Simulation Project
Case Study: Monte Carlo Simulation
Evaluating Investments for the 2025 Energy Efficient Challenge

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Table of Contents

1 Introduction 3

2 Decision Criteria 4

3 Deterministic NPV Results 5

3.1 Current Oven – Baseline Energy Costs 6

3.2 New Ovens – Energy Savings 6

3.3 Failure Costs (Expected Values) 6

3.4 Storage Costs (Capacity Constraints) 7

3.5 Annual Net Incremental Cash Flow 8

3.6 NPV Calculation 8

4 Impact of Removing the Government Subsidy for Oven 3 9

5 Application of the IMA® Statement of Ethical Professional Practice 10

6 Considerations Beyond the NPV Calculation 11

7 Monte Carlo Simulation 12

7.1 What New Information Does Monte Carlo Simulation Provide? 12

7.2 Monte Carlo Analysis 13

8 Conclusion 16

1 Introduction

Kühle Engler Kraftwagen AG (KEK AG) is currently evaluating a significant capital investment as part of its **2025 Energy Efficiency Challenge**, a strategic initiative aimed at improving energy efficiency, reducing environmental impact, and maintaining cost competitiveness under increasingly stringent European Union energy and environmental regulations. Within this broader program, the bumper production department at KEK AG's main manufacturing site in Germany has been identified as a priority area for improvement due to its relatively high and volatile energy consumption.

A major contributor to energy usage in this department is the **industrial oven used in the painting process**. The existing oven is oversized, energy-intensive, and subject to increasing operational and reliability risks. Management has therefore requested a detailed financial and risk-based evaluation of three alternative energy-efficient ovens that could replace the current equipment. The decision is non-trivial: while newer ovens promise lower energy consumption and improved environmental performance, they also differ substantially in upfront investment costs, operating characteristics, capacity constraints, reliability, and eligibility for government subsidies.

The objective of this report is to support **Andreas Graf**, Management Accountant at KEK AG, by developing a **quantitative decision-support model** that evaluates these investment alternatives over a **five-year planning horizon**, consistent with internal company guidelines. The analysis focuses on **Net Present Value (NPV)** as the primary financial performance metric, applying a discount rate of 5% and evaluating cash flows before taxation. In line with KEK AG's accounting policies, linear depreciation is assumed for all new production assets.

Unlike a purely deterministic capital budgeting exercise, this project explicitly recognizes the **high degree of uncertainty** surrounding several key input variables. These include future energy prices, daily production batch sizes, failure rates, maintenance costs, storage costs arising from capacity constraints, and the probability of receiving government subsidies for highly energy-efficient equipment. To address these uncertainties, a **Monte Carlo simulation model** is developed to complement traditional NPV calculations and to provide a more comprehensive view of the risk–return trade-offs associated with each investment option.

The report is structured as follows. The **Executive Summary** presents the headline results and key managerial insights, highlighting the most economically attractive investment alternative under uncertainty. The **Technical Appendix** documents the structure of the simulation model, key assumptions, probability distributions, and sensitivity analyses, and explains how uncertainty is incorporated into the NPV calculations. Together, these sections aim to provide Andreas Graf—and ultimately KEK AG's senior management—with clear, transparent, and decision-relevant insights that balance financial performance, risk, and strategic alignment with the company's long-term energy efficiency objectives.

2 Decision Criteria

The investment decision cannot be based on upfront costs alone. The following key criteria were identified:

Financial criteria

- Initial investment cost (including potential subsidy effects).
- Energy cost savings (gas and electricity).
- Maintenance and repair costs.
- Failure-related costs, including catastrophic breakdown risk.
- Storage and rescheduling costs due to capacity constraints.
- Five-year Net Present Value (NPV) discounted at 5%.

Non-financial and strategic criteria

- Energy efficiency and compliance with EU regulations.
- Reliability and operational robustness.
- Flexibility with respect to changing batch sizes.
- Reputational benefits and environmental certification.
- Alignment with KEK AG's long-term energy efficiency strategy.

The oven suppliers provided preventive maintenance at a fixed cost per year, and they have quoted their prices as part of their proposals, which is presented in the following Table 1:

Running Costs	**Current Oven**	**Oven 1**	**Oven 2**	**Oven 3**
Maintenance costs per year	€15,000	€20,000	€25,000	€30,000
Electricity usage (units per hour)	3.0	2.7	2.5	1.9
Gas usage (units per hour)	2.7	2.2	2.0	1.7
Failure probability (per day)	3%	2%	2%	1%
Capacity (units)	300	180	200	220
Predicted energy usage savings for the whole building				
Gas	0%	5%	10%	15%
Electricity	3%	10%	15%	15%

Table 1: Data with technical specifications for the oven investment alternatives.

As you can see in the table, all ovens require less energy compared to the current one. The percentages on the energy savings are also shown in the Table 1. The predicted energy usage savings for the whole buildings refer to the savings you can expect in the whole system - so the building including the oven - because using the new oven affects energy usage elsewhere in the building. Since the current oven is so big that they can pack in any batch size, sometimes even multiple batches, this oven is definitely too big for its purpose. The current oven has a small but not insignificant risk of breaking down beyond repair at some points. The estimations for these breakdown probabilities every year are 2% for the first year, increasing to 4%, 6%, 8%, and 10% in the next five years. If this happens, the consequences are pretty drastic. We have to switch the entire painting process to another production facility, and this would cause a one-time setup cost, which is estimated to be something like **€500,000**. They basically produce one batch every day in batch sizes of 120, 160, 200, or 240 bumpers. These all occur equally often. This is also our expectation for the first year when we work with the new oven. But we expect a trend that the smaller batch sizes will become more frequent, which is represented in the following Table 2.

Batch size	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
120	25%	30%	30%	35%	40%
160	25%	25%	30%	30%	30%
200	25%	25%	20%	20%	20%
240	25%	20%	20%	15%	10%

Table 2: Daily batch sizes and the probability they will break down in the future.

3 Deterministic NPV Results

Using expected (average) values for all inputs and assuming receipt of the government subsidy for Oven 3, the deterministic NPV analysis is presented as follows.

Time and Production

- One production batch per day.
- 365 operating days per year.
- Oven runs once per day.
- Energy usage per hour $\times$ 1 hour per batch.

  (No duration is given $\rightarrow$ conservative simplifying assumption)

Energy Prices

- Gas price = €1.30 per unit.
- Electricity price = €1.80 per unit.

Average building energy usage (given by facility manager)

- Gas: 54.6 units/day.
- Electricity: 318.0 units/day

3.1 Current Oven – Baseline Energy Costs

Oven-only energy per day

Based on Table 1 in Section 2, we have 2.7 units/hour for gas and 3.0 units/hour for electricity. Thus, the daily cost for the current oven is:

$$C_{\text{oven, current}} = (2.7 \times 1.30) + (3.0 \times 1.80) = 3.51 + 5.40 = 8.91€$$

Therefore, the annual oven-only energy cost is given as:

$$8.91 \times 365 = 3252.15€$$

Whole-building energy cost

The annual whole-bulding energy cost is given as:

$$C_{\text{building}} = (54.6 \times 1.30 + 318 \times 1.80) \times 365 = (70.98 + 572.40) \times 365 = 234438€$$

This is the **baseline reference**.

3.2 New Ovens – Energy Savings

According to Table 1 of Section 2, we have the following table for annual energy savings.

Oven	**Annual € savings**
Oven 1	∼€ 22188
Oven 2	∼€ 33930
Oven 3	∼€ 35225

Table 3: Estimated annual savings per oven.

3.3 Failure Costs (Expected Values)

Normal Failures

The expected failures each year is computed as:

$$365 \times p_{\text{ failure/day}}$$

where $p_{\text{ failure/day}}$ is the failure probability for each day. Therefore, the expected annual cost can be express as:

$$365 \times p \times €5000$$

Based on the failure probability per day in Table 1 of Section 2, the expected annual costs for current oven, oven 1, oven 2, and oven 3 are €54750, €36500, €36500, and €18200, respectively.

Catastrophic Failure (Current Oven only)

The expected annual cost for the current oven for breakdown probabilities 2%, 4%, 6%, 8%, and 10% is calculated as:

$$p_t \times 500000$$

where €500000 is the one-time cost if failure occurs. Thus, the undiscounted expected annual cost over 5 years is €150000. Moreover, the discounted expected cost will be:

$$\sum_{t=1}^{5} \frac{p_t \times 500000}{(1.05)^t} \approx €125664$$

Therefore, the equivalent annual benefit of replacement is written as:

$$\frac{125664}{5} \approx €25133$$

This is a **major driver** favoring replacement.

3.4 Storage Costs (Capacity Constraints)

Storage costs were calculated as the expected value of daily overflow units beyond oven capacity, multiplied by a per-unit storage cost and annualized over 365 operating days.

Therefore, the storage cost per day is given as:

$$\mathbb{E}[\text{Storage cost per day}] = \sum_i p_i \cdot \max(0, B_i - C) \cdot 2$$

where p_i is the probability they will break down in the future (see Table 2 of Section 2), C is the capacity of the oven, and B_i the size of the batch i. Thus, the annual storage cost for this oven is given as:

$$\text{Annual storage cost} = 365 \times \mathbb{E}[\text{Storage cost per day}]$$

This formula is **perfect for Monte Carlo simulation later**. The following table is the annual storage costs of these ovens and their 5-year averages.

Oven	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**5-year avg**
Oven 1	14600	12410	11680	9490	7300	**11096**
Oven 2	7300	5840	5840	4380	2920	**5256**
Oven 3	3650	2920	2920	2190	1460	**2628**
Current Oven	0	0	0	0	0	**0**

Table 4: Annual storage costs and 5-year averages.

As you can see in the Table 4, the storage cost for the current oven is 0 because the capacity is 300, which fits every batch size. For new ovens, the oven 3 has the smallest storage cost per year.

3.5 Annual Net Incremental Cash Flow

The formula for computing the annual net incremental cash flow is given as follows:

$$\text{Net CF} = S_E - \Delta M + S_N + B_C - C_S,$$

where:

$$\begin{aligned} S_E &:= \text{Energy savings}, \\ \Delta M &:= \text{Change in maintenance cost}, \\ S_N &:= \text{Normal failure savings}, \\ B_C &:= \text{Catastrophic failure benefit}, \\ C_S &:= \text{Storage costs}. \end{aligned}$$

Therefore, the annual cash flow summary is represented as follows:

Oven	**Annual net CF (€)**
Oven 1	49475
Oven 2	62057
Oven 3	79280

Table 5: Annual net cash flows for each oven.

3.6 NPV Calculation

The discount factor over the 5-year horizon is given as:

$$DF = \sum_{t=1}^{5} \frac{1}{(1.05)^t} = 4.3295$$

In total, the net present value (NPV) is calculated as:

$$NPV = -I_0 + CF \times DF,$$

where I_0 is the initial investment, CF is the annual net incremental cash flow, and DF is the discount factor.

Therefore, the final deterministic NPV results are given in the following table:

Option	**Investment (€)**	**NPV (€)**
Oven 1	160000	+54202
Oven 2	240000	+28675
Oven 3	280000	+63243

Table 6: Investment and NPV for different oven options.

Under deterministic assumptions and including the government subsidy for Oven 3, from the Table 6, we see that **Oven 3 is the economically most attractive investment option**, delivering the highest Net Present Value over the five-year horizon.

4 Impact of Removing the Government Subsidy for Oven 3

In the previous section, the investment cost for Oven 3 included a **€50000 government subsidy**, which results in the investment cost with subsidy (€280000). According to the Energy Manager, there is only a 10% probability of receiving this subsidy. For this section, we assume no subsidy is received, which results in the revised investment cost:

$$€280000 + €50000 = €330000$$

All **operational cash flows remain unchanged**, since the subsidy affects only the upfront investment. Therefore, the **revised NPV** for Oven 3 is

$$\begin{aligned} \text{NPV (Oven 3, no subsidy)} &= -330000 + (79280 \times 4.3295) \\ &= -330000 + 343243 \\ &= 13243\ € \end{aligned}$$

Without the subsidy, Oven 3 becomes **financially unattractive**. Therefore, Oven 1 now clearly dominates from a purely financial standpoint: the highest NPV, lower capital at risk, and more stable cost structure. If KEK AG were to base the decision **strictly on NPV**, Oven 3 should not be selected in the absence of the subsidy.

The removal of the subsidy creates a fundamental managerial dilemma, forcing a balance between energy efficiency and sustainability objectives on one hand, and financial and capital allocation goals on the other. Oven 3 offers the highest energy savings, minimizes operational failures, and achieves superior environmental performance, while also enabling eligibility for environmental certification, enhancing corporate reputation, aligning with EU energy efficiency guidelines, and positioning the company as a long-term sustainability leader. These strategic benefits, however, are only partially reflected in the NPV calculation. Oven 1 delivers a strong positive NPV, lower upfront risk, and acceptable—though not best-in-class—energy efficiency. Senior management must therefore decide whether to prioritize short-term financial discipline, favoring Oven 1, or to pursue the long-term strategic and environmental advantages offered by Oven 3, balancing immediate financial prudence against broader sustainability goals that could shape the company's reputation and competitive positioning in the future.

The managerial dilemma cannot be fully resolved using NPV alone. While the NPV framework provides a structured measure of financial performance, it strongly penalizes large upfront investments and is highly sensitive to the chosen time horizon of five years. Moreover, NPV does not fully capture critical factors such as regulatory tightening beyond year five, reputational value, strategic learning in energy management, or spillover benefits to other departments. As a result, Oven 3 may appear financially unattractive despite being strategically superior.

The removal of the government subsidy fundamentally alters the investment decision. Although Oven 3 remains the most energy-efficient and aligned with long-term strategic objectives, it becomes financially unfavorable in NPV terms, creating a clear tension between maximizing short-term financial value and investing in long-term sustainability and regulatory resilience. This dilemma highlights the need for a more comprehensive evaluation that explicitly addresses uncertainty, for example through **Monte Carlo simulation**, and considers broader strategic factors beyond NPV alone.

5 Application of the IMA® Statement of Ethical Professional Practice

The case presents several ethical challenges relevant to Andreas's role, including high uncertainty in key input data (energy prices, failure rates, subsidy availability), pressure to support the 2025 Energy Efficiency Challenge, potential bias toward favorable assumptions—especially regarding the subsidy for Oven 3—and the risk that senior management may rely too heavily on single-point NPV estimates. These issues also highlight the inherent tension between financial performance and sustainability objectives. Collectively, they engage all four IMA ethical principles: Competence, Confidentiality, Integrity, and Credibility.

Under **Competence**, Andreas must maintain professional expertise by selecting appropriate analytical tools and recognizing the limitations of deterministic NPV analysis under uncertainty. While he follows KEK AG's internal NPV guidelines (5% discount rate, pre-tax analysis), competence requires him to explicitly communicate the limitations of fixed assumptions and supplement deterministic NPVs with Monte Carlo simulation to better reflect risk. Failing to highlight uncertainty would constitute a breach of professional competence.

The principle of **Integrity** requires Andreas to avoid misleading analyses or selective disclosure. A key issue is the government subsidy for Oven 3: although the purchasing figures include a €50,000 subsidy, there is only a 10% probability of receiving it. Presenting results as if the subsidy were guaranteed would be misleading. Andreas must disclose the uncertain nature of the subsidy, present alternative NPVs with and without it, and resist implicit or explicit pressure to "make the numbers look good."

Credibility requires that information be fair, objective, and complete. Andreas must clearly document all assumptions, communicate ranges and probability distributions rather than single values, and highlight which inputs most strongly drive the results. The Monte Carlo analysis supports credibility by showing the probability distributions of NPVs, allowing decision-makers to understand downside risk and preventing false precision in financial projections.

Finally, **Responsibility** requires Andreas to consider the broader impact of his analysis on KEK AG. As this investment forms part of a strategic sustainability initiative, he must ensure that management understands the long-term implications, avoid framing the analysis purely as a short-term financial ranking, and encourage discussion of strategic trade-offs.

By transparently disclosing uncertainty, resisting biased assumptions, and clearly communicating limitations, Andreas fulfills his ethical responsibilities under the IMA framework. His role is not to provide a single "correct" answer, but to enable informed and ethically sound managerial judgment.

6 Considerations Beyond the NPV Calculation

While the NPV model provides a useful measure of financial performance, it does not fully capture organizational, strategic, and uncertainty-related factors that are critical for senior management when evaluating the oven investment.

From an **organizational and behavioral perspective**, production and purchasing staff tend to favor incremental, familiar technologies, and interest in innovative energy solutions is limited. Energy efficiency expertise is concentrated in a few individuals, such as the Energy Manager. Installing a highly efficient oven, such as Oven 3, may accelerate organizational learning in energy management, shift attitudes toward sustainability across departments, and generate internal momentum for future efficiency projects. Though difficult to quantify, these effects are strategically important.

The decision also carries significant **strategic and path-setting implications**. Choosing a best-in-class oven signals a long-term commitment to sustainability, supports compliance with anticipated regulations, and strengthens KEK AG's position with environmentally conscious customers. In contrast, selecting a financially safer but less efficient option preserves short-term capital but risks locking the firm into incremental improvement pathways. As noted by Miller and O'Leary (1997), accounting numbers shape—not merely reflect—strategic choices, highlighting the broader impact of such investment decisions.

Regulatory and reputational risks further reinforce the value of more energy-efficient options. Five-year NPV calculations may underestimate tightening EU energy regulations, rising carbon and energy taxes, reputational benefits from environmental certification, and the risk of exclusion from customer supply chains due to sustainability criteria. These considerations favor investments like Oven 3 even when short-term NPV appears weaker.

Uncertainty beyond quantifiable risk also matters. Factors such as changes in customer sustainability requirements, technological breakthroughs, organizational support or resistance, and competitor responses cannot always be modeled probabilistically. While Monte Carlo simulation can address parameter uncertainty, it cannot fully account for these structural or strategic uncertainties.

Finally, **complementarity with broader energy initiatives** amplifies the strategic value of an efficient oven. Improved measurement enables better analysis and purchasing contracts, while oven replacement may support load management, reduce peak electricity penalties, and increase returns on energy analytics investments.

In conclusion, although NPV provides essential financial discipline, senior management should interpret the results as only one input in a broader strategic decision. A comprehensive assessment must balance financial performance with regulatory preparedness, organizational learning, and long-term sustainability positioning.

7 Monte Carlo Simulation

7.1 What New Information Does Monte Carlo Simulation Provide?

A Monte Carlo simulation extends the deterministic NPV analysis by explicitly modeling uncertainty in key input parameters and translating that uncertainty into probability distributions of outcomes rather than single-point estimates. This approach provides several new and decision-relevant insights.

First, it generates a **distribution of NPVs instead of just averages**. Rather than producing a single NPV per oven, the simulation produces a full probability distribution, allowing management to observe the expected (mean) NPV, median NPV, variance, downside risk, and worst-case and best-case outcomes. This helps avoid the false precision inherent in deterministic NPV calculations.

Second, Monte Carlo simulation enables direct estimation of **the probability of financial loss**, $P(NPV < 0)$. This is particularly important for capital budgeting under uncertainty, as an oven with a higher expected NPV may still carry a substantial risk of negative returns.

Third, it supports **risk–return trade-off analysis between ovens**. By comparing the full distributions of NPVs, management can distinguish high-return but high-risk options from lower-return but more stable alternatives, facilitating risk-aware decision-making aligned with KEK AG's risk appetite.

Fourth, Monte Carlo simulation allows **explicit treatment of discrete or binary risks**, such as the government subsidy for Oven 3 (a Bernoulli event), daily failures, and catastrophic breakdowns. Unlike expected-value calculations that smooth these risks, simulation captures them realistically.

Finally, when combined with sensitivity analysis, Monte Carlo simulation helps identify **key value drivers**. Andreas Graf can determine which assumptions—such as energy prices, failure rates, or storage costs—most strongly influence NPV outcomes, enhancing the transparency and credibility of the analysis.

7.2 Monte Carlo Analysis

The standard deviation of annual cash flows was assumed to be approximately 15–20% of the expected value, reflecting uncertainty in energy prices, failure-related costs, and storage costs. This magnitude is consistent with the high operational and energy price volatility described in the case.

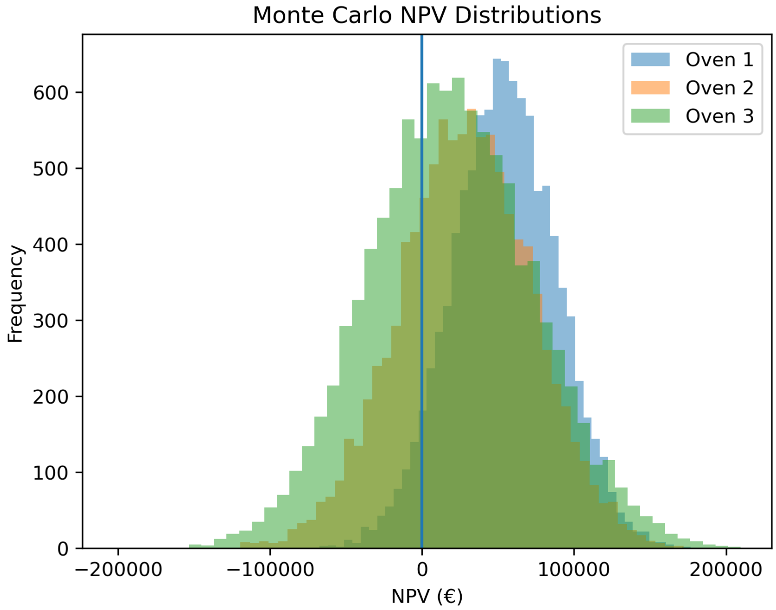

Figure 1: Monte Carlo NPV distributions for three ovens.

Figure 1 shows the Monte Carlo–simulated NPV distributions for the three oven investment options. Unlike the deterministic NPV analysis, which produced single-point estimates, the simulation reveals the entire range of possible outcomes under uncertainty.

The simulation results are summarized below:

Option	Mean NPV (€)	P(NPV < 0)
Oven 1	54472	5.7%
Oven 2	28588	25.5%
Oven 3	19312	36.7%

Table 7: Monte Carlo NPV Results for Different Ovens.

These results clearly demonstrate that expected profitability alone is not sufficient for decision-making; downside risk differs substantially across alternatives.

Comparative Risk-Adjusted Performance of Ovens

Oven 1 – Best Risk-Adjusted Performance: Oven 1 exhibits the highest mean NPV (€54472) and a very low probability of loss (only 5.7%), with a tight, right-shifted distribution. This indicates stable and robust financial performance across a wide range of scenarios. The narrow dispersion reflects lower sensitivity to uncertainty in energy prices, failure costs, and capacity-related storage costs. From a managerial perspective, Oven 1 is the financially safest option, combining positive expected value with minimal downside risk. Even under unfavorable realizations of stochastic variables, the likelihood of destroying value remains low.

Oven 2 – Moderate Returns, Substantial Risk: Oven 2 shows a positive mean NPV (€28588) but a one-in-four chance of negative NPV (25.5%) and a wider distribution than Oven 1. While it remains attractive under average conditions, its distribution overlaps significantly with zero, indicating high sensitivity to adverse combinations of energy prices, failure events, and storage costs. Practically, Oven 2 represents a borderline investment: acceptable if management is willing to tolerate moderate financial risk, but clearly inferior to Oven 1 on a risk-adjusted basis.

Oven 3 – Strategically Attractive but Financially Risky: Oven 3 displays the most uncertain financial profile, with the lowest mean NPV (€19312) and the highest probability of value destruction (36.7%). Its distribution is very wide with a heavy left tail. Despite superior energy efficiency and strategic benefits, Oven 3's financial outcome is heavily influenced by high upfront investment, uncertain government subsidy, and exposure to operational variability. The histogram shows substantial mass below zero, confirming that more than one-third of scenarios result in a negative NPV. While it performs well in best-case scenarios, Oven 3 is financially risky under the five-year horizon.

The Monte Carlo results refine and partially overturn the deterministic conclusions. While the deterministic NPV analysis suggested that Oven 3 could be an attractive option, the Monte Carlo simulation reveals that this apparent attractiveness depends heavily on optimistic assumptions. Once uncertainty and downside risk are explicitly incorporated, risk-adjusted performance clearly favors Oven 1. This demonstrates the added value of Monte Carlo simulation: it prevents overreliance on expected values and exposes hidden downside risks that are not visible in single-point NPV estimates.

-20%	Base	+20%
-25129	28588	82306

Table 8: Sensitivity results for Oven 2 (NPV in €).

The sensitivity results for Oven 2 show a base-case expected NPV of €28588, which ranges from −€25129 under a 20% decrease in annual cash flows to +€82306 under a 20% increase. This implies that a relatively modest ±20% change in operational performance can shift the investment from value destroying to highly attractive. Such an extremely wide range highlights the high sensitivity of Oven 2's NPV to underlying cash-flow assumptions, indicating substantial exposure to operational uncertainty and reinforcing its characterization as a borderline investment from a risk-adjusted perspective.

The sensitivity analysis identifies annual operating cash flows as the primary value driver, with energy savings, failure-related downtime and repair costs, capacity-related storage costs driven by batch size uncertainty, and energy prices also exerting a significant influence on NPV. Because these drivers are highly interconnected, relatively small deteriorations in any of them are sufficient to eliminate the investment's financial attractiveness.

From a managerial perspective, this implies that Oven 2 requires tight and consistent operational control to remain profitable. Even modest adverse deviations in energy prices or failure rates can quickly destroy value. In contrast, Oven 1 is far more resilient to such deviations, reinforcing its superiority on a risk-adjusted basis.

The **Monte Carlo Simulation** thus provides critical insight that cannot be obtained from deterministic NPV analysis alone and strongly supports Oven 1 as the preferred financial investment under uncertainty.

8 Conclusion

The **Monte Carlo Simulation** significantly enhances the investment analysis by explicitly incorporating uncertainty into the NPV calculations. While all three oven options exhibit positive expected values under deterministic assumptions, the simulation reveals substantial differences in risk profiles. Oven 1 emerges as the most economically attractive option, combining the highest mean NPV with a very low probability of negative returns, making it the most robust choice from a risk-adjusted financial perspective. Oven 2 delivers moderate expected returns but is highly sensitive to adverse operational and cost conditions, resulting in a considerable downside risk. Oven 3, although strategically superior in terms of energy efficiency and sustainability, shows the highest probability of value destruction due to its high upfront investment and subsidy uncertainty. Overall, the analysis demonstrates that relying solely on deterministic NPV can be misleading and that Monte Carlo simulation provides essential insights into risk, robustness, and decision confidence, supporting Oven 1 as the preferred financial investment under uncertainty.

TECHNICAL APPENDIX

A. Model Overview

- Time horizon: 5 years
- Resolution: annual cash flows
- Comparison: incremental with current oven
- Method: deterministic NPV and Monte Carlo Simulation

B. Key Assumptions Table

Parameter	Type	Source
Energy prices	Fixed	Purchasing
Batch sizes	Probabilistic	Painting supervisor
Failure rates	Probabilistic	Production
Subsidy	Bernoulli ($p = 0.1$)	Energy manager
Discount rate	Fixed (5%)	Accounting manual

Table 9: Model parameters, their types, and data sources.

C. Stochastic Variables

Variable	Distribution
Energy prices	Normal
Failure cost	Normal
Daily failures	Binomial
Batch size	Discrete
Subsidy	Bernoulli

Table 10: Probability distributions of model variables.

D. Treatment of Uncertainty in NPV Calculations

Uncertainty is incorporated by repeatedly simulating annual cash flows using the probability distributions defined above and computing the resulting NPVs for each iteration. This process generates a distribution of NPVs rather than a single point estimate. The Monte Carlo simulation thus provides a more comprehensive and risk-aware basis for decision-making than deterministic NPV analysis alone.