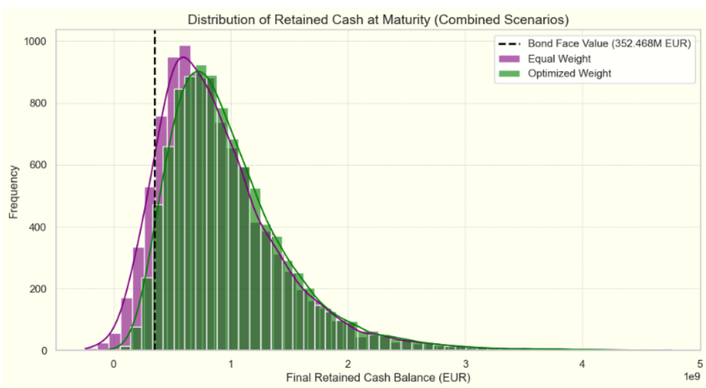
DEFAULT RISK ANALYSIS



By compounding these cash flows at a risk-free rate of 2% per year, we assess whether each project can meet its bond obligations at maturity. Comparing the accumulated funds to the bond's face value of EUR 352.468 million, we estimate the probability of default under various economic conditions. The default frequency is computed as the percentage of simulations where total retained cash flows fall below EUR 352.468 million at the end of the 5-year period.

The Wind Energy project exhibits the lowest default frequency (3.9%), making it the most financially stable investment. The Optimized Weight scenario (65% Coal, 35% Wind) follows with a 4.8% default probability, suggesting a similarly low level of financial risk. The Coal Plant project has a slightly higher default probability of 5.6%, reflecting a moderate risk of default due to its greater cash flow volatility. To determine the optimal portfolio mix, we analysed the default probabilities and return profiles of each investment scenario. The Wind Energy project had the lowest default probability, making it the most stable option, while the Coal project also exhibited a relatively low default probability but offered higher returns. Based on this, we selected an optimized allocation of 65% Coal and 35% Wind to balance financial stability with return potential.



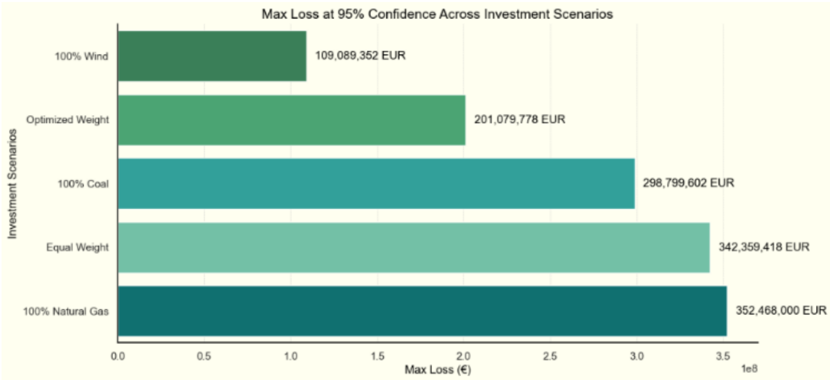


In contrast, the Equal Weight scenario (33% allocation to each project) carries a significantly higher default probability of 12.2%, indicating that spreading investment across all three energy sources does not necessarily minimize risk. The Natural Gas project presents the highest default probability at 27.4%, highlighting a significant risk of financial distress. This is driven by high exposure to costs, market volatility, and operational constraints, making it the riskiest investment among the available options.

Value at Risk (VaR) and Maximum Loss Assessment

To further quantify financial risk, we compute the 95% Value at Risk (VaR) for each project, estimating the maximum expected losses under adverse market conditions with 95% confidence. This measure helps determine worst-case financial impacts, excluding the most extreme 5% of outcomes. The Natural Gas project exhibits the highest VaR, primarily due to its high exposure to fuel price volatility and operational costs, making it the most financially uncertain investment

Beyond VaR, we estimate the maximum potential loss at 95% confidence for each investment scenario. This provides a more direct measure of potential downside exposure:



The Natural Gas project exhibits the highest maximum loss (EUR 352.4 million), indicating a complete shortfall in its ability to repay the bond at maturity. This aligns with its high default probability of 27.6%, confirming that it carries the greatest financial risk. On the other end, the Wind project has the lowest maximum loss (EUR 95.1 million), reinforcing its status as the most financially stable investment.

Dealing with Potential Outliers

Since energy prices are highly volatile, extreme price movements could skew cash flow projections and distort risk assessments. To mitigate this, we apply a clipping-based winsorization process at the top and bottom 0.1% of price movements. This prevents outliers from disproportionately affecting simulations while preserving critical downside risks. Additionally, a price floor of EUR 0.1 was implemented to avoid unrealistic near-zero price scenarios that could artificially impact future cash flow projections. This ensures that model estimates remain robust while maintaining financial realism.

Investment Implications

Using VaR and default probability analysis, we observe that the Wind Project stands out as the least risky option, while the Natural Gas project carries the highest financial risk due to its greater sensitivity to market volatility and operational costs. Although the Coal project has a relatively lower default risk, its potential for large losses under adverse conditions is significant, making it a higher-risk investment compared to Wind Energy.

By incorporating these risk metrics into decision-making, management can select investment opportunities that align with their risk tolerance while ensuring long-term financial stability. The results underscore the importance of evaluating both expected returns and potential downside risks, rather than relying solely on projected cash flows.

Optimization of Bond Face Value

To ensure the investment firm achieves its targeted 12% annualized return, we optimize the bond face value for each investment scenario. The results reveal that 100% Natural Gas requires the highest bond face value at €432.49M, indicating that natural gas projects generate lower retained cash flows relative to the expected risk, necessitating a higher repayment obligation to meet investor return expectations. In contrast, 100% Wind (€353.89M) has the lowest required bond face value, suggesting that wind projects produce more stable cash flows, allowing for a lower repayment requirement. 100% Coal (€358.44M) and Equal Weight (€367.91M) portfolios fall within a similar range, highlighting the trade-offs between fossil fuel stability and diversification benefits. The Optimized Weight portfolio (€355.75M), which strategically blends wind and coal, strikes a balance between risk and return, requiring a moderately adjusted bond face value. Overall, the results indicate that fully investing in natural gas is the riskiest option, requiring the highest repayment to compensate for potential shortfalls, while diversified or renewable-heavy portfolios provide more predictable returns with lower debt obligations.

Investment Scenario	Optimized Bond Face Value (€M)
100% Wind	353.89
Optimized Weight	355.75
100% Coal	358.44
Equal Weight	367.91
100% Natural Gas	432.49

Hedging Cash Flows

The investment firm's exposure to cash flow volatility and financial distress costs highlights the importance of implementing hedging strategies to mitigate risk and enhance financial stability. Given that the firm fully debt-finances its projects, stabilizing cash flows is essential for reducing default risk and ensuring debt obligations are met.

If monthly cash flows become negative, the project incurs distress costs amounting to an additional 10% penalty on shortfalls. This exacerbates financial instability, making it critical for the underlying firm to hedge its cash flows effectively. The investment firm has a strong incentive to ensure that the underlying firm implements hedging strategies to mitigate these risks. Without hedging, volatile cash flows increase the probability of default, leading to higher financial distress costs and a greater likelihood of failing to meet bond repayment obligations. Stabilizing cash flows through hedging reduces financial uncertainty, enhances the predictability of returns, and minimizes exposure to extreme losses.

A structured hedging approach ensures that the underlying projects maintain sufficient liquidity to cover operational expenses and debt repayments. By reducing financial distress, hedging improves the firm’s ability to service its debt while making its bonds more attractive to investors. In turn, this could lead to lower required bond yields and better overall financing conditions. Therefore, the investment firm has a direct financial interest in ensuring that the projects it finances actively manage their exposure to market fluctuations.

To protect against negative cash flow risks, an investment bank has proposed a derivative that guarantees that a project never experiences negative monthly cash flows. This derivative would compensate for any shortfall by paying an amount equal to –min {cash flow, 0}, effectively ensuring non-negative cash flows for the project. However, the derivative does not cover distress costs, meaning that even with this financial instrument in place, any shortfall below zero would still result in a 10% penalty on negative cash flows.

To estimate the value of this derivative, a Monte Carlo simulation was conducted to project monthly cash flows across 10,000 scenarios for each investment. The total value of the derivative is derived from the sum of all negative cash flows in these simulations, representing the compensation required to offset shortfalls. The results indicate that projects with high volatility, such as natural gas, require a significantly higher derivative value compared to more stable projects like wind energy.

The cost of implementing the derivative varies across different projects due to their respective risk profiles. Wind energy, with its stable generation output and exemption from fuel and carbon costs, experiences relatively few instances of negative cash flows. Therefore, the cost of a derivative ensuring non-negative cash flows for a wind project remains relatively low. In contrast, coal and natural gas projects, which are subject to fluctuations in fuel costs, carbon pricing, and market volatility, require significantly higher compensation for negative cash flow periods. The estimated cost of the derivative for each project is summarized as follows:

Investment Scenario	Estimated Derivative Value (€M)
100% Wind	0
Optimized Weight	0.4
100% Coal	1.46
Equal Weight	2.87
100% Natural Gas	33.58

In practice, this derivative could be structured using different financial instruments depending on the energy source. For wind energy, a combination of weather derivatives and put options on electricity prices could be used to hedge against periods of low wind utilization and declining market prices. For fossil fuel-based projects, spread options on fuel costs, carbon swaps, and electricity futures would provide protection against fluctuations in input costs and regulatory risks.

Determining whether purchasing this derivative is financially viable requires a cost-benefit analysis comparing the price of the derivative to the expected reduction in financial distress costs and default risk. If the cost of the derivative is lower than the total expected financial distress and default-related losses, purchasing it would be justified. Additionally, the firm should assess whether reducing default probability through hedging improves bond pricing to the extent that it offsets the cost of the derivative.

Another key consideration is whether alternative risk management strategies, such as increasing liquidity reserves, could achieve similar protection at a lower cost. Maintaining a cash buffer might offer the same benefits as a derivative without incurring the cost of purchasing financial instruments. Therefore, the firm must evaluate whether hedging through derivatives is the most efficient solution or if alternative financial strategies provide a better return on risk reduction. The final decision should balance the derivative's cost, the expected financial distress avoided, and broader risk management strategies to determine the most cost-effective approach.

Risk Overview

Market price risk remains a key factor in this investment, as the projects are exposed to fluctuating electricity, fuel, and carbon credit prices. Commodity prices can be influenced by macroeconomic trends, geopolitical events, and supply chain disruptions. If electricity prices decline or fuel costs rise, projected cash flows may be negatively affected, leading to financial distress. To mitigate this, the firm should hedge against these risks using futures, options, and swaps, particularly for coal and natural gas projects that are highly sensitive to fuel cost fluctuations.

Credit risk is another major consideration, as all projects are fully debt-financed, making the firm entirely reliant on cash flows for debt repayment. The Monte Carlo simulations indicate that the probability of default varies across projects, with the natural gas project carrying the highest risk due to its volatility and fuel dependency. To address credit risk, the firm should not only optimize its bond face value but also explore alternative risk-mitigation techniques such as liquidity reserves, structured debt agreements, or credit default swaps to provide additional security against adverse market conditions.

Operational risks should also be factored into the risk management framework. Wind energy, despite being less volatile in pricing, is subject to utilization rate fluctuations due to weather conditions, which can lead to unpredictable power output and revenue inconsistencies. Conversely, coal and natural gas projects rely heavily on stable supply chains, which may be disrupted by sanctions, trade restrictions, or geopolitical tensions. The firm should incorporate operational risk assessments into its scenario analysis and consider contingency planning, such as securing diversified fuel suppliers or investing in battery storage solutions to smoothen wind power output variability.

Regulatory and environmental risks further complicate the investment decision. The European Union's Emissions Trading System (EU ETS) continues to tighten regulations on fossil fuels, and future increases in carbon taxes could erode the profitability of coal and natural gas investments. Wind energy, in contrast, benefits from subsidies and tax incentives, making it a more stable option from a policy standpoint. To manage these risks, the firm should stay informed about policy changes, model future carbon price scenarios, and adjust its investment allocation accordingly.

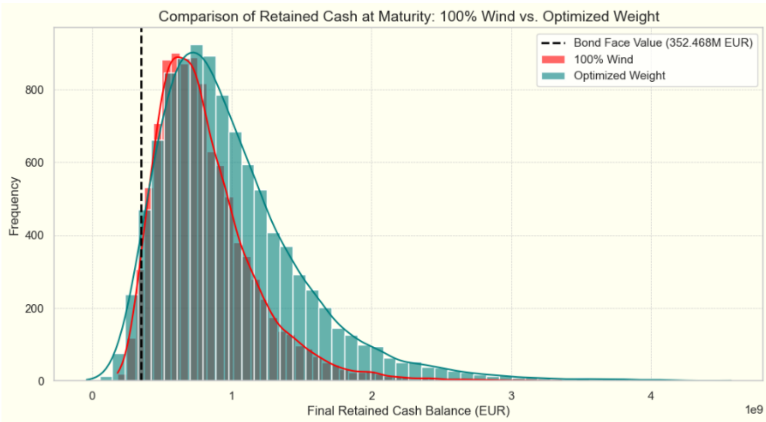
Liquidity risk is particularly important in this investment, as the firm is issuing a zero-coupon bond, meaning all repayments will be due at maturity. If cash flows are insufficient over time, the firm risks facing liquidity shortfalls that could trigger financial distress. Given that the bond repayment is highly dependent on project performance, the firm must either adjust its cash reserve strategy or consider financial instruments such as standby credit lines or cash flow hedging derivatives to ensure liquidity.

Correlation risk must also be considered when constructing the optimal portfolio. Historical data suggests that natural gas and electricity prices have a moderate correlation (0.44), meaning that fluctuations in gas prices can directly impact revenue from electricity sales. Similarly, coal and gas prices have a positive correlation (0.34), reducing the diversification benefits of holding both assets. However, carbon prices exhibit weak or negative correlations with fuel and electricity prices, meaning that they may increase independently of energy revenues, leading to higher costs for fossil fuel projects. Given these correlation dynamics, a diversified portfolio of 65% wind and 35% coal balances risk and return more effectively than allocating to natural gas, which shows the highest volatility and correlation risks.

When implementing a hedging strategy, the firm must carefully evaluate the cost-effectiveness of using derivatives relative to the expected reduction in financial risk. While hedging can stabilize cash flows and reduce financial distress costs, it comes at a cost, and the firm must ensure that the benefits outweigh the expenses. For instance, long-term coal price swaps or carbon price hedges could provide cost certainty but may also reduce the firm's ability to benefit from favourable price movements. Additionally, the firm must consider liquidity risks associated with certain derivative instruments, particularly in low-volume markets such as carbon trading, where exiting a hedging position may be costly.

RECOMMENDATION

Considering these factors, the optimal investment strategy is to allocate 65% to wind energy and 35% to coal, as this portfolio offers the best balance between financial returns, regulatory stability, and risk mitigation. Wind energy, while susceptible to utilization rate variability, remains a low-risk asset due to its zero-carbon pricing exposure and government incentives. Coal, while subject to fuel price volatility and regulatory scrutiny, provides stable base-load generation, complementing wind's intermittency. Natural gas, in contrast, faces high fuel cost uncertainty, correlation risks, and default probability, making it less attractive for inclusion in the portfolio.



The firm's risk management strategy should take a holistic approach by considering a wide range of financial and operational risks that could impact the viability of its energy investments. While market price volatility, regulatory uncertainties, and liquidity constraints are well-recognized concerns, other risks—such as credit risk, operational challenges, and correlation effects—must also be incorporated into the decision-making process.

To further strengthen risk management, the firm should integrate stress testing and scenario analysis into its investment decision process. By modelling extreme cases, such as a sudden carbon tax increase, supply chain disruptions, or electricity market downturns, the firm can develop contingency strategies to minimize potential losses. Periodic reassessment of portfolio performance, coupled with a dynamic risk management strategy, will ensure the firm remains resilient in a highly volatile energy market.

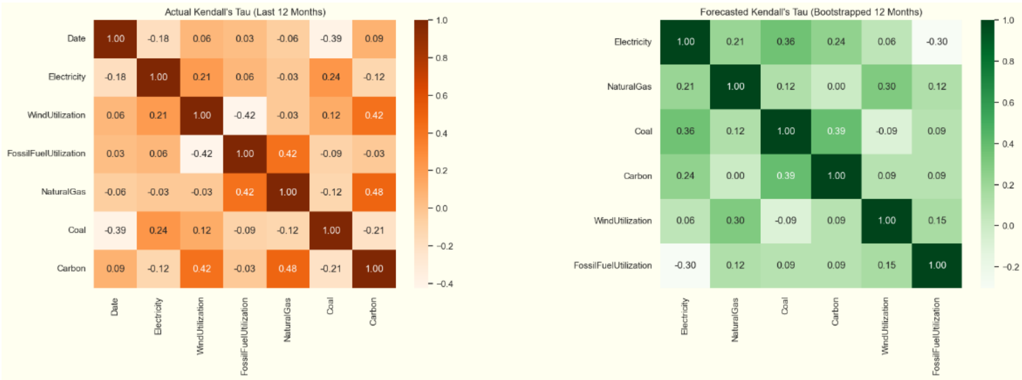
AREAS FOR IMPROVEMENT: LIMITATIONS AND FUTURE WORKS

This serves as a guide for future iterations. This recognises potential improvements which have not/could not be accounted for.

Stress Testing Enhancements: While we considered broad risks, future work could explicitly test specific scenarios such as a sharp carbon tax hike, volatility shocks or extreme supply chain disruptions.

Improved Bootstrapping with Copula: We must train on larger datasets for more accurate analyses through the bootstrapping with copula. Our results suggest deviation in some correlations when back testing and comparing Kendall Tau matrix's.

Incorporating Regulatory Uncertainty: Commodity prices, particularly energy prices, are highly sensitive to changing regulatory frameworks. We strive to incorporate elements such as carbon taxation policies, energy subsidies etc.



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