A Framework for Navigating Climate Uncertainty

Scenario Analysis for Financial Institutions in the EU

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Abstract
In response to regulatory directives mandating climate risk assessment and mitigation by financial institutions, this thesis examines the broader impact of climate change on this sector. The European Union's CRR3/CRD6 mandates the integration of climate risks into financial institutions' Internal Capital Adequacy Assessment Process (ICAAP), guided by the European Banking Authority (EBA). Through a 10-year horizon climate scenario analysis, policy implications on income streams and sectoral performance are explored. This analysis provides insights for effective risk management strategies. Sectors like oil, gas, coal, aviation, cement, steel, and power are identified as particularly vulnerable to regulatory shifts driven by evolving climate ambitions outlined in the Paris Agreement. The thesis analyzes three climate policy scenarios and presents a framework for incorporating climate risks into ICAAP, projecting sectoral dynamics in response to varying climate ambitions. These insights inform base scenario analyses, facilitating the evaluation of financial trajectories across different climate scenarios. Additionally, the impact of increased natural disaster frequency on market dynamics is explored, with findings suggesting minimal or insignificant influence.

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1 Introduction

1.1 Background

Policy makers, business leaders, and individuals worldwide have increasingly recognized climate change as a pressing issue. The 12 months leading up to February 2024 set a record for the highest average temperature, exceeding the pre-industrial average by 1.56°C [20]. Climate change has grown into a complex issue, not only affecting the state of the planet, but also economies, households and people all over the world. Although efforts have been made to mitigate this issue, there is still a long way to go to reach the desired goals and extend the sustainability of our planet.

The European Union (EU), as a global leader in climate action, has been at the forefront of implementing stringent regulations to mitigate climate change and transition towards a low-carbon economy. The EU's regulatory framework includes directives such as the Renewable Energy Directive, the Energy Efficiency Directive, the Emissions Trading System (ETS) and the Fit for 55- package, all aimed at reducing greenhouse gas emissions and promoting sustainable practices across various sectors [17].

In the near future, there are plans to reform the existing ETS, alongside the introduction of the Carbon Border Adjustment Mechanism (CBAM). Under the proposed ETS reform, certain sectors, including aviation, steel, and cement, will gradually lose their entitlement to free allowances, beginning in 2026. Concurrently, the EU aims to implement the CBAM as a means of levying a fair price on carbon emissions associated with the production of goods imported into the EU [16].

Furthermore, the landmark Paris Agreement, adopted in December 2015 under the United Nations Framework Convention on Climate Change (UNFCCC), represents a significant international effort to combat climate change. The agreement aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels, with efforts to pursue limiting the temperature increase to 1.5 degrees Celsius. Signatories to the Paris Agreement commit to nationally determined contributions (NDCs) to reduce emissions and enhance resilience to climate impacts [14].

In recent years, financial institutions have been mandated by regulatory directives to assess the influence of climate change on their operations. The impacts of climate change on financial institutions are multifaceted and complex. Physical risks, such as extreme weather events, sea-level rise, and resource scarcity, pose direct threats to assets and infrastructure. Transition risks arise from the shift to a low-carbon economy, including policy changes, technological advancements, and market dynamics, which may devalue carbon-intensive assets and expose institutions to stranded asset risks, where some sectors are at more risk than others.

As part of the revised Capital Requirements Regulation and Capital Requirements Directive (CRR3/CRD6), the EU requires financial institutions to consider climate related risks in their Internal Capital Adequacy Assessment

Process (ICCAP). In January 2024 the European Bank Authority (EBA) released a consultation paper on guidelines on the management of Environmental, Social and Governance (ESG) risks. This is with the purpose to ensure the safety and soundness in the short, medium and long run for financial institutions by setting requirements for the ESG risk management arrangements [9]. Furthermore, starting in 2024, the Swedish Financial Supervisory Authority (Finansinspektionen) will monitor how Swedish banks integrate short-term climate scenario analysis, defined as a period of 10 years, into their operations [26].

1.2 Problem Formulation

This thesis focuses on climate scenario analysis for financial institutions, examining the impact of short-term climate scenarios on income streams and sectoral performance. By defining realistic and broad scenarios, the study identifies the susceptibility of different sectors to climate policies and regulations. Additionally, the impact of increasing frequency and intensity of natural disasters on market dynamics will be explored. Ultimately, the aim is to provide financial institutions with insights into potential risks and strategies to mitigate these risks, considering current and upcoming regional and global regulations.

1.3 Delimitations

This thesis includes several delimitations and assumptions. Primarily, there is a focus on EU policies within the climate scenarios, emphasizing upcoming regulatory changes affecting EU members. However, due to the lack of available data, some sectoral analyses use data from the USA or globally, under the assumption that the effects would be similar in the EU.

Another delimitation is the exploration of only three distinct climate scenario narratives, without considering any intermediate scenarios. This approach means that the analysis does not cover all possible future paths, focusing instead on three specific possibilities. Additionally, the thesis does not assess the probability of each scenario, as this would require a complex and thorough analysis, introducing further uncertainty.

The sectoral analysis concentrates on sectors with significant climate impacts. Some sectors with a climate impact are excluded to restrict the scope of the thesis, as there are already extensive studies on these industries or they have made significant progress towards green technologies.

In conducting the sectoral analysis for the different climate narratives, several assumptions and delimitations are made. Current relationships between different variables are assumed to remain constant in the future for forecasting purposes. Different modeling techniques are used for different sectors, chosen based on available data and the current outlook of the sector. Stock indexes often represent entire sectors in the modeling process.

Furthermore, the thesis does not investigate the impact of different sectors on each other due to the complex and uncertain relationships between them.

When modeling, the models are constructed to include only environmental aspects, although sectors are affected by various factors. This is done in order to isolate the impact of climate-related matters. Uncertainties are quantified to the greatest extent possible and where applicable.

1.4 Uncertainties

Throughout the methodology of this thesis, several uncertainties are introduced. First and foremost, the delimitations and assumptions discussed in the previous section contribute to uncertainties in the estimates.

A significant source of uncertainty arises from the utilization of historical data, upon which most models are built. This data often contains missing points and outliers, which, although addressed, still introduce uncertainties into the estimates. Additionally, the modeling techniques employed often rely on external forecasts for prices and market sizes, which themselves include assumptions about the future that are inherently uncertain.

The three scenario narratives further introduce uncertainties related to assumptions about market reactions and the associated risks of each climate scenario. Since it is impossible to predict exactly how the stock market will respond to different future shocks, there are inherent uncertainties surrounding these assumptions.

Political risk is another major source of uncertainty. In most countries, political power is reevaluated periodically, leading to uncertainties regarding future policy changes. One example of this, with contemporary relevance (2024), is the upcoming election for the European Parliament. Although this type of uncertainty is nearly impossible to quantify, it is important for the reader to be aware of the potential for unpredictable regulatory behaviors.

Lastly, the models created in this thesis do not fully replicate reality, which introduces additional uncertainties into the model forecasts. Despite efforts to account for various factors, the inherent limitations of modeling mean that the forecasts cannot be entirely accurate.

Overall, while uncertainties are quantified to the greatest extent possible, they remain an inherent part of the analysis and should be considered when interpreting the results.

2 Climate Scenarios

Currently, there is limited research on short-term climate scenarios. However, the Network for Greening the Financial System (NGFS) addressed this gap in October 2023 with the publication of the "Conceptual Note on Short-Term Climate Scenarios"[28]. In this document, NGFS explores five distinct climate scenario narratives that illustrate the short-term dynamics of various transition and physical impacts. These scenarios vary in their levels of transition and physical risks. Three of the scenarios emphasize mitigation efforts, providing insights into transition risks. Additionally, one scenario highlights high physical risks in the short term, while another scenario combines significant transition and physical risks.

For this thesis, three of these scenarios, which encompass the majority of possible outcomes, were selected as the foundation: "Low Policy Ambition and Disaster," "Sudden Wake-Up," and "Highway to Paris." These scenarios represent diverse paths: the first depicts minimal climate ambition, the second illustrates procrastination followed by a sudden shift toward stronger climate policies, and the third envisions a consistent and ambitious approach to climate policy.

However, the scenarios in the "Conceptual Note on Short-Term Climate Scenarios" are quite detailed by describing potential behaviors as a result of each scenario. For the purposes of this thesis, these scenarios were reconstructed to generalize the analysis, resulting in a simpler framework for further examination. Simplifying the NGFS scenarios also broadens their scope, which is beneficial since this thesis will focus on only three scenarios. Furthermore, the NGFS scenarios described in their report are set on a 3-5 year horizon whereas this thesis explores a time horizon extending to 10 years.

Additionally, it is important to note that the NGFS does not specify the likelihood of each scenario. Given this and the complexity of the issue, this thesis will also refrain from evaluating the likelihood of each scenario.

The scenarios are then applied, according to the consultation paper on guidelines on the management of Environmental, Social and Governance (ESG) risks by EBA, extending to a 10 year time horizon. Each possible climate scenario entails a range of climate related risks, including both transitional and physical risk. Transitional risk includes risks associated with the transition to a lower carbon-economy, whereas physical risks are the physical consequences of climate change. Furthermore, all of the climate related risks identified impact each other and create complex relations.

For the purposes of this thesis, the three main climate scenarios have been simplified and renamed to Low Policy Ambition, Sudden Change in Policy Ambition, and High Policy Ambition. The primary focus of these scenarios is on the political actions taken to accelerate the transition to a low-carbon world. Each scenario differs in its level of ambition and whether the goals set by the Paris Agreement are achieved. In subsequent modeling for each scenario, the key distinction will be the attainment of net zero emissions by 2050.

2.1 Low Policy Ambition

Just like the "Low Policy Ambition and Disasters" scenario specified by NGFS [28] the Low Policy Ambition scenario depicts a future where climate-related issues and regulations are not met with the required urgency and stringency, resulting in heightened vulnerability to environmental catastrophes. There is a lack of political ambition, in the short term as well as in the long term. Hence, this scenario is not in line with the Paris Agreement's goal of net zero emissions by 2050. Unlike the corresponding NGFS scenario, for modeling purposes and to follow the guidance set by EBA, the time horizon of this scenario is set to 10 years.

This scenario unfurls as a tapestry of disasters, transcending borders and impacting all corners of the globe. These indiscriminate events, ranging from the effects of extreme weather to the compounding impacts of rising sea levels, underscore the urgent necessity for international cooperation on climate change. However, such concerted efforts remain absent.

The risk profile of this scenario is characterized by heightened physical risks, primarily stemming from climate disasters. These disasters, ranging from extreme weather events like hurricanes and wildfires to the slow-onset impacts of rising sea levels, pose significant threats to infrastructure, livelihoods, and ecosystems. The frequency and severity of these events are exacerbated by the lack of robust climate policies and may impact the stock market dynamics as well.

Moreover, there is a notable political risk associated with this scenario. The failure to enact stringent climate regulations and address environmental challenges with the required urgency can lead to political instability and social unrest. In this scenario upcoming EU regulations such as the revised ETS system and CBAM will not be implemented as previously determined.

2.2 Sudden Change in Policy Ambition

This scenario reflects a long period of ignorance suddenly challenged by a change in political ambitions in 2026. This change could stem from a political decision, a technological breakthrough, or a natural disaster that abruptly makes decision-makers realize the immediate need for change to achieve the Paris Agreement goal of net zero emissions by 2050.

The Sudden Change in Policy Ambition scenario follows the same narrative as the "Sudden Wake-up Call " scenario described by NGFS [28]. However, this scenario is also extended to cover a 10-year horizon. Further alterations to the corresponding NGFS scenario is that the sudden change is set to happen in 2026. The significance of the choice of 2026 lies in the planned changes in the ETS and CBAM regulations, which are expected to accelerate the climate transition. Additionally, setting this change in 2026 allows its effects to be captured within the time horizon examined in this thesis. However, as previously mentioned, the sudden change effect could stem from other causes and it is near impossible to know when this would occur.

In the context of the Sudden Change in Policy Ambition scenario, the associated shocks manifest in both transitional and physical forms, each presenting distinct challenges and disruptions to businesses, governments, and societies at large. Transitional shocks, characterized by abrupt policy changes such as the implementation of carbon pricing mechanisms, are instrumental in catalyzing the transition towards a low-carbon economy.

What distinguishes the Sudden Change in Policy scenario from more gradual transitions is the compressed timeframe within which these shocks occur. Unlike scenarios characterized by incremental policy changes or slow-onset environmental trends, the abrupt nature of the wake-up call leaves stakeholders with significantly less time to adapt and prepare. This heightened sense of urgency amplifies the disruptive effects of both transitional and physical shocks, magnifying the challenges faced by businesses, governments, and societies.

For modeling purposes in this thesis, the Sudden Change in Policy Ambition scenario will initially follow a trajectory similar to the Low Policy Ambition scenario, where net zero emissions by 2050 are not achieved. However, in 2026, this scenario will experience a sudden shift, transitioning to a path that successfully achieves net zero emissions by 2050. This abrupt change is what will constitute the ”shock” in this scenario.

2.3 High Policy Ambition

The Highway to Paris scenario, described by NGFS [28], reflects a rapid shift in climate-related policy and green technology to align with the goals of the Paris Agreement by 2050. The High Policy Ambition scenario once again covers a 10-year horizon unlike the corresponding NGFS scenario.

Achieving the goal of net zero emissions in 2050 requires a change in emissions policy, which will, in turn, reduce demand for carbon-intensive products while promoting innovation in green technology. However, a rapid transition may initially lead to imbalances between demand and supply in certain sectors.

Heightened uncertainty surrounding fossil energy reserves prompts governments to swiftly implement carbon pricing mechanisms, with the aim of achieving net-zero emissions by 2050, as widely anticipated within policy circles. In this scenario, the revised ETS system and CBAM, along with other similar carbon pricing mechanisms, will be implemented as planned.

Moreover, revenues generated from carbon pricing schemes are channeled partially into green public investments, catalyzing a rapid redistribution of private capital away from emission-heavy industries, both domestically and internationally. This anticipatory approach yields significant reductions in fossil fuel demand as green technologies become more profitable, aligning closely with the targets set forth in the Paris Agreement. However, the pace of this transition may initially outstrip the readiness of certain sectors, leading to temporary mismatches between supply and demand.

The main risk landscape of this scenario consists primarily of transition risks. Sectors and industries reliant on fossil fuels need to adapt in order to remain profitable and competitive. Companies failing to transition efficiently may face financial instability, reduced market share, and potential bankruptcy. Additionally, rapid policy changes and technological advancements could lead to regulatory compliance challenges, increased operational costs, and shifts in consumer preferences, further complicating the transition for these sectors.

3 Industry Overview and Financial Dynamics

In this section, a current situation analysis will be provided for each climate-sensitive sector examined in this thesis. The aim is to offer readers background information on each sector and explain why they might be impacted by climate scenarios. The section will conclude with a brief explanation of revenue generation in financial institutions.

3.1 Climate Sensitive Secors

To assess exposure to various climate-affected sectors, the Paris Agreement Capital Transition Assessment (PACTA) tool was utilized [31]. This tool is accessed on the Transition Monitor website, providing insights into the sectors most impacted by climate change and their exposure in the portfolio. PACTA covers eight climate-relevant sectors, focusing on technologies and their impact on climate change. However, it is important to note that the analysis is limited to those parts of the portfolio with direct exposure to relevant technologies.

The sectors covered by PACTA include oil and gas, coal, power, aviation, automotive, steel and cement. Moreover, the PACTA methodology can be applied to financial assets as listed equity, corporate bonds and corporate loans.

In this thesis, the analysis will focus on all sectors identified by PACTA except for the automotive sector. The rationale for this exclusion is based on the considerable progress towards sustainability achieved by the automotive industry. Substantial advancements have been driven by innovations in electric vehicles, improvements in fuel efficiency, and increased regulatory pressures. Consequently, the current trajectory towards a sustainable future within the automotive sector reduces its immediate relevance for this study, allowing concentration on sectors where the impacts of climate change and the need for transition are more pronounced.

Oil and Gas

The oil and gas industry is a diverse industry, spanning from small specialized operators to massive national oil companies. Critical decisions are on the horizon regarding the industry's position within the global energy framework, particularly in light of the escalating climate crisis, largely attributed to its primary outputs. Given the industry's immense scale and diversity, perspectives on these issues are multifaceted.

A peak in demand for all fossil fuels is forecasted to occur before 2030 [8], given the current policy landscape. However, these policies are deemed insufficient to induce significant declines in demand thereafter. If governments keep their promises about energy and climate, especially if they manage to limit global warming to 1.5°C, it will have a huge impact on the oil and gas industry.

Consequently, the industry finds itself at a defining moment regarding its involvement in clean energy transitions. Thus far, its participation has been minimal with less than 1% of global clean energy investment emanating from oil and gas companies. However, no segment of the industry will remain unscathed by the shift toward net zero. Every sector within it must adapt.

In the scenario where net zero emissions are achieved by 2050, oil and gas prices swiftly plummet to the operational costs of marginal projects required to meet declining demand. Specifically, the forecast indicates a decrease in oil prices to USD 25 per barrel and an expected gas price in Europe of USD 4.1 per MBtu [8].

Aviation

The aviation sector faces significant risks associated with regulatory changes and emission reduction requirements set by policymakers. Regulatory changes pose a substantial risk to the aviation industry. The EU's ETS has undergone revisions, and by 2026, all free emission allowances within the sector will be phased out [19]. This transition necessitates a rapid adoption of Sustainable Aviation Fuel (SAF), as well as other techniques, to meet the evolving emission reduction targets.

According to a report by IATA [33], SAF is projected to contribute 65% of the efforts required to achieve net-zero emissions in the aviation industry by 2050. However, in 2023, SAF accounted for only 3% of all renewable fuel produced and less than 1% of the sector's total fuel consumption. This supply-demand imbalance has resulted in high SAF prices. Furthermore, IATA predicts that SAF production will reach 6% of all renewable fuel produced in 2024, representing 0.53% of the sector's fuel supply [32]. To achieve net-zero emissions by 2050 using current strategies, the sector would require 20-30% of its fuel to be renewable. This necessitates substantial policy interventions, prioritization, and a general acceleration of renewable fuel production.

The transition to a sustainable aviation industry requires a multifaceted approach that addresses regulatory risks, promotes SAF production, and encourages technological advancements. The sector is also exposed to political risks, as policymakers can change or withdraw regulations after being established.

Coal

Coal mines are significant contributors to anthropogenic methane emissions, releasing methane, a potent greenhouse gas with a global warming potential 28–36 times greater than that of CO_2 over a 100-year period. This methane, known as coal mine methane (CMM), remains closely associated with coal production. Even after operations cease and mines are abandoned, methane continues to be emitted, termed as abandoned mine methane (AMM), persisting for extended periods. Estimates indicate that the coal mining industry alone contributes approximately 11% of global methane emissions from human activities [36].

Coal mining and utilization both significantly contribute to greenhouse gas emissions, with coal alone responsible for approximately 40% of global greenhouse gas emissions [27]. Coal remains a dominant force in global electricity generation, providing just over a third of the world's power despite being the most carbon-intensive fossil fuel. However, there's a gradual shift underway in many nations toward alternative sources for generating electricity [6]. Significantly cutting coal emissions is crucial for achieving our climate goals. Therefore, in order to reach net zero emissions, the global coal demand use must decrease by 90% until 2050 [3].

Steel

The steel industry is a significant contributor to global greenhouse gas emissions, accounting for approximately 7% of total global emissions. Within the European Union (EU), the sector's emissions represent around 5% of the total. Recognizing the urgency of climate action, the EU has set ambitious goals to decarbonize the steel industry, aiming for an 80-95% reduction in emissions by 2050 compared to 1990 levels [18]. The current free allowances given to the sector will gradually phase out until 2035 and CBAM will be introduced affecting steel producers globally [4].

The significant market size of the stainless steel industry underscores the potential impact of the transition to low-CO2 production methods. Valued at USD 205.87 billion in 2023, the market is projected to grow steadily, reaching USD 342.07 billion by 2032, with a CAGR of 5.8% [35]. This substantial growth potential highlights the economic importance of developing sustainable steel production methods that can cater to this expanding market while addressing environmental concerns. Notably, the green steel market is anticipated to experience a more explosive growth from $2.70 billion in 2023 to $98.84 billion by 2030, reflecting a CAGR of 67.2% [34].

The EU's REPowerEU plan outlines a comprehensive strategy to accelerate the decarbonization of the steel industry. A key component of this plan is the expectation that by 2030, around 30% of primary steel production within the EU will be decarbonized through the utilization of renewable hydrogen. In the short to medium term, it is anticipated that the production of low-CO2 steel will be more expensive compared to current conventional methods. The long-term cost of hydrogen-based steel remains uncertain, as it is heavily dependent on the future pricing of renewable hydrogen and electricity [18].

Cement

Annually, the global production of approximately 4.5 billion tons of cement results in carbon dioxide emissions totaling 2.7 billion tons, constituting 8 percent of global emissions [39]. The main challenge confronting the cement industry is to simultaneously curb CO2 emissions while satisfying escalating global demand [5]. There is a projected surge in cement demand by 2050, ranging between 12-15% compared to the levels in 2020 [43]. At the same time, the sector must reduce its annual carbon dioxide emissions by 4% by 2030 to reach net-zero emissions by 2050 [5]. To achieve that, companies within the cement industry need to produce more green cement. The manufacturing process of green cement is carbon-negative, utilizing industry's primary waste products to create raw materials [21].

Due to increasing demand, the global regular cement market size is expected to surge from USD 423.24 billion in 2024 to USD 592.38 billion by 2032, with a compound annual growth rate (CAGR) of 4.3% [12]. Likewise, the global green cement market size is forecasted to expand from USD 39.32 billion in 2024 to USD 83.28 billion by 2032, experiencing a CAGR of 9.9% over the same period [13].

CBAM will be introduced in 2026, and free allowances of ETS will be phased out, with carbon dioxide penalties imposed on imported cement. Companies that have been at the forefront of green cement production will benefit as the traditional cement industry must undergo a transition to new rules of the game.

Power

Electricity plays a central role in modern societies, with its significance poised to increase further as it becomes integral in transportation and heating, fueled by the growing adoption of electric vehicles and heat pumps. Currently, power generation stands as the primary contributor to global CO_2 emissions. The power sector is leading the way in moving towards zero emissions by quickly adding renewable sources like solar and wind. The urgent need to fight climate change is pushing for more things to run on electricity, from cars to factories. As more things go electric, we're using a lot more power, making it crucial to generate as much as possible from renewable sources. Electricity has traditionally been generated from various sources, including coal, oil, natural gas, nuclear, hydropower, wind, and solar [7].

The power industry is experiencing substantial growth globally, driven by rising global population and the development of emerging economies. Projections indicate a continuous surge in global electricity generation, expected to increase by 3% annually until 2050 to meet escalating demand [22].

3.2 Revenue Generation in Financial Institutions

The income statement of a financial institution closely resembles that of other corporations. It begins with non-interest revenue, which includes broker fees, commissions, fees from products and services, underwriting fees, and other customer fees. Following this, the income statement captures interest revenue, representing the interest payments the bank receives on the loans it issues. Additionally, financial institutions incur interest expenses, which are the direct costs paid to depositors for the funds used to issue loans. These interest expenses exclude those associated with general debt.

4 Natural Disasters

Building on the understanding of climate-sensitive sectors and financial dynamics outlined in the previous section, it becomes imperative to delve deeper into the escalating frequency and economic ramifications of natural disasters.

There is significant evidence that the frequency of climate-related catastrophes is increasing. Climate-related problems pertain to floods, storms, temperature extremes, droughts, and wildfires. These are then grouped into hydrological events, which include floods; meteorological events, which include storms and temperature extremes; and climatological events, which include droughts and wildfires. On a global scale, hydrological disasters have increased significantly, from an average of forty-five events annually during the 1975–1984 period to exceeding 180 events per year between 2005 and 2014. Meteorological disasters have more than doubled, surging from an average of forty-five events annually to nearly 120 occurrences per year during comparable time spans [44].

The economic costs of natural events and disasters can vary depending on the level of analysis. In addition to direct damages, supply disruptions from such disasters often lead to a redistribution of producer surplus from negatively impacted enterprises to those unaffected. This redistribution overlooks distributional effects and focuses on other impacts affecting society as a whole - encompassing tangible elements like infrastructure damage and production loss, as well as intangible factors such as loss of life and social upheaval. Interestingly, these intangible costs often dominate the total costs of a given event [1].

Furthermore, it has been observed that natural disasters frequently pose significant risks for both insurance companies and policyholders. Studies indicate a positive association between unforeseen catastrophes and large-scale events, and subsequent increases in losses and loss ratios. In response, insurers typically adjust by raising insurance rates, resulting in reduced loss ratios following such catastrophic occurrences [11].

Moreover, research underscores the influence of natural disasters on the stock market. However, the extent of this impact varies depending on the nature of the disaster, with each type exerting differing degrees of influence on market dynamics [40].

5 Theory

5.1 Linear Regression Model

Linear regression is a method used for modeling the relationship between a dependent variable and one or more independent variables.

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + ... + \beta_p \cdot x_p + \epsilon \tag{1}$$

In eq. (1) y is the dependent variable while $x_1, x_2, ..., x_p$ are independent variables. β_0 is the intercept while $\beta_1, \beta_2, ..., \beta_p$ are coefficient to the independent variables. The error term, ϵ, is assumed to be independently and identically distributed (IID) [30].

To estimate the coefficients Ordinary Least Squares (OLS) can be used. The objective in OLS is to minimize the sum of the squared differences between the observed Y values and the predicted values $\hat{Y}$ obtained from the linear regression equation. That is, OLS minimizes the esidual sum of squares (RSS).

$$RSS = \sum_{i=1}^{p}(y_i - \hat{y_i})^2 \tag{2}$$

There are a few assumptions of the linear regression model that must be fulfilled. Firstly, it assumes linearity, signifying that the relationship between the independent and dependent variables follows a linear pattern. This implies that changes in the independent variables lead to proportional changes in the dependent variable. Secondly, the model assumes independence among observations in the dataset, meaning there should be no correlation among the residuals. Thirdly, it presupposes homoscedasticity, indicating that the variance of errors remains constant across all levels of the independent variables [41].

5.2 Linear Extrapolation

Linear extrapolation is a method to find the analytical function $f(x)$ so that it can be used to estimate values outside the range of known data. If one has two data points (x_1, y_1) and (x_2, y_2) and they form a straight line, you can find the equation of the line

$$y = kx + m, \tag{3}$$

and then use this equation to predict the value of y for any value of x outside the range of x_1 and x_2 [45].

5.3 ARIMA model

The AutoRegressive Integreate Moving Average (ARIMA) process is useful for characterizing non-stationary behaviors, such as stochastic trends. $\{Y_t\}$ is an ARIMA(p,d,q) if it can be defined as

$$\phi(B)\delta^d Y_t = \theta(B)\epsilon_t \quad d \in \mathbb{N} \tag{4}$$

where $\{\epsilon_t\}$ is white noise, $\phi(B)$ and $\theta(B)$ are polynomials of order p and q respectively. Both polynomials must have all their roots inside the unit circle [38].

5.4 Maximum Likelihood Estimation

Maximum Likelihood Estimation (MLE) is a method used to estimate the parameters of a statistical model. The idea behind MLE is to find the set of parameter values that maximizes the likelihood function [38]. The MLE is defined as

$$\hat{\theta}_{MLE} = \arg\max_{\theta \in \Theta} \mathcal{L}(\theta). \tag{5}$$

where

$$\mathcal{L}(\theta) = p(x_0, ..., x_N|\theta) \tag{6}$$

$$= (\prod_{n=1}^{N} p(x_n|x_{n-1}, ..., x_0, \theta))p(x_0|\theta). \quad (7)$$

Since the argument that maximixes $L(\theta)$ is not affected by a logarithmic transformation, eq. (5) can be written as

$$\hat{\theta}_{MLE} = \arg\max_{\theta \in \Theta} \log p(x_0|\theta) + \sum_{n=1}^{N} \log p(x_n|x_1, ..., x_{n-1}, \theta). \quad (8)$$

5.5 Volatility Modeling

GARCH

The Generalized ARCH (GARCH) model is a model describing the conditional variance. The conditional variance is a linear function of past sample variances and past values of the conditional variance.

The GARCH model is defined as

$$\epsilon_t|\mathcal{F}_{t-1} \sim F(0, \sigma_t^2) \quad (9)$$

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-i}^2 \quad (10)$$

where the coefficient (α_i, β_i) $\forall$i must be non-negative. This condition must be fulfilled in order to ensure positive variances. Furthermore, $\sum_i^p \alpha_i + \sum_j^q \beta_j < 1$ in order to preserve stability [38].

EGARCH

The GARCH model presents two primary limitations: symmetry and parameter requirements. Its symmetry means it does not anticipate volatility to vary based on the sign of ϵ_t. Additionally, its stringent parameter requirements pose challenges, potentially making numerical optimization difficult. As a response, Nelson [1991] introduced the EGARCH model to tackle the issues inherent in the GARCH model [38].

The EGARCH model is specified as

$$\epsilon_t = w_t \sigma_t \quad (11)$$

$$\sigma_t = \exp(\frac{1}{2} h_t) \quad (12)$$

$$h_t = \omega + \sum_{i=1}^{p} \alpha_i w_{t-1} + \sum_{i=1}^{q} \beta_i h_{t-i}. \quad (13)$$

5.6 Poisson Distribution

The Poisson distribution is a discrete probability distribution that quantifies the likelihood of a particular number of events occurring within a designated time frame. Poisson processes refer to discrete, independent, and mutually exclusive processes. The probability density function of the Poisson distribution is defined as

$$f(x;\mu) = \frac{\mu^x e^{-\mu}}{x!}, \tag{14}$$

where $x = 0, 1, 2...$ represents a discrete random variable. The occurrence count of an event within a time interval of length t follows a Poisson distribution with parameter μ, where μ equals the product of λ and t. The Poisson probability mass function is represented as

$$P(X = x) = \frac{\mu^x e^{-\mu}}{x!}. \tag{15}$$

Drawing samples from a Poisson distribution is straightforward, requiring only the specification of the rate parameter λ. This parameter, representing the average rate of event occurrence within a fixed interval, serves as the sole input for generating Poisson-distributed random numbers. This simplicity in parameterization makes Poisson sampling particularly accessible and efficient for modeling stochastic processes and conducting probabilistic analyses [37].

5.7 Bootstrap

A general regression model can be formulated as

$$Y_i = g_i(\beta_i) + \epsilon_i \qquad \forall i = 1, 2, ..., n, \tag{16}$$

where g_i are of known form while $\boldsymbol{\beta}$ is a vector of unknown parameters. The residuals, ϵ_i, are IID with some distribution F.

Given the observed vector

$$\boldsymbol{y} = \begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{pmatrix}, \tag{17}$$

the estimate of $\boldsymbol{\beta}$ can be computed by minimizing the distance measure between $\boldsymbol{y}$ and $\boldsymbol{\gamma(\beta)}$, which is defined as

$$\boldsymbol{\gamma(\beta)} = \begin{pmatrix} g_1(\beta) \\ g_2(\beta) \\ \vdots \\ g_n(\beta) \end{pmatrix} \tag{18}$$

The estimated $\hat{\beta}$ are then used to compute following:

$$\hat{\epsilon_i} = y_i - g_i(\hat{\beta}). \tag{19}$$

Bootstrapping the residuals is accomplished by constructing the distribution F_n that places probability $\frac{1}{n}$ at each $\hat{\epsilon}_i$. To generate bootstrap residuals $\epsilon_i^\star$ independent sampling from F_n is conducted. It is then possible to obtain a bootstrap sample data set

$$y_i^\star = g_i(\hat{\beta}) + \epsilon_i^\star \qquad \text{for} \quad i = 1, 2, ..., n \tag{20}$$

For each $y_i^\star$, following is obtained

$$\hat{\beta^\star} = \min_{\beta}[y^\star, \gamma, \beta]. \tag{21}$$

The procedure is then repeated B times [15].

6 Method

6.1 Sectoral Analysis

After defining three different climate policy ambition scenarios, it is of interest to study the sectors identified by PACTA in Section 3.1 and their performance and development in each scenario. The methods introduced in this section are chosen based on the industry outlook and the available data within each sector. These methods explore possible paths and forecasts, highlighting the uncertainties inherent in each model. Despite these uncertainties, the aim is to provide financial institutions with insights into potential outcomes in an uncertain future. By examining the narratives for each sector under the different climate scenarios, this methodology seeks to illustrate the diverse impacts of varying levels of climate policy ambition.

6.1.1 Oil and Gas

To evaluate the performance of companies within the oil and gas sectors across various scenarios, an index that was representative for this sector was selected as a measure of overall industry response. With the projected decline in oil and gas demand and the subsequent price decrease in scenarios targeting net zero emissions by 2050, as discussed in Section 3.1, a linear regression model was developed.

In pursuit of simplicity, it was decided to use only one of the oil or gas prices as an independent variable in the model. To determine which variable to include, the correlation between each fossil fuel price and the Dow Jones U.S. Oil & Gas Index was computed. The fossil fuel exhibiting the highest correlation (r)

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2(y_i - \bar{y})^2}} \tag{22}$$

with its price (x) and the index (y) that was selected as the independent variable. Due to the substantially higher correlation with oil prices, the decision was made to utilize oil prices in the model. After careful consideration, it was concluded that utilizing the S&P Global Oil Index as an indicator would better capture the index variation, especially considering its global scope and the primary focus on the oil price.

This approach allowed the model to be streamlined while still capturing essential industry dynamics. Consequently, the model incorporated the S&P Global Oil Index as the dependent variable, with the chosen fossil fuel price, the S&P 500 Index, and the volatility of the S&P Global Oil Index as independent variables. The linear model was defined as

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \beta_3 \cdot x_3 + \epsilon, \tag{23}$$

where x_1 represents the oil prices, x_2 is the S&P 500 index and x_3 represents the volatility of the S&P Global Oil Index.

The inclusion of the S&P 500 Index as an independent variable was motivated by its ability to capture broader market movements and provide valuable context for assessing industry-specific trends. Including the volatility of the S&P Global Oil Index in the regression model is crucial for assessing risk in the industry. By incorporating the volatility as an independent variable, the model can account for this inherent risk and give a better understanding of how companies within the sector may respond to changing market conditions and potential shocks.

The dataset utilized in this analysis spans from January 2018 to March 2024. Prior to its incorporation into the regression model, a monthly mean was computed. This preprocessing step of calculating monthly means helps to smooth out short-term fluctuations and provide a clearer representation of the underlying trends within the data. The data is averaged over monthly intervals, aiming to reduce noise and enhance the reliability of the analysis. This approach ensures that the regression model is based on more stable and representative data, thereby improving its robustness and accuracy in capturing the relationships between variables over the specified time period.

After completing the regression analysis, it became imperative to generate forecasts for the data utilized as independent variables. Predictions for the oil price were conducted under two scenarios: one where the net zero emissions goal is achieved and another where it is not. In the scenario where net zero emissions are not achieved, data on predicted yearly oil prices spanning from the end of 2024 to the end of 2035 were used [8]. Linear interpolation was employed to interpolate all intermediate oil prices within this time frame.

In the other scenario where the net zero emissions goal is attained, projections for the oil price in 2030 and 2050 were obtained, as detailed in Section 3.1. To obtain a comprehensive set of oil prices spanning from the present to 2050, two linear interpolations were required. Initially, a linear interpolation was performed between the current oil price and the projected oil price for 2030. Subsequently, a linear interpolation was carried out between the price in 2030 and the price in 2050. The rationale behind the utilization of linear interpolation lies in its ability to provide a straightforward and systematic approach for estimating intermediate values based on known data points, thus enabling a smooth transition and approximation of oil prices over the specified time horizon.

Different oil price predictions were employed for each scenario. In the High Policy Ambition scenario, oil prices aligned with the net zero emissions goal were utilized. Conversely, for the Low Policy Ambition scenario, oil prices reflecting a situation where net zero is not achieved were employed. However, for the Sudden Change in Policy Ambition scenario, a blend of these two predictions was utilized. Until the year 2026, the oil prices mirrored those of the Low Policy Ambition scenario. However, a significant change occurs in 2026, resulting in a decrease in oil prices to align with the forecasted prices detailed in Section 3.1. Consequently, a linear interpolation is performed between the price in 2026 and the projected price in a net zero emissions scenario for 2030. Subsequently, the same interpolation technique used in the High Policy Ambition scenario is applied from 2030 to 2050.

As for forecasting the S&P 500 Index, a simplified method was adopted. This method entailed assuming that future yearly growth would mirror the average yearly growth observed in past years. The rationale behind selecting this method stemmed from the necessity to forecast over a ten-year period. Implementing a time series method would have proven exceedingly challenging to capture a realistic future outcome within this time frame.

The volatility modeling of the returns of the S&P Global Oil Index involved the initial calculation of log returns. To ensure statistical robustness and mitigate inherent biases, the returns were adjusted by subtracting their mean value. Subsequently, a smoothing technique was applied by averaging the returns over a month, serving to attenuate short-term fluctuations while emphasizing longer-term trends in the data.

A GARCH(1,1) model was then fitted to the data

$$\sigma_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \tag{24}$$

, with the parameters in the model estimated using maximum likelihood estimation. Finally, the estimated GARCH model was utilized to forecast future volatility. Employing a simulation approach, random draws were generated from the conditional variance process, and their square root was computed to obtain volatility estimates for future periods.

Following the completion of oil price, S&P 500 Index, and volatility predictions, the analysis progressed to evaluating potential changes in the S&P Global Oil Index value across various scenarios. This was done by utilizing the variables from the multivariate regression analysis together with the forecast data for the different scenarios. The future values of the S&P Global Oil Index were then computed, with any negative values constrained to zero to align with real-world constraints.

In addition to forecasting oil prices, an integral component of the analysis involved examining historical trends and projecting future scenarios of oil demand. Given the projections of decreasing oil prices in scenarios where net zero emissions are achieved, it was imperative to also scrutinize the underlying trends in oil demand.

Historical data on oil demand spanning from 1971 to 2023 [2] was analyzed to understand the patterns of oil consumption within the industry. To explore how this trend would continue, an investigation was conducted through time series analysis on the data, followed by forecasting. The time series plot of oil demand was visually inspected, and an Augmented Dickey-Fuller (ADF) test was conducted to assess stationarity. Initially, non-stationarity in the data was identified. Differencing was then applied to render the data stationary, and stationarity was verified using the ADF test. The autocorrelation function (ACF) and partial autocorrelation function (PACF) of the differenced series were examined to identify potential autoregressive (AR) and moving average (MA) orders. Based on the ACF and PACF plots, potential orders for the ARIMA model were selected. The differencing order (d) was specified, and candidate orders for AR (p) and MA (q) were identified. The model was fitted to the differenced series using maximum likelihood estimation. Residuals were extracted from the fitted model, and their autocorrelation and partial autocorrelation were examined to ensure model adequacy. Future oil demand was forecasted using the fitted ARIMA model. An ARIMA (AutoRegressive Integrated Moving Average) model was utilized to project future oil demand under the assumption of current trends continuing. Specifically, an ARIMA(1,1,1) model with the following equation was fitted to the data.

$$(1 - \phi_1 B)(1 - B)Y_t = c + (1 + \theta_1 B)\epsilon_t. \tag{25}$$

Moreover, oil demand scenarios under the premise of achieving net zero emissions by 2050 were calculated, incorporating an annual 5% reduction in demand. As mentioned in Section 3.1, achieving net zero emissions is expected to result in an average annual decrease in oil and gas demand of more than 5%. However, for the sake of simplification, a consistent 5% reduction was applied throughout the entire time period.

6.1.2 Aviation

Due to the complexity of the aviation sector, influenced by seasonal variations, household consumption, and other factors, modeling the returns of an airline index is considered suboptimal. Therefore, volatility is used as a proxy to gain some insight into the industry.

The volatility of the European airline industry is assessed using the STOXX Europe Total Market Airlines Index, which comprises the leading industry participants within the European market. The European market is focused on due to the primary risks associated with EU regulations. To model the historical volatility within the sector, the GARCH modeling framework is utilized. First a GARCH(1,1) model with the following equation was fitted to the STOXX index.

$$\sigma_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \tag{26}$$

Secondly, an EGARCH(1,1) model with the following equation fitted to the STOXX index.

$$h_t = \omega + \alpha w_{t-1} + \beta h_{t-i} \tag{27}$$

To determine which model is preferred, penalized-likelihood criterias are used. Both the Akaike Information Criterion (AIC) and the Schwarz's Bayesian Information Criterion (BIC) are applied to each model to determine the strongest evidence towards one model.

By simulating a random path of conditional variances from the fully specified conditional variance model, one can gain insights into potential future volatility trends. This analysis is conducted without incorporating the climate related risks, solely aiming to establish a baseline scenario for the volatility of the aviation index within the current time frame. This baseline is then tailored to the three different climate scenarios, where scenario-specific risks play a significant role in determining the outcomes.

To explore the potential impacts of various climate scenarios on the aviation industry, short-, medium-, and long-term horizons are considered. Within each scenario, volatility changes and investor behaviors are evaluated based on reasonable assumptions regarding the associated risks. The primary focus is on political risks, encompassing potential regulatory modifications and reversals. This includes the possibility of delayed or canceled ETS phase-outs for specific sectors, or the implementation of stricter regulations. Furthermore, assumptions about the evolution of Sustainable Aviation Fuel are also made for each scenario. Where the highest ambition scenario generates higher usage of SAF.

The methods employed aim to provide a comprehensive understanding of how different levels of policy ambition might affect the aviation sector. By examining the sector's response to these scenarios, valuable insights into the potential future landscape of the aviation industry are offered. It is important to note that the results are based on assumptions and should be viewed as potential anticipations rather than definitive outcomes. This analysis sets the stage for the results, which detail the anticipated outcomes for the aviation sector under each climate scenario.

6.1.3 Coal

As the shift towards achieving net zero emissions implies a reduced demand for coal, it follows that the price of coal will decline as well. To assess the implications of these shifts on companies in the coal mining industry, a linear regression model was employed. The model utilized the S&P Global Mining Reduced Coal Index as the dependent variable, while the independent variables included coal price and the S&P 500 index. The selection of the dependent variable stemmed from the belief that such an index effectively encapsulates the dynamics of coal mining companies and their response to fluctuations in coal prices and market conditions.

The historical dataset covered the period from 2018 to March 2024, including data on the S&P Global Mining Reduced Coal Index, coal price per ton, and the S&P 500 index. Given the extensive volume of data available, a decision was made to compute monthly averages. This approach aimed to mitigate the impact of fluctuations, ensuring a smoother regression analysis.

Following the fitting of a linear regression to the dataset

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \epsilon, \tag{28}$$

forecasts were required for the independent variables. Considering that coal prices are influenced by multiple factors, notably demand, which fluctuates depending on the attainment of net zero emissions, it became imperative to forecast coal prices under two scenarios: one involving the achievement of net zero emissions and another where they were not achieved.

To forecast coal prices in the scenario without achieving net zero emissions by 2050, predictions from The World Bank [10] were utilized, spanning the years 2030 and 2035. Linear interpolation was employed to estimate prices from March 2024 to 2034, involving interpolation between the March 2024 price and the predicted 2030 price, followed by interpolation between the predicted 2030 and 2035 prices.

In contrast, forecasting under the scenario of achieving net zero emissions necessitated a different approach, as there were no specific predictions available for coal prices in this context. Therefore, a simplified assumption was adopted: the coal price would decrease proportionally to the decrease in the price of oil under the net zero scenario. Percentage decreases in oil price were calculated from March 2024 to 2030 and from 2030 to 2050, then applied to estimate coal prices for 2030 and 2050. Linear interpolation was again utilized to estimate prices from March 2024 to 2034, involving interpolation between the March 2024 price and the calculated 2030 price, followed by interpolation between the calculated 2030 and 2050 prices. Only interpolated values up to the year 2034 were utilized for further analysis.

As for forecasting the S&P 500 index, a simplified method was adopted. This method entailed assuming that future yearly growth would mirror the average yearly growth observed in past years. The rationale behind selecting this method stemmed from the necessity to forecast over a ten-year period. Implementing a time series method would have proven exceedingly challenging to capture a realistic future outcome within this time frame.

To further explore the potential changes in the coal index value across different scenarios, the coefficients derived from the linear regression were utilized alongside the coal price predictions and the S&P 500 index forecast. Although the methodology for analyzing the scenarios remained consistent, the coal price data input varied among the scenarios.

For the scenarios representing Low Policy Ambition, the coal price predictions corresponding to a scenario where net zero emissions by 2050 were not achieved were employed. Conversely, for the High Policy Ambition scenario, the coal price predictions associated with achieving net zero emissions were utilized.

In the case of the Sudden Change in Policy Ambition scenario, the coal price prediction was derived through a linear interpolation process. This involved interpolating between the coal price in March 2024 and the projected coal price in 2026 under a scenario where net zero emissions were not achieved. Subsequently, another linear interpolation was conducted between this calculated price and the coal price projected for 2035 under the assumption of achieving net zero emissions.

6.1.4 Steel and Cement

The analysis of the steel and cement sectors was conducted differently compared to the oil and gas and coal sectors for several reasons. Firstly, there are no indexes representing the steel and cement industries, unlike the previously mentioned sectors. This lack of representation made it challenging to perform a similar analysis without creating industry-specific indexes. Additionally, these industries have made significant strides toward sustainability, with many companies already offering green alternatives and focusing heavily on sustainability. Therefore, it was of interest to analyze how green companies would develop in contrast to those that are not in each scenario.

Steel

The analysis of the steel sector's market dynamics involved compiling data on market values for both traditional steel and green steel. This dataset covered market values for the current year and projected values up to the year 2032 for traditional steel and 2030 for green steel. To ensure a comprehensive analysis, linear interpolation techniques were utilized to address any gaps in the dataset.

Since the projected data did not extend to the entire horizon of the analysis, extrapolation was necessary to obtain market values for the subsequent years, specifically from 2033 to 2035 for conventional steel and 2031 to 2035 for green steel. This extrapolation utilized a linear extrapolation method, providing insights into future market trends beyond the available data points.

The extrapolation process involved employing linear regression to calculate the coefficients required for extrapolation. By fitting a linear polynomial to the existing data points, a mathematical relationship between the years and their corresponding market values was established. Using these coefficients, market values for both green steel and traditional steel were projected for the years 2033 to 2035 using the polynomial equation.

Subsequently, the market values for green steel and traditional steel were combined to represent the entire steel market. The growth of the steel market for the period 2024-2035 was calculated and converted into annual growth rates.

Further analysis included conducting market share modeling for each scenario individually. In the Low Policy Ambition scenario, 80% of the total market growth was allocated to traditional steel, while the remaining 20% was assigned to green steel. Conversely, in the High Policy Ambition scenario, these proportions were reversed, with 80% of the total market growth attributed to green steel and 20% to traditional steel. Finally, in the Sudden Change in Policy Ambition scenario, 80% of the total market growth was driven by traditional steel until the year 2026, after which green steel emerged as the dominant component.

These allocations were based on reasoned assumptions, taking into account the specific policy ambitions outlined for each scenario and their potential effects on market dynamics. The objective was to simulate plausible market behaviors under different policy contexts, reflecting the anticipated shifts in demand for traditional and green steel products. Such assumptions facilitated a structured exploration of potential outcomes, aiding in the interpretation of scenario results and offering valuable insights into the potential trajectories of the steel market under varying policy environments.

Cement

The analysis of the cement sector's market dynamics involved gathering data on market values for both regular cement [12] and green cement [13]. This dataset encompassed market values for the current year and forecasted values up to the year 2032. To ensure comprehensive analysis, linear interpolation techniques were applied to address any missing data points within the dataset.

Given that the forecasted data extended only until 2032, further projection was necessary to obtain market values for the subsequent years, specifically from 2033 to 2035. This projection employed a linear extrapolation method, allowing insights into future market trends beyond the known data points.

Further analysis of this sector follows the same methodology as in the section above.

6.1.5 Power

As discussed in Section 3.1, the power industry is projected to experience growing demand until 2050, regardless of the prevailing climate scenario. Consequently, a distinct approach was adopted to analyze this sector, emphasizing the evolving energy mix and its variation across different scenarios. While the entire power sector is expected to expand, the predominant energy sources and the leading companies within the industry will shift.

PACTA provides a segmentation of energy holdings within the sector. The segmentation includes categories such as renewable, hydro, nuclear, gas, oil, and coal. To simplify the analysis and facilitate data accessibility, the segments were grouped into three categories:

- Fossil-Free Energy: renewable- and hydropower
- Fossil Energy: gas-, oil-, and coal power
- Nuclear Energy: nuclear power

The data on energy composition in the OECD countries spanning from 2000 to 2024 was used [42]. This data was then used as a basis to model the energy mix up to the year 2050 for the three different scenarios. Data of forecasted energy mix year 2050 in a scenario where the net zero emission is achieved [25, 24] was used as well as forecasts in a scenario where the goal is not achieved [23, 29].

To calculate the energy mix for each year between 2024 and 2050, linear interpolation was utilized. While linear interpolation does not account for sudden changes or disturbances, it can provide a fundamental understanding of the overall trends and their potential impact on the energy mix over time. In the Low Policy Ambition scenario, linear interpolation was conducted between the current energy mix and the projected values for 2050 in a society where net-zero is not achieved. For the High Policy Ambition scenario, linear interpolation was performed between the current energy mix and the projected values for 2050 in a society where the net-zero goal is achieved. In the Sudden Change in Policy Ambition scenario, the values from the linear interpolation in the Low Policy Ambition scenario were used until 2026. Subsequently, linear interpolation was conducted between the energy mix in 2026 and the projected mix for 2050 in a society where the net-zero goal is achieved.

In this process, a benchmark is provided by the ratio between the current allocation of the portfolio and the composition of the global energy mix. By understanding how the portfolio is currently distributed in relation to the types of energy sources used globally, insights are gained into its alignment with broader energy trends. This ratio is then applied to the projected future global energy mix to predict how the allocations of the portfolio might evolve over time. Essentially, it aids in anticipating how changes in the global energy landscape could impact the composition of the investment portfolio, ensuring that it remains aligned with overarching energy trends and objectives.

6.2 Natural Disasters

The data from the EM-DAT (Emergency Events Database) on natural disasters related to climate change in the USA from 2000 to 2024 was gathered. Only natural disasters mentioned in Section 4 of the dataset were utilized for analysis.

Although the primary focus of this thesis is on the European market, the USA was selected for preliminary analysis due to its extensive natural disaster data and numerous national stock indexes available for selection. Limiting this preliminary analysis to one country aimed to minimize the influence of external factors on market fluctuations. Consequently, the S&P 100 index was employed for this examination to gather insights into the potential impact of natural disasters on market behavior.

This methodology provides valuable information about the effect of natural disasters and how an increase in their occurrence might influence the market, specifically in terms of affecting the mean return and the standard deviation of returns. These findings will then be used to infer potential implications for the European market, which is the primary focus of this thesis.

Initially, it was essential to determine if there was a significant difference in the mean and standard deviation of S&P 100 index returns during periods of natural disasters compared to non-disaster times. To facilitate this, a binary vector was created to indicate the occurrence (1) or absence (0) of a natural disaster on any given day. Subsequently, the logarithmic returns of the S&P 100 index

$$R_t = \log\left(\frac{P_t}{P_{t-1}}\right) \tag{29}$$

were computed. These returns were analyzed for both disaster and non-disaster periods. Since the occurrence of natural disasters was found to affect the mean return and standard deviation of the S&P 100 index, natural disasters were further classified into three categories: hydrological, meteorological and climatological. Each category underwent identical analytical procedures, which included initializing binary vectors to denote the occurrence or absence of a disaster.

Following the determination of the λ parameter in the Poisson distribution for each disaster category through averaging specific disaster occurrences, these λ values signify the monthly frequency of disaster events. The overall disaster rate was computed by adding rates for hydrological, climatological and meteorological disasters.

$$\lambda_{tot} = \lambda_{hydrological} + \lambda_{climatological} + \lambda_{meteorological} \tag{30}$$

Subsequently, a semiparametric bootstrapping method was employed similar to the theory described in Section 5.7. This method combines parametric modeling of disaster occurrence rates with nonparametric resampling of return data to analyze the influence of disasters on financial returns.

Using the total rate, the total number of disasters, which is the parametric part of the model, was then calculated over the entire period of the dataset using a Poisson distribution. The number of each type of disaster was calculated using a multinomial distribution, with probability $\frac{\lambda_i}{\lambda_{tot}}$. Next, returns corresponding to each type of disaster occurrence were sampled by a bootstrap from the observed data. Similarly, normal (non-disaster) returns were sampled from the non-disaster part of the dataset.

To explore various disaster scenarios, adjustments were made to the disaster rates, and the sampling process was iterated. Determining the appropriate λ values involved consulting Section 4, which provided insights into the increasing occurrences of different types of natural disasters over time. For instance, hydrological disasters surged fourfold between 2005-2014 compared to 1975-1984, while meteorological disasters doubled over the same periods. However, as the time span between 1984 and 2005 exceeds the forecasting period of this thesis, it cannot be assumed that the increase in disaster frequency will persist. Therefore, a stress test was conducted on the original λ, a λ increased by 50%, and a λ doubled in magnitude. The procedure of the stress test followed the same methodology as for the statistical analysis of the original λ.

The sampled disaster returns for each disaster category are combined into a single array, and histograms are created to visualize the distribution of returns with the original occurrence rate together with the distribution of returns with an increased occurrence rate. Statistical analysis is performed to compute the means and standard deviations for both distributions, providing insights into the distributional properties of the data.

To gain a better understanding of how the different disaster categories might occur in the future, simulations were conducted to predict the number of disasters in upcoming months. Using the λ parameter as the rate parameter for the Poisson distribution, the number of disasters for each month was generated using random values generated from this Poisson distribution. This process involves generating random numbers such that the frequency of each number aligns with the probabilities defined by the Poisson distribution. Essentially, for each month, a random integer x is produced, where the likelihood of x follows the Poisson probability mass function

$$P(X = x) = \frac{\mu^x e^{-\mu}}{x!}, \tag{31}$$

with the given parameter μ.

This generation process was repeated for each month in the 100-month simulation period, resulting in a sequence of integers representing the simulated number of disasters per month.

7 Results

7.1 Oil and Gas

To decide which of the two fuel prices to use in the regression, the correlation between the natural gas price and the Oil and Gas Industry Index, as well as the correlation between the oil price and the Oil and Gas Industry Index, are examined. The correlation between the gas price and the Oil and Gas Industry Index is 0.2715, while the correlation between the oil price and the Oil and Gas Industry Index is 0.8025. Given that the latter correlation is higher, the analysis will use the oil prices in the regression model.

The linear regression model, employed to forecast the S&P Global Oil Index value, is expressed as

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \beta_3 \cdot x_3 + \epsilon, \tag{32}$$

where x_1 represents the oil prices, x_2 is the S&P 500 index and x_3 represents the volatility of the S&P Global Oil Index.

The estimated coefficients along with their t-statistics and p-values are summarized in Table 1.

The performance of the regression model in predicting the value of the S&P Global Oil Index was evaluated through rigorous validation procedures. Strong predictive capability was observed in the model. The proportion of variance in the S&P Global Oil Index explained by the regression model was determined to be 0.74 for R-squared. Additionally, a value of 0.726 was obtained for the adjusted R-squared.

Variable	Estimate	t-statistics	p-value
x_0	12920	8.102	$4.6544 \cdot 10^{-11}$
x_1	13.03	11.032	$9.0959 \cdot 10^{-16}$
x_2	-2.5736	-3.0313	0.0036585
x_3	-89734	-3.0618	0.0033544

Table 1: Estimated coefficients in eq. (23) along with their t-statistics and p-values

The volatility of the S&P Global Oil Index was modeled using a GARCH(1,1).

$$\sigma_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \tag{33}$$

The volatility, reflecting the fluctuation and uncertainty within the oil market, is depicted in Figure 1. This measure provides a snapshot of historical volatility trends and includes a forecast of the index's volatility under the assumption that current market conditions persist. The forecasted volatility was subsequently used as input, x_3 the linear regression model, eq. (23).

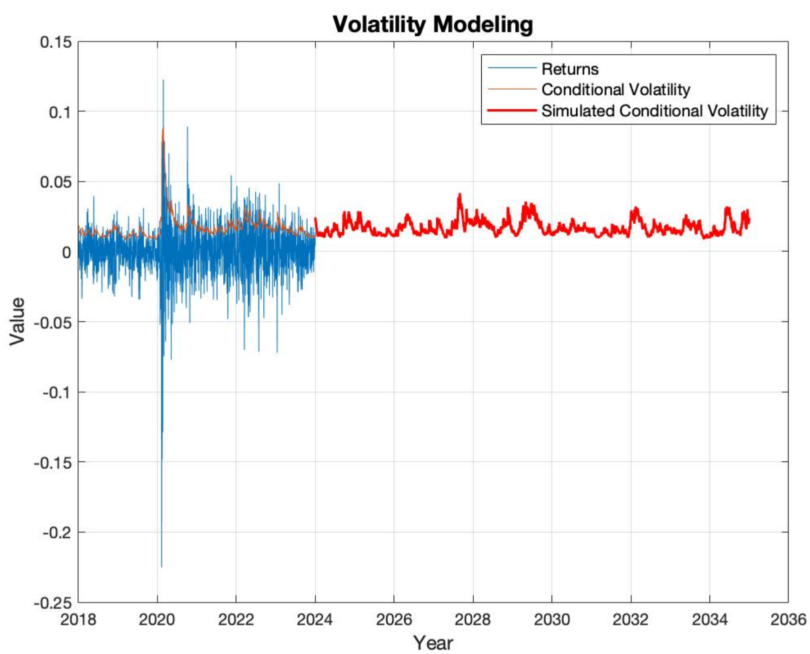

Figure 1: Returns of the S&P Global Oil Index alongside the corresponding conditional volatility and simulated conditional volatility.

The estimated coefficients in eq. (24) along with their t-statistics and p-values are summarized in Table 2.

Variable	Estimate	t-Statistics	p-Value
ω	$4.2585e-06$	2.4303	0.015087
α	0.10697	17.266	$8.5372 \cdot 10^{-67}$
β	0.88622	82.44	0.0013488

Table 2: Estimated coefficients in eq.(26) along with their t-statistics and p-values

Figure 2 illustrates the interpolated oil prices from 2024 to 2035 across various scenarios. The Low Policy Ambition scenario shows a continuous upward trajectory of crude oil prices. In contrast, the Sudden Change in Policy Ambition and High Policy Ambition scenarios exhibit significant declines in crude oil prices. The High Policy Ambition scenario shows an immediate downward trend, while the Sudden Change in Policy scenario features an initial price increase followed by a decline starting in 2026.

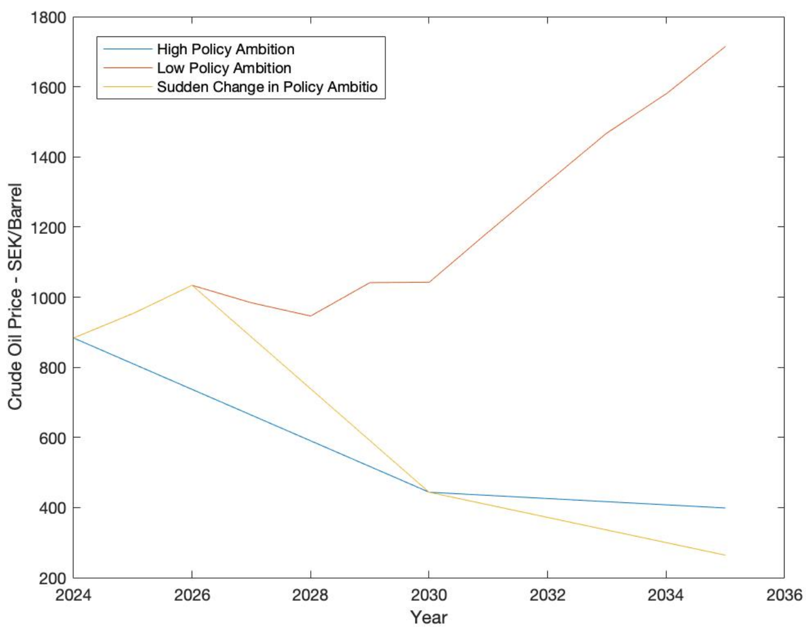

Figure 2: Crude oil price in SEK per barrel for the years 2024 to 2035 across three distinct scenarios

Oil and Gas - Low Policy Ambition

In the Low Policy Ambition scenario, analysis of the S&P Global Oil Index reveals a dynamic pattern of fluctuation characterized by notable volatility, see

Figure 3. Particularly noteworthy is the observed trend of significant fluctuations in the index's value up to the year 2030. However, a discernible shift occurs beyond the year 2030, as the index demonstrates a consistent upward trajectory. This uptrend suggests a potential stabilization and subsequent growth in the value of the S&P Global Oil Index.

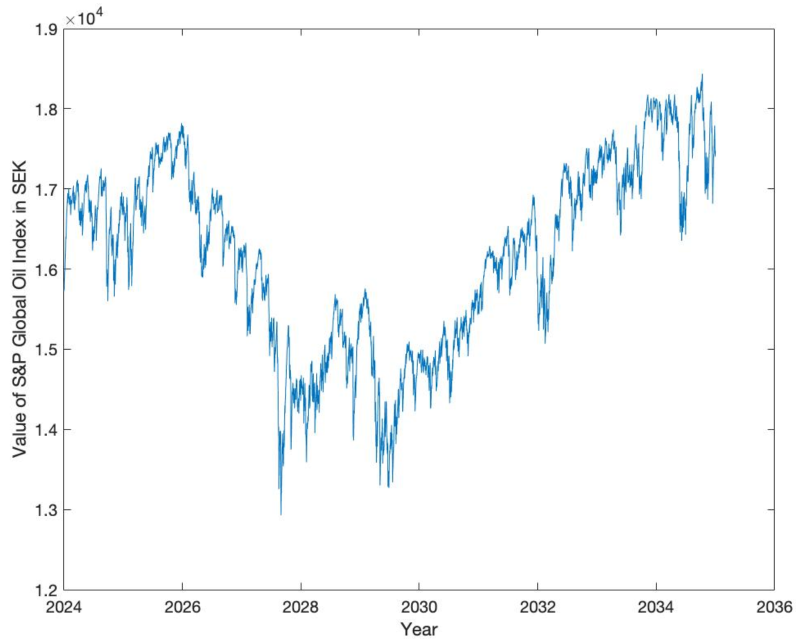

Figure 3: The projected value of the S&P Global Oil Index in SEK under the Low Policy Ambition scenario.

Oil and Gas - Sudden Change in Policy Ambition

In the Sudden Change in Policy Ambition scenario, the trajectory of the S&P Global Oil Index unfolds in a distinct manner, marked by a period of relative stability followed by a sharp and abrupt decline, see Figure 4. Initially, the index exhibits a notable stability, maintaining consistent levels up to the year 2026. However, this stability is abruptly disrupted as the index experiences a precipitous decline from this point onward. Of particular significance is the observation that by the year 2034, the value of the index plummets to zero.

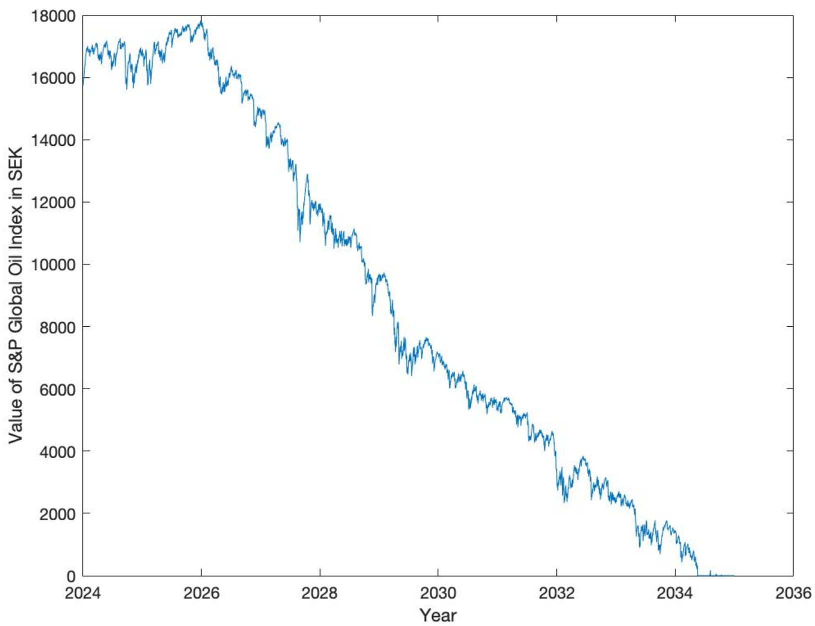

Figure 4: The projected value of the S&P Global Oil Index in SEK under the Sudden Change in Policy Ambition scenario.

Oil and Gas - High Policy Ambition

In the High Policy Ambition scenario, the trajectory of the S&P Global Oil Index is marked by a persistent and gradual decline over the projection period, see Figure 5. Beginning with a steady decrease from the onset, this downward trend persists consistently over time. Notably, this decline reaches a significant milestone in the year 2034 when the value of the index reaches zero.

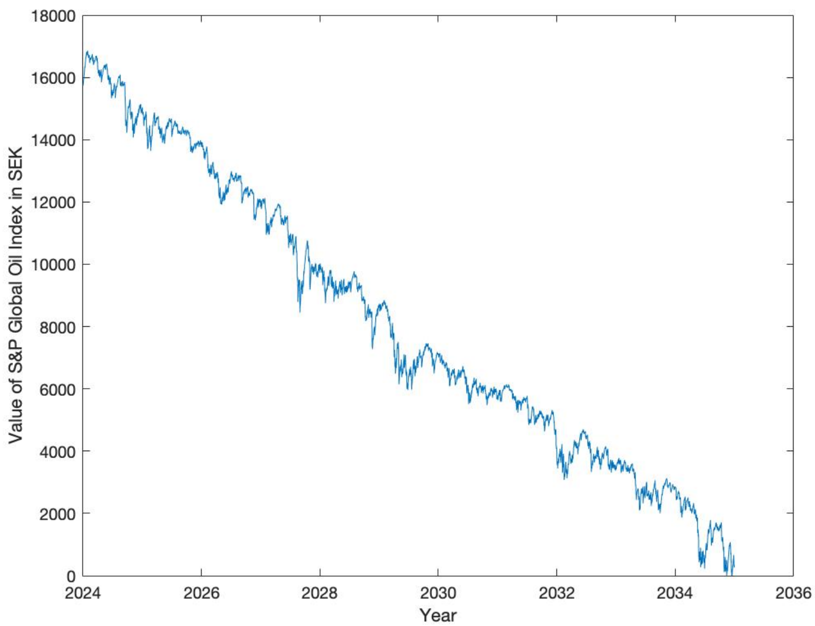

Figure 5: The projected value of the S&P Global Oil Index in SEK under the High Ambition Scenario scenario.

Oil Demand

In Figure 6, the historical oil demand is presented alongside two distinct forecasted scenarios. The red line depicts the projected oil demand under the assumption that current trends persist, a prediction derived from an ARIMA(1,1,1) model,

$$(1 - \phi_1 B)(1 - B)Y_t = c + (1 + \theta_1 B)\epsilon_t. \tag{34}$$

The estimated coefficients in the ARIMA(1,1,1) model along with their t-statistics and p-values are summarized in Table 3.

Variable	Estimate	t-Statistics	p-Value
c	59.608	4.8837	$1.0413{\cdot}10^{-06}$
ϕ_1	-0.72531	-6.4876	$8.7201{\cdot}10^{-11}$
θ_1	-0.958	16.06	$4.8886{\cdot}10^{-58}$

Table 3: The estimated coefficients in the ARIMA(1,1,1) model along with their t-statistics and p-values.

Contrarily, the green line in Figure 6 represents the forecasted oil demand in a scenario where net zero emissions are achieved.

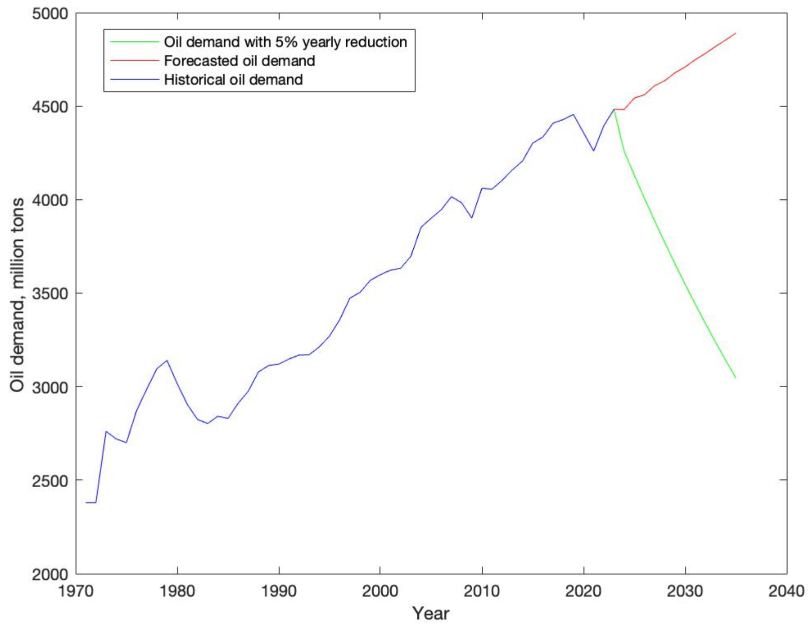

Figure 6: Historical and projected oil demand under two scenarios: continuation of current trends and a 5% annual reduction aimed at achieving net zero emissions.

7.2 Aviation

The volatility for the STOXX Europe Total Market Airlines index was modeled by fitting a GARCH(1,1) with the following equation.

$$\epsilon_t|\mathcal{F}_{t-1} \sim F(0, \sigma_t^2) \tag{35}$$

$$\sigma_t^2 = \omega + \sum_{i=1}^{q} \alpha_i \epsilon_{t-1}^2 + \sum_{i=1}^{q} \beta_i \sigma_{t-i}^2 \tag{36}$$

For comparison an EGARCH(1,1) was also fitted to the index with the following equation.

$$\epsilon_t = w_t \sigma_t \tag{37}$$

$$\sigma_t = \exp\left(\frac{1}{2} h_t\right) \tag{38}$$

$$h_t = \omega + \sum_{i=1}^{p} \alpha_i w_{t-1} + \sum_{i=1}^{q} \beta_i h_{t-i}. \tag{39}$$

With resulting AIC and BIC values seen in Table 4.

Model	AIC	BIC
GARCH(1,1)	-9941	-9945
EGARCH(1,1)	-9962	-9967

Table 4: AIC and BIC values for the GARCH(1,1) and EGARCH(1,1)

The AIC and BIC suggests a slight preference towards the EGARCH(1,1) model and hence that model was selected for modeling the volatility.

By employing this modeling technique, one can gain insights into the underlying volatility patterns of the index, thereby enhancing the understanding of market dynamics and risk assessment, see Figure 7.

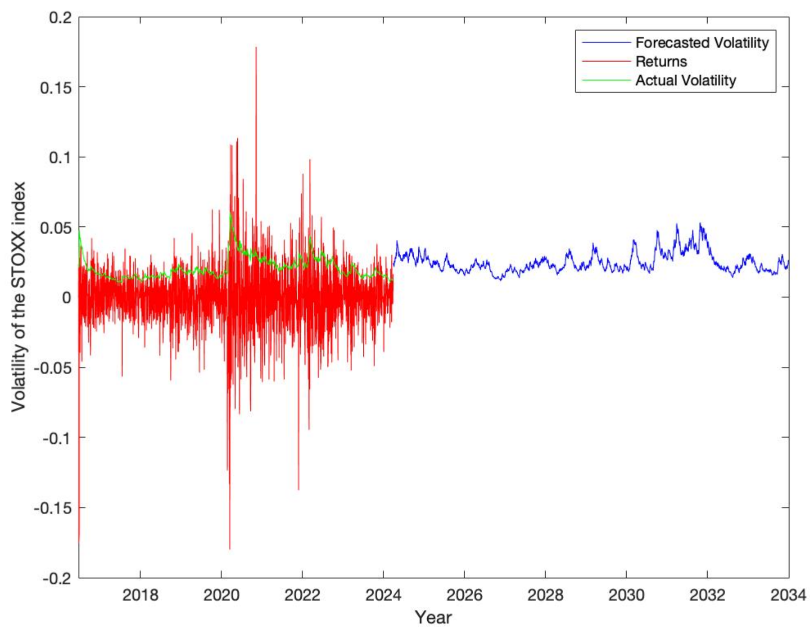

Figure 7: Historical and forecasted values of the returns of the STOXX Europe Total Market Airlines index, the volatility of the index as well as the forecasted volatility

The results for each climate scenario are tailored based on the base volatility modeling. Relevant policy trajectories are incorporated for each scenario, and assumptions related to investor behavior are made to evaluate potential impacts.

Aviation - Low Policy Ambition and Disasters

In the short term, the aviation industry is expected to continue high emissions, while volatility is anticipated to track the base scenario closely.

Looking at the medium term, investors may recalibrate their portfolios to navigate long-term risks, resulting in fluctuations in stock prices.

In the long term, volatility is expected to persist at elevated levels, yet it may gradually stabilize as investors deepen their comprehension of the aviation industry's future trajectory.

Aviation - Sudden Change in Policy Ambition

In the short term, initial volatility is expected to align with the base scenario, where climate-related uncertainties hold minimal influence on sector volatility. With a prevailing lack of awareness regarding climate risks, market stability persists, prompting investors to maintain conventional investment strategies with minimal stock price fluctuations.

Transitioning to the medium term, an accelerated shift may ensue, potentially prompting temporary bans on air traffic and precipitating a sectoral crisis. Consequently, volatility escalates significantly, driven by the unexpected nature of changes and the necessity for swift adaptation, fostering high risk aversion and sharp swings in stock prices. Investors attempt to navigate the new situation and adjust their portfolios accordingly.

Looking ahead to the long term, post-volatility shock, the market may gradually stabilize as investors assimilate the initial disruption. Confidence in the sector may progressively rebound following a period of reduced volatility.

Aviation - High Policy Ambition

In the short term, volatility is anticipated to surge initially as the aviation industry swiftly adjusts to stringent EU requirements and regulations. This rapid transformation is characterized by heightened volatility, driven by high prices of Sustainable Aviation Fuel (SAF) and a notable upswing in renewable energy production.

Transitioning to the medium term, volatility is expected to moderate somewhat as the aviation sector adapts to the new regulatory landscape and embraces green technologies. Nevertheless, a degree of uncertainty may persist, prolonging the stabilization process.

Looking ahead to the long term, the aviation industry is projected to firmly establish its commitment to green transition efforts. Initial high volatility stemming from climate-related transitions is anticipated to diminish and stabilize over time. With a stable and sustainable outlook, investor confidence is anticipated to rebound, facilitated by the seamless integration of green technologies.

7.3 Coal

The linear regression model, employed to forecast the S&P Global Mining Reduced Coal Index value, is expressed as

$$y = \beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \epsilon, \tag{40}$$

where x_1 represents the coal prices and x_2 is the S&P 500 index. The estimated coefficients along with their standard errors, t-statistics, and p-values are summarized in Table 5.

Variable	Estimate	t-Statistics	p-value
x_0	3552	5.5522	$8.4079 \cdot 10^{-07}$
x_1	0.36098	1.8207	0.074087
x_2	0.22875	10.95	$1.9537 \cdot 10{-}15$

Table 5: The estimated coefficients in eq.(40) along with their standard errors, t-statistics, and p-values.

The proportion of variance in the S&P Global Mining Reduced Coal Index explained by the regression model was determined to be 0.79 for R-squared. Additionally, a value of 0.77 was obtained for the adjusted R-squared.

Coal - Low Policy Ambition

In the Low Policy Ambition scenario, the trajectory of the S&P Global Mining Reduced Coal Index showcases a gradual decrease in value. Initially, the index experiences a modest decline. However, a notable shift occurs at the breakpoint in 2030, where the rate of decline slows down significantly. This indicates a stabilization or moderation in the downward trend of the index beyond this point. While the overall decline persists, it is characterized by a more gradual pace compared to earlier years.

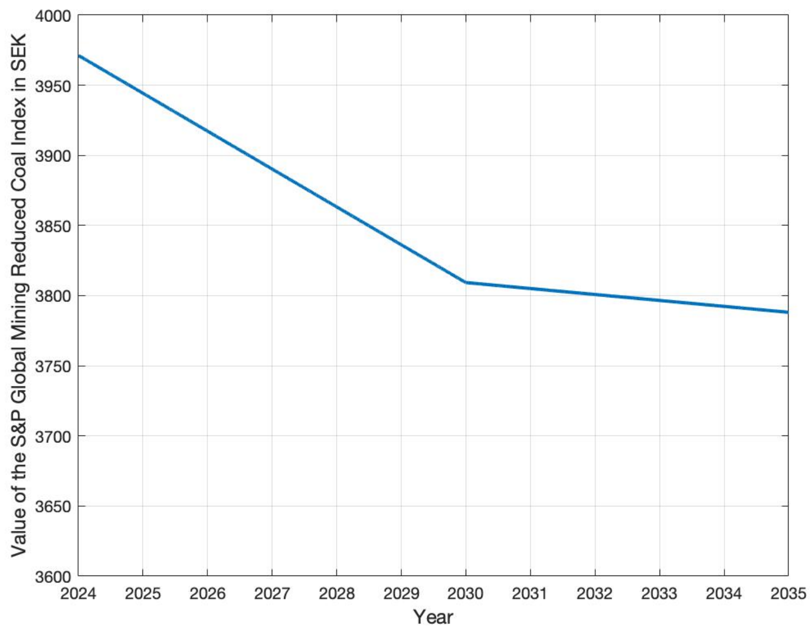

Figure 9: Projected value of the S&P Global Mining Reduced Coal Index under the Low Policy Ambition scenario

Coal - Sudden Change in Policy Ambition
In the Sudden Change in Policy Ambition scenario, the trajectory of the S&P Global Mining Reduced Coal Index is predominantly characterized by a consistent decrease in value throughout the projection period. While there is a slight deviation in the rate of decline around the year 2026, the overall trend remains downward.

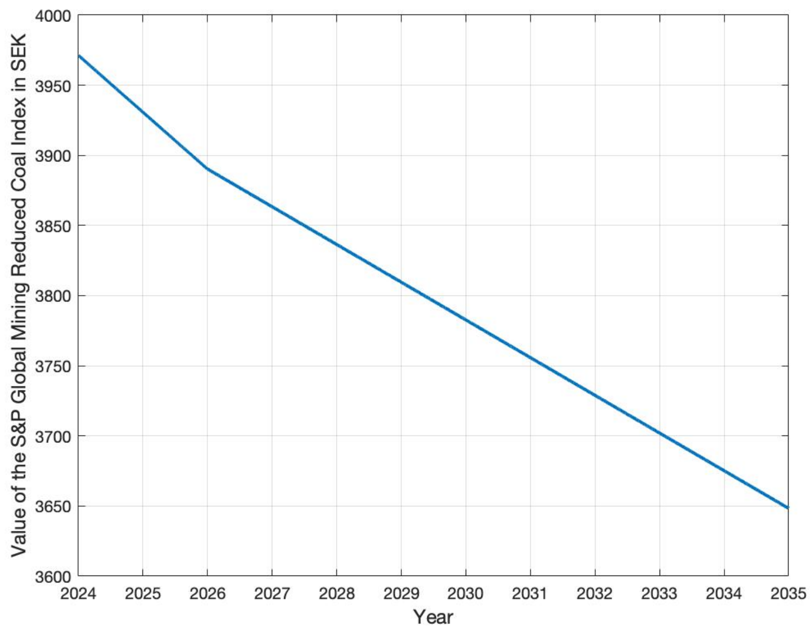

Figure 10: Projected value of the S&P Global Mining Reduced Coal Index under the Sudden Change in Ambition Scenario

Coal - High Policy Ambition

In the High Policy Ambition scenario, the trajectory of the S&P Global Mining Reduced Coal Index is characterized by a notably aggressive decrease in value up to the year 2030. However, beyond 2030, there is a notable shift in the rate of decrease, with the decline becoming much smaller. This change in trajectory suggests a moderation or stabilization in the downward trend of the index post-2030. While the index continues to decrease, the pace of decline is significantly reduced compared to earlier years.

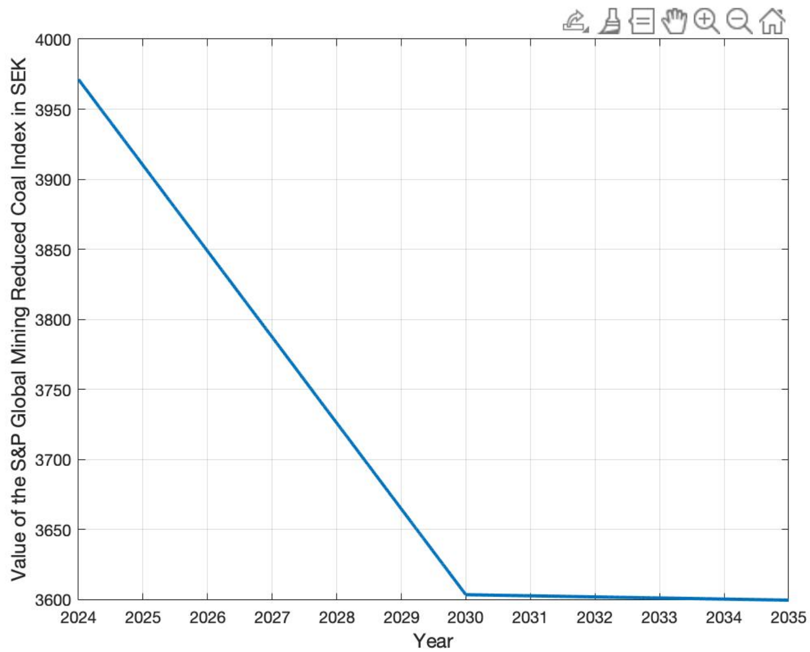

Figure 11: Projected value of the S&P Global Mining Reduced Coal Index under the High Policy Ambition scenario

7.4 Steel and Cement

7.4.1 Steel

The analysis of this sector utilized market values for conventional steel and green steel to project their respective market shares across various scenarios. As detailed in Section 3.1, the value of the conventional steel market was USD 205.87 billion in 2023, with projections indicating growth to USD 342.07 billion by 2032. Consequently, through linear extrapolation, the market value of conventional steel in 2035 is estimated to be USD 388.75 billion.

As outlined in Section 3.1, the market value for green steel was USD 2.70 billion in 2023 and is projected to grow to USD 98.84 billion by 2030. Using linear extrapolation, the estimated market value for green steel in 2035 is USD 167.51 billion.

In Table 6, values obtained from the extrapolation are presented.

	Conventional Steel	Green Steel	Total
2024	217.59	16.43	234.02
2035	388.75	167.51	556.26

Table 6: Projected market values (in USD billions) for conventional steel, green steel and the total steel market

The total market value is projected to grow by 137.69% from 2024 to 2035, based on the figures in Table 6. This translates to an CAGR of 8.19%.

Steel - Low Policy Ambition

Using the annual growth rate as an approximation for the entire steel market, and assuming that 80% of the growth will come from the conventional steel market and 20% from the green steel market, the results in Table 7 were derived. The table indicates that in the Low Policy Ambition scenario, the conventional steel industry is projected to grow, while the green steel sector experiences a decline.

	2025	2027	2029	2031	2033	2035
Regular steel	93.28%	93.85%	94.37%	94.85%	95.29%	95.70%
Green steel	6.72%	6.15%	5.63%	5.15%	4.71%	4.30%

Table 7: Projected market shares for regular and green steel for different years up to 2035 under the Low Policy Ambition Scenario.

Steel - Sudden Change in Policy Ambition

Using the annual growth rate as an approximation for the entire steel market, and assuming that 80% of the growth will come from the conventional steel market and 20% from the green steel market until 2026, followed by a reversal where green steel contributes 80% and conventional steel 20%, the results in Table 8 were derived. In the Sudden Change in Policy Ambition scenario, the market share of green steel initially declines while that of conventional steel increases. However, a subsequent shift occurs, leading to an increase in green steel and a decrease in conventional steel.

	2025	2027	2029	2031	2033	2035
Regular steel	93.28%	93.57%	92.98%	92.34%	91.64%	90.89%
Green steel	6.72%	6.43%	7.02%	7.66%	8.36%	9.11%

Table 8: Projected market shares for regular and green steel for different years up to 2035 under the Sudden Change in Policy Ambition scenario.

Steel - High Policy Ambition
Using the annual growth rate as an approximation for the entire steel market, and assuming that 80% of the growth will come from the green steel market and 20% from the conventional steel market, the results in Table 9 were derived. In the High Policy Ambition scenario, green steel increases its market share while conventional steel decreases in market share.

	2025	2027	2029	2031	2033	2035
Regular steel	92.66%	91.99%	91.27%	90.49%	89.64%	88.73%
Green steel	7.34%	8.01%	8.73%	9.51%	10.36%	11.27%

Table 9: Projected market shares for regular and green steel for different years up to 2035 under the High Policy Ambition scenario.

7.4.2 Cement

In Section 3.1, the predicted values of the cement market up to the year 2032 are presented. To extend the analysis, market values until 2035 were calculated using linear extrapolation. The results are presented in Table 10.

	Conventional Cement	Green Cement	Total
2024	423.24	39.32	462.56
2035	655.81	99.76	755.58

Table 10: Projected market values (in USD billions) for conventional steel, green steel and the total steel market

The total market value is projected to grow by 63.35% from 2024 to 2035, based on the figures in Table 10. This translates to a compound annual growth rate (CAGR) of 4.56%.

Cement - Low Policy Ambition and Disasters
Using the annual growth rate as an approximation for the entire cement market, and assuming that 80% of the growth will come from the conventional cement market and 20% from the green cement market, the results in Table 11 were derived. In the low policy ambition scenario, the analysis reveals divergent trajectories between the regular cement market and the green cement market, see

Table 11. While the regular cement market is projected to experience growth, the green cement market is anticipated to decline.

	2025	2027	2029	2031	2033	2035
Regular cement	91.71%	92.10%	92.48%	92.85%	93.20%	93.53%
Green Cement	8.29%	7.90%	7.52%	7.15%	6.80%	6.47%

Table 11: Projected market shares for regular and green cement for different years up to 2035 under the Low Policy Ambition scenario.

Cement - Sudden Change in Policy Ambition
Using the annual growth rate as an approximation for the entire cement market, and assuming that 80% of the growth will come from the conventional cement market and 20% from the green cement market until 2026, followed by a reversal where green cement contributes 80% and conventional cement 20%, the results in Table 12 were derived. In the sudden change in policy ambition scenario, market shares between regular cement and green cement remain relatively equal up to the year 2027, see Table 12. Following this period, a notable shift occurs, with the green cement market exhibiting growth momentum while the regular cement market experiences a decline.

	2025	2027	2029	2031	2033	2035
Regular cement	91.71%	91.91%	91.50%	91.07%	90.63%	90.16%
Green Cement	8.29%	8.09%	8.50%	8.93%	9.37%	9.84%

Table 12: Projected market shares for regular and green cement for different years up to 2035 under the Sudden Change in Policy Ambition scenario.

Cement - High Policy Ambition
Using the annual growth rate as an approximation for the entire cement market, and assuming that 80% of the growth will come from the green cement market and 20% from the conventional cement market, the results in Table 13 were derived. In the high ambition scenario, an immediate decline is observed in the regular cement market, coinciding with a simultaneous growth trajectory in the green cement market, see Table 13.

	2025	2027	2029	2031	2033	2035
Regular cement	91.29%	90.85%	90.40%	89.92%	89.43%	88.91%
Green Cement	8.71%	9.15%	9.60%	10.08%	10.57%	11.09%

Table 13: Projected market shares for regular and green cement for different years up to 2035 under the High Policy Ambition scenario.

7.5 Power

Power - Low Policy Ambition and Disasters
In the Low Policy Ambition scenario, fossil energy is projected to continue its decline, mirroring previous trends. Conversely, nuclear energy is anticipated to experience a significant uptick, compensating for the diminishing role of fossil fuels. However, fossil-free energy sources are expected to maintain a relatively stable or slightly decreasing contribution, see Figure 12.

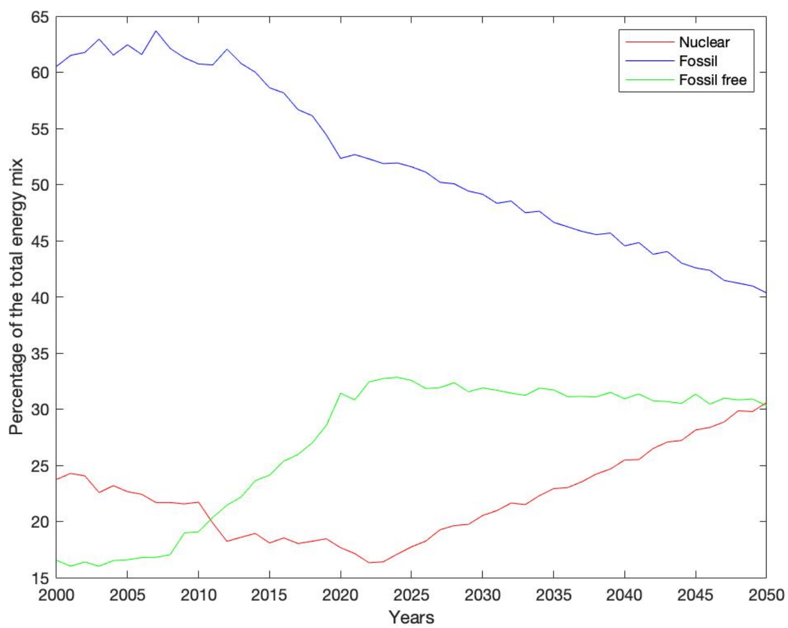

Figure 12: Historical and predicted energy mix under the Low Policy Ambition scenario

Power - Sudden Change in Policy Ambition
In the scenario of a Sudden Change in Policy Ambition, the energy mix follows established trends with minimal active intervention in policy. Fossil-free energy demonstrates a rapid increase. Conversely, fossil energy decreases in tandem with the rise of renewables, indicating a gradual transition away from traditional fuels. Nuclear energy remains relatively stable, see Figure 13.

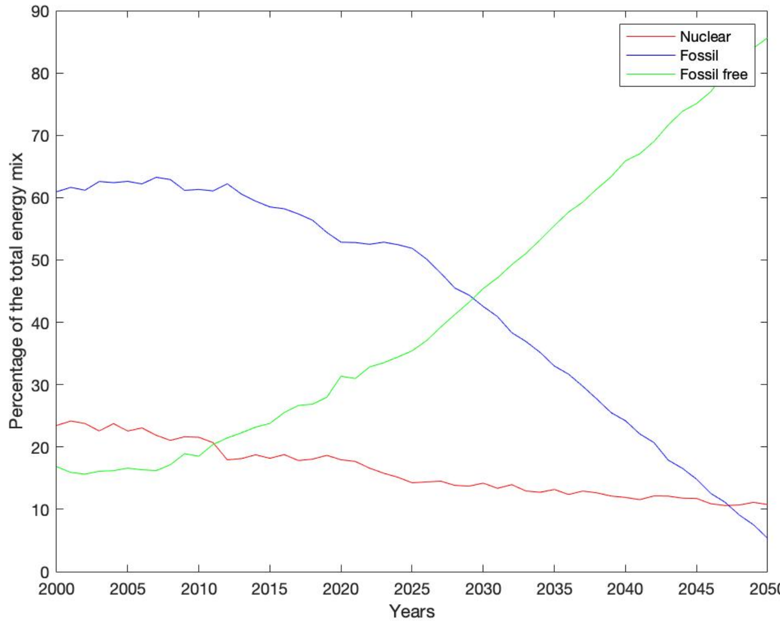

Figure 13: Historical and predicted energy mix under the Sudden Change in Policy Ambition scenario

Power - High Policy Ambition

In the High Policy Ambition scenario, almost identical patterns to those seen in the Sudden Change in Policy Ambition scenario are observed. Fossil-free energy experiences a rapid increase. Similarly, fossil energy decreases at a rate comparable to the rise of renewables. Nuclear energy maintains stable, see Figure 14.

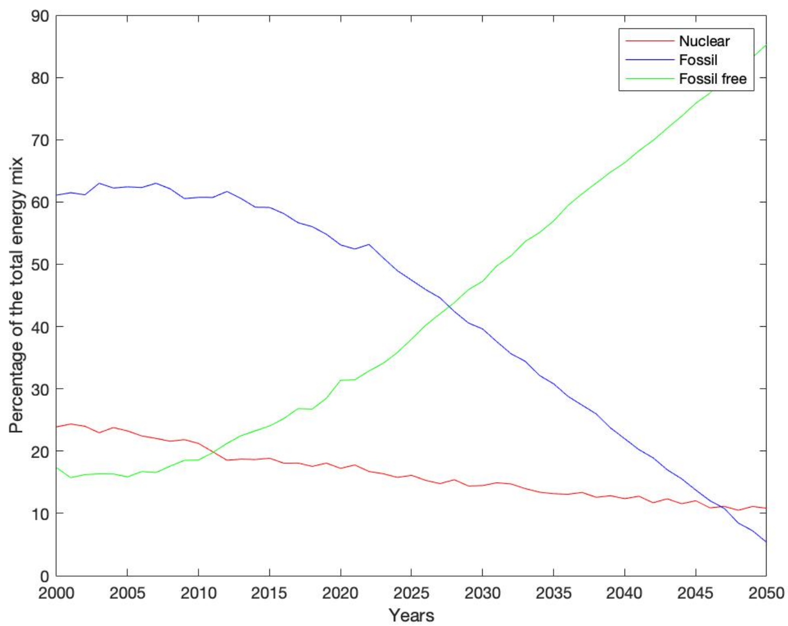

Figure 14: Historical and predicted energy mix under the High Policy Ambition scenario

7.6 Natural Disasters

Incorporating all returns alongside occurrences of natural disasters, a histogram was generated to visualize their distributions, see Figure 15. Observing the histogram reveals a slight difference in the distributions, which could be attributed to the inherent stochastic nature of the data or genuine differences in the distributions.

The returns coinciding with disasters exhibit a peak slightly leaning towards negative values. This observation is further supported by the data in Table 14, where it can be observed that the mean return is lower in the case of natural disasters. Additionally, from Table 14, it is apparent that the standard deviation is higher in the case of natural disasters.

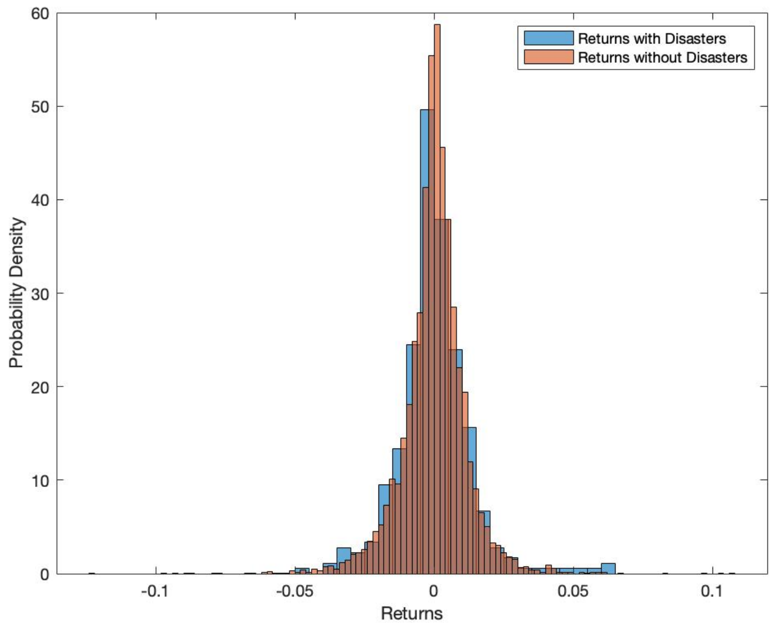

Figure 15: Distribution of returns with and without natural disasters.

	Disaster	No Disaster
Mean Return	$-1.4067 \cdot 10^{-04}$	$8.7831 \cdot 10^{-06}$
Standard Deviation of Return	0.0133	0.0123

Table 14: Mean returns and standard deviation of in case of disaster occurrence and non-occurrence.

Given the indication that the occurrence of natural disasters could affect the expected return of the S&P 100 index, the analysis was extended as explained in Section 6.2. Initially, λ values for the three different natural disaster categories were computed. The resulting λ values for the occurrence of the three categories of natural disasters are presented in Table 15. These λ values represent the average rate at which these events are expected to happen over a monthly time period.

	Meteorological	Climatological	Hydrological
λ	1.2474	0.237	0.3986

Table 15: λ values for the different natural disaster categories.

After obtaining the different λ values, stress-testing was initiated. The objective of stress-testing is to evaluate how an increase in λ affects the distribution of returns. To simulate returns with increased occurrence rates, the semiparametric bootstrap sampling method described in Section 6.2 is employed. The sampled returns with increased disaster events are then plotted in a histogram together with the original returns. These results offer insights into the distributional characteristics of returns under various disaster scenarios. To investigate the impact of increased disaster rates, the λ values were initially adjusted by a factor of 1.5 (Figure 16) and then by a factor of 2 (Figure 17). Moreover, the statistical characteristics of the distributions for the stressed λ values are shown in Tables 16 and 17.

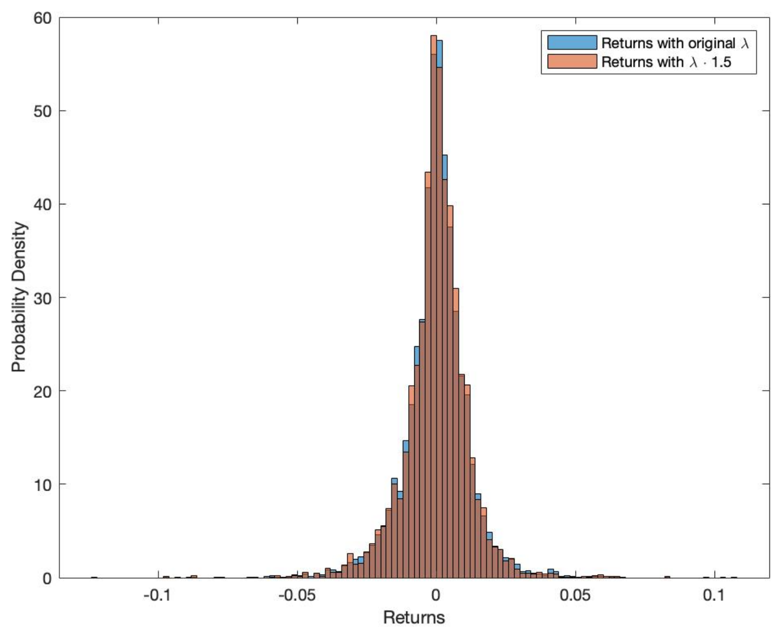

Figure 16: Distribution of returns with the original λ and $\lambda \cdot 1.5$

	λ	$\lambda \cdot 1.5$
Mean Return	-2.0266$\cdot 10^{-18}$	-2.4428$\cdot 10^{-04}$
Standard Deviation of Return	0.0123	0.0127

Table 16: Mean and standard deviation of returns with λ and $\lambda \cdot 1.5$

As mentioned earlier, the same semiparametric bootstrapping technique was utilized when increasing λ by a factor of 2. Figure 17 displays histograms illustrating the distribution of returns during disasters with an occurrence rate that is increased by a factor of 2, alongside the distribution of original returns.

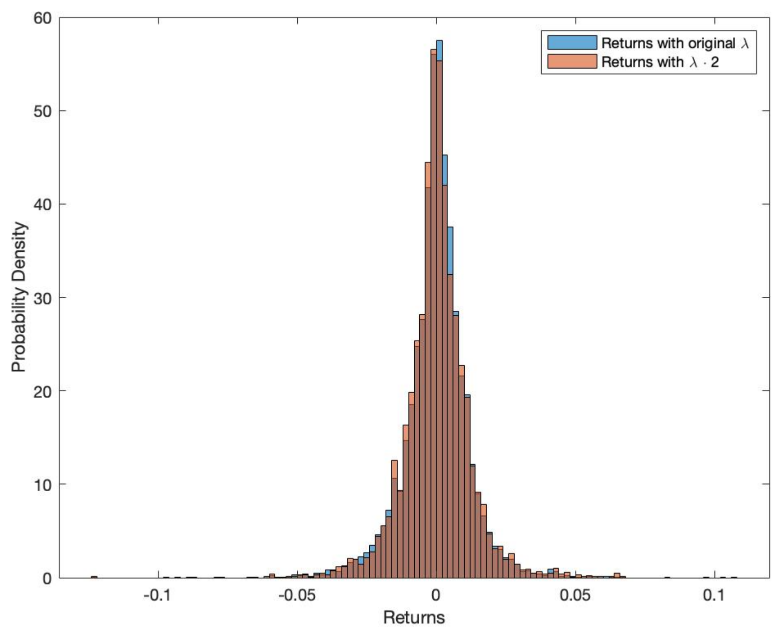

Figure 17: Distribution of returns with the original λ and $\lambda \cdot 2$

	λ	$\lambda \cdot 2$
Mean Return	-2.0266$\cdot 10^{-18}$	-1.3483$\cdot 10^{-04}$
Standard Deviation of Return	0.0123	0.0125

Table 17: Mean and standard deviation of returns with λ and $\lambda \cdot 2$

When comparing the results presented in Tables 16 and 17, particular attention is drawn to the columns indicating where λ is increased. It is noticeable that the standard deviation remains approximately the same for the different λ values. However, the mean return suggests a slight difference when the intensity is increased.

To visualize the occurrence of natural disasters over the next 100 months, a simulation was conducted, see Figures 18-20. This simulation forecasts the occurrence of these events based on historical data and the calculated λ value.

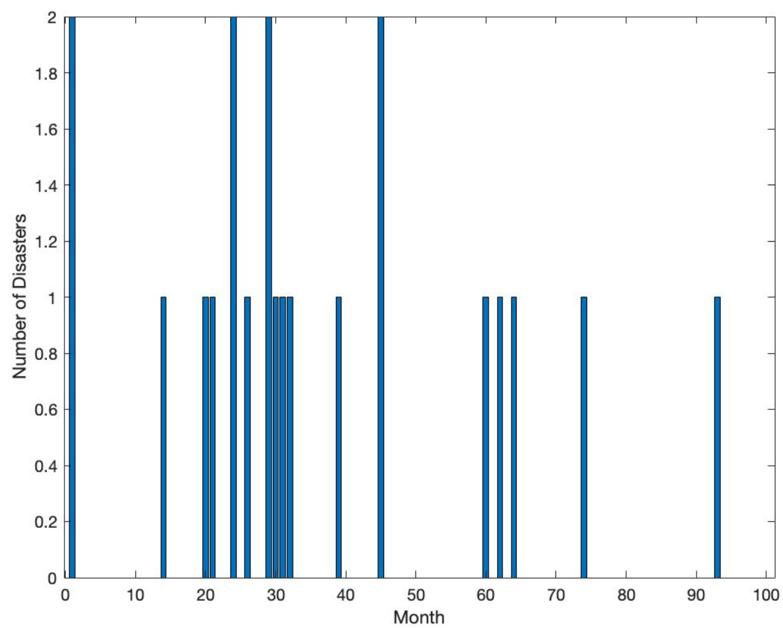

Figure 18: Forecasted frequency of climatological disasters per month over the next 100 months.

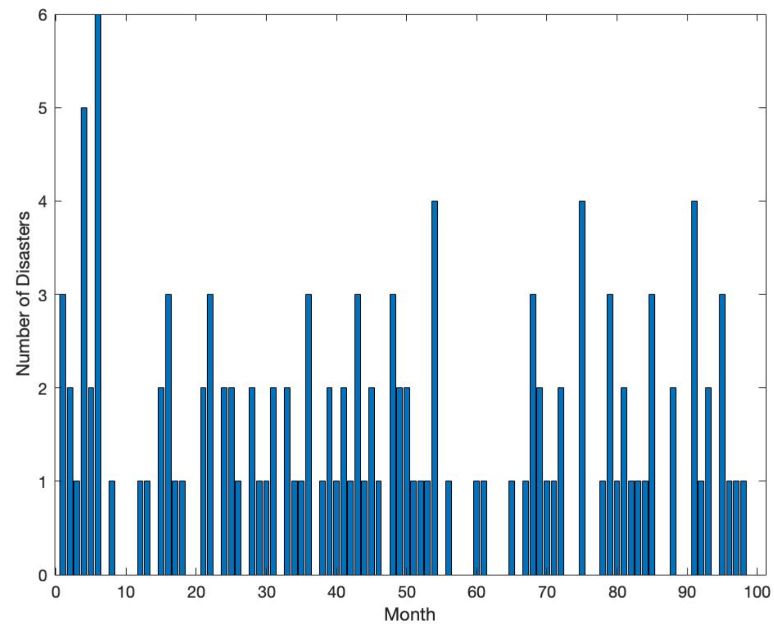

Figure 19: Forecasted frequency of meteorological disasters per month over the next 100 months

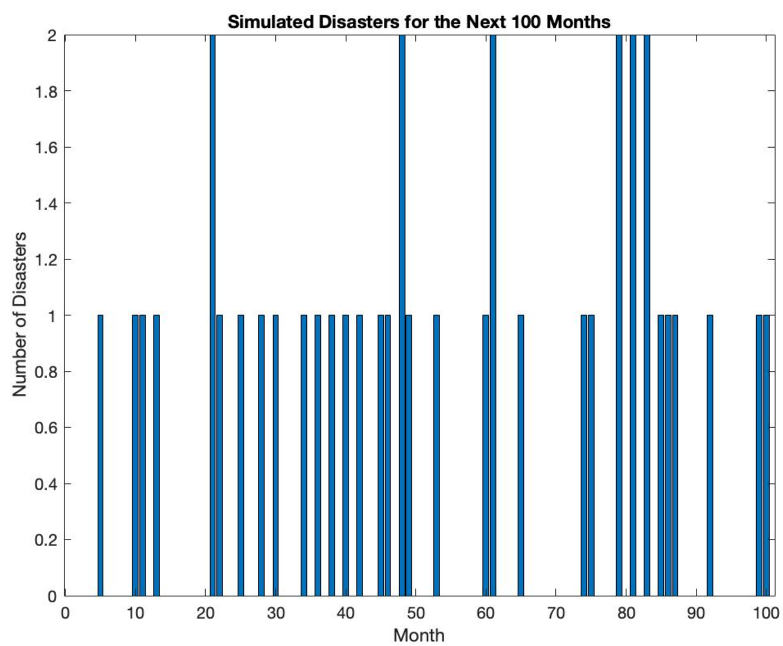

Figure 20: Forecasted frequency of hydrological disasters per month over the next 100 months

8 Discussion

After assessing all sectors thoroughly, it is essential to evaluate their potential impact on financial institutions. As outlined in Section 3.2, financial institutions derive revenue from various sources, including brokerage fees and interest earnings from diverse loan types. Examining the specific financial institution's income and balance sheet is crucial to identify primary revenue sources. This allows for a focused analysis on the most significant income streams. Once identified, employing the PACTA tool aids in gauging the institution's exposure to climate-sensitive sectors discussed in this thesis.

In the following sections, the results for each sector and climate scenario will be discussed in detail. Potential strategies to mitigate losses resulting from future climate change and climate policies will also be explored. This discussion aims to provide a comprehensive understanding of the risks and opportunities presented by each sector, thereby informing effective decision-making and strategic planning for financial institutions.

Natural Disasters

As presented in Table 14, the expected return is slightly lower in the case of natural disasters compared to non-disaster returns. Furthermore, Figure 15 indicates a possible difference in distribution for the two events. However, when increasing the intensity parameter λ, the distributions of the returns with the original λ and the increased λ are very similar indicating that the results show minimal affect on market dynamics. Tables 16 and 17 suggests slightly lower expected returns when intensity is increased, being at its lowest in the case of $\lambda \cdot 1.5$. Moreover, the small difference in standard deviation seems to be more or less stochastic indicating no difference when λ is increased.

It is also crucial to highlight that the historical data on natural disasters used in this analysis are based on events in the USA. It was assumed that a natural disaster in the USA would have the same effect on the market as a similar event in a European country. This assumption may not fully capture the nuances of regional market responses.

Another aspect to acknowledge is the limited availability of data on the occurrence of natural disasters, which adds to the uncertainty of the analysis. When modeling a higher frequency of disasters, the outcomes are based on a few data points, potentially skewing the results. Consequently, drawing definitive conclusions about the effects is challenging, although the results presented in Section 7.6 suggest that market dynamics could be slightly affected by natural disasters.

It is important to note that although Table 14 suggests that natural disasters slightly effect the market dynamics, the market tends to react to unforeseen events in complex ways. The results presented in Section 7.6 assume that market dynamics and the relationship between natural disasters and the returns and standard deviation of the S&P 100 index remain consistent with historical data. This is a simplification, as such relationships are more fluid in reality.

To gain a deeper understanding of the effect of natural disasters on market dynamics, the model could be advanced by accounting for the number of disasters occurring in a single day, rather than using a binary 1 or 0 to indicate whether a disaster occurred. Currently, the model only captures the presence of a natural disaster on a given day without considering the quantity of such events. Another factor to consider is the nature of different disasters. Some, such as droughts, take longer to reach their maximum impact and have prolonged effects, while others occur more rapidly and have an immediate, shocking impact.

Figures 18, 19, and 20 show forecasted occurrences of different disasters for the upcoming 100 months. Although this result is uncertain, it is important to note that the effect of natural disasters extends beyond market dynamics. Properties may be destroyed, leading to the adaptation of new insurance policies. People and municipalities with investments in highly exposed landscapes could face significant losses as natural disasters become more frequent. These broader implications underscore the multifaceted nature of the risks posed by natural disasters and the need for comprehensive risk assessment and management strategies.

8.1 Oil and Gas

As presented in the results in Section 7.1, the regression model explained 74% of the variance in the S&P Global Oil Index, as indicated by an R-squared value of 0.74. Additionally, the adjusted R-squared value was 0.726, further confirming the model's explanatory power. These metrics suggest that the model is robust and captures the significant factors influencing the index. Moreover, the small difference between the R-squared and adjusted R-squared values implies that the model is not overly complex. This high level of explanatory power underscores the reliability of the findings and supports the validity of the analysis.

Future research could build on this model by incorporating additional variables or exploring non-linear relationships to enhance predictive accuracy. Further improvements could include making independent oil price predictions using suitable time series models and adjusting them to different scenarios.

Oil and Gas - Low Policy Ambition

The analysis of the S&P Global Oil Index under the Low Policy Ambition scenario reveals a dynamic pattern of fluctuations, characterized by notable volatility. Until the year 2030, the index displays significant fluctuations in its value, reflecting the inherent uncertainties and challenges within the global oil market. However, beyond 2030, a discernible shift occurs as the index demonstrates a consistent upward trajectory, indicating a potential stabilization and subsequent growth in its value.

Several factors may contribute to the observed trends in the S&P Global Oil Index. Up to 2030, geopolitical tensions, supply-demand dynamics, and uncertainties surrounding global energy policies could drive the volatility. The lack of clear policy direction and ongoing debates regarding energy transition may exacerbate market uncertainties, leading to the observed fluctuations.

Transitioning to the analysis of factors contributing to the observed upward trajectory post-2030, several drivers come into focus. Firstly, increased global demand for oil, driven by economic growth, industrialization, and population expansion in emerging markets, could underpin the index's growth.

Oil and Gas - Sudden Change in Policy Ambition

The trajectory of the S&P Global Oil Index under the Sudden Change in Ambition scenario reveals an intriguing pattern. Initially, the index maintains a relatively flat trajectory, with a slight uptick in value. However, this trend abruptly shifts around 2026, as the index experiences a rapid and sustained decline, ultimately reaching zero by 2034.

While it's unlikely that the industry will lose all of its value by 2034, the precipitous decline in the S&P Global Oil Index serves as a stark reminder of the significant risks and uncertainties facing the sector. These results underscore the industry's vulnerability to sudden shifts in policies, technologies, and unforeseen events.

Oil and Gas - High Policy Ambition

The trajectory of the S&P Global Oil Index in the High Policy Ambition scenario presents a clear and persistent decline over the projection period. Unlike scenarios with lower climate ambition, where fluctuations or modest declines were observed, the High Policy Ambition scenario reflects a more aggressive approach towards climate action, resulting in a rapid and consistent decrease in the value of the index. Notably, the decline in the value of the index reaches a significant milestone in the year 2034 when its value reaches zero. Even though this extreme value decrease is unlikely to occur this fast, this result is a stark indication of the devaluation of the sector.

Oil and Gas - Risk Mitigation

The sustained growth of the S&P Global Oil Index post-2030 in the Low Policy Ambition scenario presents both opportunities and challenges for investors and industry stakeholders. While it underscores the resilience of the oil industry in meeting global energy needs, it also highlights the imperative for diversification and adaptation to evolving market dynamics. Investors should consider the long-term viability of oil investments in their portfolios, as the value of companies in the oil and gas industry is projected to increase over the long run. Financial institutions can incorporate companies within the oil and gas sector into diversified funds that can enhance portfolio performance. Also offering security-based lending on stocks within the oil and gas sector, which provides stability and attractive returns.

In the Sudden Change in Policy Ambition scenario, it is crucial to note the sharp downturn occurring in the year 2026. This downturn reflects the profound impact that rapid policy changes can have on the oil and gas sector. Therefore, it is important for financial institutions to closely monitor oil price fluctuations and regulatory changes to mitigate risks by reducing loan values extended to this sector.

In the High Policy Ambition scenario investors are likely to reevaluate their portfolios and consider minimizing their exposure to this sector. One strategic approach for investors may involve divesting or selling off assets tied to companies within the oil and gas industry. In addition to reassessing their investment strategies, financial institutions should also consider limiting security-based lending for assets within the oil and gas sector. By reducing exposure to these assets, financial institutions can mitigate their own financial risks and contribute to the overall shift towards cleaner energy alternatives.

Given the significant anticipated decline in the value of the oil and gas industry in the coming years, particularly under the Sudden Change in Policy Ambition and High Policy Ambition scenarios, it is crucial for financial institutions to limit the inclusion of companies from these sectors in their funds to avoid devaluing their portfolios. Additionally, if a substantial portion of broker fees currently arises from trading in this volatile sector, institutions must account for these changes early, as these are expected to decrease significantly.

8.2 Aviation

The analysis of the aviation sector presented unique challenges, distinct from sectors like oil and gas or coal, which have direct raw material dependencies. Unlike these sectors, where raw material extraction and production processes play a central role in valuation, the aviation industry is influenced by a multitude of factors, both economic and non-economic. Factors such as fuel prices, geopolitical tensions, regulatory frameworks, technological advancements, and environmental considerations all contribute to the complexity of analyzing the aviation industry's trajectory. As such, truly understanding the dynamics of the aviation sector requires a comprehensive approach that considers the interplay of various variables and their impacts on industry performance and investor decisions.

Although a scenario-based model was not conducted for the aviation industry, this section aims to discuss potential trajectories for the industry and outline risk management strategies that could be employed to minimize financial losses under each climate scenario.

Aviation - Low Policy Ambition

In the near future, the aviation industry faces the challenge of sustaining high emissions levels due to its carbon-intensive operations. Simultaneously, heightened volatility in stock prices, influenced by variables such as fuel costs, geopolitical tensions, and demand fluctuations, could be expected. Adapting risk management strategies to these fluctuating conditions becomes imperative for effectively navigating short-term market dynamics. In the medium term, investors may choose to review their portfolios to mitigate long-term risks linked to the aviation industry.

In the long term, volatility is expected to persist, influenced by uncertainties surrounding regulatory frameworks and technological advancements. In response to this, investors may choose to adopt a strategic approach, focusing on long-term investment horizons and diversification strategies to mitigate the impact of market fluctuations.

In addition to the existing challenges faced by the aviation industry, the escalating frequency and severity of natural disasters present a significant concern. Climate change-induced events such as hurricanes, wildfires, and flooding pose substantial risks to aviation infrastructure, operations, and supply chains. These disasters can disrupt flight schedules, damage critical infrastructure, and lead to financial losses for airlines and other industry stakeholders. Furthermore, the ripple effects of natural disasters extend beyond immediate operational disruptions, impacting investor confidence, insurance premiums, and regulatory scrutiny.

Aviation - Sudden Change in Policy Ambition

The analysis of the aviation industry under the sudden change in ambition scenario explores the market volatility across short-, medium-, and long-term horizons. Initially, in the short term, it would be reasonable to assume that the volatility aligns with the base scenario presented in Section 7.2, reflecting minimal influence from climate-related uncertainties. This stability is driven by a prevailing lack of awareness among investors regarding climate risks, leading to conventional investment strategies and minimal stock price fluctuations.

Transitioning to the medium term, an accelerated shift occurs, characterized by potential temporary bans on air traffic and sectoral crises. This abrupt change triggers a significant escalation in volatility as investors grapple with the unexpected nature of regulatory changes and the imperative for swift adaptation. High risk aversion and sharp swings in stock prices ensue as market participants navigate the evolving landscape and adjust their portfolios accordingly.

Looking ahead to the long term, post-volatility shock, the market gradually stabilizes as investors assimilate the initial disruption. Confidence in the sector begins to rebound following a period of reduced volatility, signaling a return to more stable investment conditions.

Aviation - High Policy Ambition

In the High Policy Ambition scenario, the aviation industry faces a significant challenge as the development of green substitutes has not yet progressed at a rapid pace. In the short term, the aviation sector is poised for a period of heightened volatility as it navigates the rapid implementation of stringent EU requirements and regulations. This period of adjustment is expected to be marked by significant fluctuations, driven in part by the increased costs associated with adopting SAF and the transition to renewable energy sources. The industry's swift response to these changes is likely to generate uncertainty among investors and stakeholders, contributing to market volatility.

Transitioning to the medium term, volatility is anticipated to moderate somewhat as the aviation sector begins to adapt to the new regulatory landscape and integrate green technologies into its operations. While challenges and uncertainties may persist during this transitional phase, the industry's proactive efforts to embrace sustainability initiatives are expected to contribute to a gradual stabilization of market conditions.

Looking ahead to the long term, the aviation industry is forecasted to solidify its commitment to green transition efforts, resulting in a more stable and sustainable operating environment. As the initial turbulence associated with climate-related transitions subsides, volatility is expected to diminish over time, paving the way for a more predictable investment landscape. With the successful integration of green technologies and practices, investor confidence is anticipated to rebound, further bolstering the industry's long-term prospects.

Aviation - Risk Mitigation

The volatility in the aviation industry, driven by fluctuating fuel costs, geopolitical tensions, and demand variations, necessitates robust risk management tools. Banks can offer hedging products and derivatives to aviation companies to manage fuel price risks. These financial instruments help stabilize cash flows and protect against price volatility, thereby earning banks fees and fostering long-term client relationships.

Due to the increased frequency of natural disasters in the Low Policy Ambition scenario, financial institutions could develop specialized insurance products to cover risks associated with climate change-induced natural disasters. This can include coverage for physical damage to aircraft and infrastructure, as well as business interruption insurance to cover loss of revenue due to operational disruptions.

The volatility in the aviation industry for each scenario could increase the risk of loan defaults. Financial institutions should consider tightening credit assessments for aviation clients and possibly increase interest rates to compensate for higher risk. In the two more ambitious scenarios it could also be of interest for financial institutions to incorporate sustainability metrics into credit evaluations, assessing how well aviation clients are adapting to environmental regulations and their efforts to reduce carbon emissions.

To support the aviation industry's shift towards sustainability, banks can introduce green financing options, such as issuing green bonds to finance environmentally friendly projects. These bonds can attract socially responsible investors and provide capital for long-term sustainability initiatives. Projects financed by green bonds might include the development of SAF, investment in electric or hybrid aircraft technology, and improvements in energy efficiency at airports.

8.3 Coal

The methodology employed in this study involved utilizing a linear regression model with coal price and the S&P 500 index as independent variables, and the S&P Global Mining Reduced Coal Index as the dependent variable. This methodology offers significant insights into the operational dynamics of the coal mining industry and its adaptability to evolving market dynamics.

In Section 7.3, it was revealed that the regression model applied to the S&P Global Mining Reduced Coal Index yielded an R-squared value of 0.79, indicating that 79% of the index's variance is accounted for by the model. Additionally, the adjusted R-squared value, which adjusts for the number of predictors and potential overfitting, stands at 0.77. Despite being marginally lower, this value reaffirms the model's robustness and reliability, instilling confidence in its ability to capture underlying trends and relationships while mitigating the risk of overfitting.

To enhance the model's effectiveness in analyzing the coal sector across different scenarios, several refinements could be considered. For instance, incorporating additional relevant variables could offer a more comprehensive understanding of the index's influencing factors. Additionally, generating independent forecasts for coal prices, rather than assuming their correlation with oil prices, would provide more precise insights. However, such enhancements necessitate thorough analysis of the coal market dynamics and pricing specifics, ensuring a holistic approach to refining the model.

Based on the analysis, it's clear that the coal industry is facing challenges across different scenarios. This expectation is based on historical trends where coal prices have consistently decreased.

Coal - Low Policy Ambition

In the Low Policy Ambition scenario, the trajectory of the S&P Global Mining Reduced Coal Index suggests a gradual decline in value over time, with a noticeable moderation in the rate of decline beyond the breakpoint in 2030. This stabilization reflects a shifting landscape within the coal industry, prompted by the projected decrease in the price of coal until 2035. This projection indicates a fundamental shift in market dynamics, compelling both investors and financial institutions to reevaluate their strategies.

Coal - Sudden Change in Policy Ambition

The trajectory of the S&P Global Mining Reduced Coal Index in the sudden change in policy ambition scenario depicts a steady decline in value, punctuated by a subtle shift around the year 2026. This pattern reflects the anticipated impact of policy changes aimed at achieving net zero emissions, leading to a reduced demand for coal and consequent downward pressure on coal prices and industry performance.

The slight shift in trajectory around the year 2026 may signify a pivotal moment for the industry, reflecting the impact of sudden policy changes or market disruptions on coal prices and industry sentiment. This inflection point underscores the importance of responding to regulatory shifts and market developments, as well as the need for proactive risk management strategies.

Coal - High Policy Ambition
In the High Policy Ambition scenario, the trajectory of the S&P Global Mining Reduced Coal Index exhibits a pronounced decline in value up to the year 2030. However, a noteworthy shift occurs beyond this point, wherein the rate of decrease notably slows down. This alteration in trajectory indicates a moderation or stabilization in the downward trend of the index post-2030. Although the index continues to diminish, the pace of decline diminishes considerably compared to earlier periods.

Coal - Risk Mitigation
The observed linear decline in the index value underscores the significant challenges facing coal mining companies in the transition towards a low-carbon economy. As policy measures aimed at curbing carbon emissions gain momentum, investors and industry stakeholders must confront the reality of diminishing demand for coal and the need to adapt to evolving market dynamics.

Investors are likely to divest a significant portion of their holdings within this sector before the year 2030 under the High Policy Ambition scenario, as the rapid decline in the index value is anticipated. However, for those who retain their holdings, they may encounter a challenge as the industry reaches stagnation, which may not be conducive to profit generation for either short-term traders or long-term investors. This stagnant state may compel investors to hold onto their assets in the hope of future value appreciation.

Due to the high probability of devaluation of coal commodities, stocks of coal companies, and coal-related derivatives it is reasonable to assume that the trading volume will gradually decrease. Reduced trading volumes and lower demand for coal-related securities can impact trading revenues and market-making income.

In this context, it's noteworthy that the turning point in the year 2026 does not seem to significantly impact the sector. Across different scenarios, the results exhibit a similarity in the devaluation of the index, emphasizing the sector's susceptibility to broader market trends.

Consequently, financial institutions with exposure to the coal mining industry must reassess their loan portfolios, meticulously evaluating potential risks stemming from diminishing coal demand. Proactive measures such as diversification of loan portfolios and robust risk management strategies are imperative to mitigate potential losses and safeguard financial stability amidst the evolving landscape of the coal sector.

8.4 Steel and Cement

The analysis of the steel and cement industries presented particular challenges for modeling purposes due to the lack of sectoral representation in the form of an index. To address this, the technique employed involved exploring potential market mixes between conventional materials and their green equivalents. This approach relied on external forecasts of market shares, introducing a degree of unquantifiable uncertainty in the estimates.

By making reasonable assumptions about market shares in each scenario and using linear interpolation, possible paths for market development in each scenario were explored. Further research in these sectors could include defining highly correlated variables and their interactions with the industries, thus enabling a more robust model of the industries' sensitivities to climate-related political regulations.

Steel and Cement - Low Policy Ambition
In the Low Policy Ambition scenario, the analysis reveals divergent trajectories between the steel and cement markets. While the regular cement and steel markets are projected to experience growth, the green cement and steel markets are anticipated to decline. Hence, investors may shift their focus towards investments in regular cement and steel companies.

Steel and Cement - Sudden Change in Policy Ambition
In the Sudden Change in Policy Ambition scenario, both the steel and cement industries undergo a notable shift in market dynamics. Initially, there is observed growth in the conventional industries. However, a discernible transition occurs over time, marked by an increase in green production and a corresponding decline in the market share of conventional industries. This shift is likely attributable to abrupt policy changes or technological advancements, akin to those experienced in other sectors.

This transition carries significant implications for the steel and cement industries. As demand for environmentally sustainable alternatives rises, companies within these sectors must adapt to evolving market preferences and regulatory frameworks. The growth of green production underscores the increasing importance of sustainability and climate considerations in shaping industry dynamics. Companies that have already started the journey towards fossil free steel and cement will benefit from the transition, whereas others are in desperate need for change.

Steel and Cement - High Policy Ambition
In the High Policy Ambition scenario, the steel and cement industries exhibit divergent trajectories reflective of ambitious climate goals. Immediate changes are evident, with traditional cement and steel markets experiencing declines while green alternatives see growth. This shift underscores the diminishing demand for carbon-intensive materials as stakeholders prioritize sustainable solutions to combat climate change.

Steel and Cement - Risk Mitigation
If regular cement and steel markets demonstrate stronger performance compared to their green counterparts, investors may prioritize investments in these sectors to maximize returns. Especially in this scenario where there is low policy ambition towards sustainability, there may be less regulatory pressure or incentives to support green industries. This could lead investors to perceive

regular cement and steel companies as safer investment options due to reduced regulatory risks.

However, in a scenario where strict regulatory changes are implemented suddenly, some investors might quickly reallocate their investments between conventional and green alternatives. This rapid shift in investment strategies could generate significant brokerage income as funds and stocks are actively traded in response to the new regulatory environment.

In these industries, there's a noticeable division between environmentally conscious and non-environmentally conscious companies. Transitioning towards greener practices often entails significant investments of both time and capital, sometimes necessitating loans. Nevertheless, it's crucial for financial institutions to assess the circumstances and acknowledge the potential for companies that have already embraced green technology to suffer substantial losses in a scenario of low policy ambition. Such companies may struggle to generate sufficient demand to justify their prior investments, putting them at risk of operating at a loss.

8.5 Power

To examine the performance of the power sector under the three scenarios, the historical energy mix in the OECD countries was utilized. Furthermore, predictions of future energy mixes in scenarios where net zero is achieved as well as when it is not were employed. This methodology was chosen due to the many components of the energy sector. However, this methodology is not really suitable for capturing certain nuanced aspects of the sector.

Power holds fundamental significance and will continue to do so across all societal contexts. What undergoes transformation are the origins of energy production. Hence, it's imperative to analyze the energy mix rather than viewing the power sector as a whole. This approach offers deeper insights into the emerging dominant subsectors within the power domain. Such insights empower financial institutions and investors to strategically allocate investments, aiming to maximize profitability.

Analyzing this sector, it was assumed that the distribution of capital within the power sector in a financial institution aligns with the energy mix. This simplification provides a foundational understanding but requires further refinement to account for sector-specific dynamics.

It is also important to acknowledge the complex landscape of the power sector, which relies on finite resources like oil and coal and requires continuous technological advancements to expand green energy. The power sector's evolution is strongly linked to traditional sectors such as oil and gas. Recognizing these dependencies and innovations is crucial for understanding the sector's future trajectory and making informed investment decisions. By focusing on the energy mix and emerging technologies, stakeholders can better navigate the challenges and opportunities within the power sector.

Power - Low Policy Ambition
In the Low Policy Ambition scenario, the power sector exhibits a nuanced landscape characterized by contrasting trends among different energy sources. Fossil energy continues its decline, aligning with previous trajectories. Conversely, nuclear energy emerges as a significant player in the power sector, experiencing an uptick to compensate for the diminishing role of fossil fuels. However, despite the rise of nuclear energy, fossil free energy sources are projected to maintain a relatively stable or slightly decreasing contribution.

Power - Sudden Change in Ambition
In this scenario, the power sector experiences a sudden surge in renewable energy sources, accompanied by a sharp decline in fossil fuel-based energy sources. This significant shift in the energy mix carries profound implications for the power industry and energy markets as a whole.

Power - High Policy Ambition
In the High Policy Ambition scenario, fossil-free energy sources witness a rapid surge, signaling a robust commitment to renewable energy sources. Concurrently, fossil energy experiences a substantial decline, mirroring the ascent of renewables. Nuclear energy, meanwhile, maintains stability, reflecting a passive response to policy changes.

For investors, these trends present both opportunities and challenges. The rapid increase in renewable energy underscores the potential for growth and investment in the clean energy sector. However, it also requires careful consideration of risks associated with declining fossil energy assets. Investors may need to adapt their strategies to capitalize on the burgeoning renewables market while mitigating exposure to fossil-based assets.

Power - Risk Mitigation
Financial institutions should inform investors about the evolving dynamics of the power sector, encouraging them to explore alternative investment options that align with changing market trends. Section 7.5 highlighted various energy mixes, revealing stagnation in some energy categories under certain scenarios. As financial institutions generate income from transactions and investments, they are well-positioned to guide investors towards alternative opportunities and strategies that are better suited to the evolving market landscape.

In scenarios like the Sudden Change in Policy Ambition and High Policy Ambition, where there is a rapid transition to renewable energy. The shift towards renewable energy sources is accelerating as global efforts to combat climate change intensify. This rapid increase in renewables presents significant opportunities for capital investment and financial growth.The transition to renewable energy requires substantial capital to fund a variety of projects, including solar farms, wind turbines, hydroelectric plants, and energy storage solutions. This demand for capital can be met through various financing alternatives such as green bonds and sustainability-linked loans. These financing options offer lower interest rates and favorable terms due to their alignment with environmental goals.

8.6 Integrating Climate Risk into ICAAP

A potential method for integrating climate risk and climate scenario analysis into the Internal Capital Adequacy Assessment Process (ICAAP) of financial institutions involves utilizing the scenarios and results presented in this thesis. Firstly, financial institutions could use tools like the PACTA (Paris Agreement Capital Transition Assessment) [31] tool to evaluate the exposure of different portfolios to climate-sensitive sectors, as discussed in Section 3.1.

Given that financial institutions already employ base scenario analyses to forecast potential future trajectories of their income statements and balance sheets, it would be advantageous to incorporate climate scenario analyses into this existing framework.

Integrating the thesis results into the base scenario would entail calculating returns for the oil and gas industry as well as the coal industry under different scenarios. The thesis provides potential trajectories for these industry indexes, making the return calculations straightforward. For the steel, cement, and power industries, returns are expected to follow historical growth patterns, reflecting the anticipated expansion in these sectors. Therefore, it is crucial to consider how income streams will shift due to capital reallocation between green and non-green investments. In the aviation industry, revenue streams could either grow or decline depending on the scenario.

For sectors not covered in this analysis, other identifiers specific to each scenario can be applied to the remaining portfolio. For example, an inflation model could be used, incorporating oil price forecasts under net zero and non-net zero scenarios to represent different climate scenarios. This model could then inform assumptions about interest rates and stock market trends, providing insights into the potential performance of the remaining portfolio.

By integrating these results and potentially including other relevant sectors, financial institutions can generate comprehensive projections for their income statements and balance sheets within the base scenario. These projections can then be included in the ICAAP, enabling financial institutions to understand how their financials will change under different scenarios and allowing them to develop early risk mitigation strategies.

8.7 Conclusion

Incorporating short-term climate scenario analysis into the operations of financial institutions is a relatively new concept that has not yet been fully explored. It will likely take years for financial institutions to fully implement these analyses and develop robust methodologies. Each analysis will require ongoing evaluation and refinement.

The thesis aims to provide a framework for how financial institutions can incorporate climate scenario analysis in their operations. Furthermore, this thesis aims to give a broad insight into highly polluting sectors and their potential future trajectories. The goal is to make financial institutions aware of their exposure to these risks and to explore ways to navigate the uncertainties of the future. It is important to recognize that evaluating the results of this thesis is challenging since it involves forecasting. This inherently adds to the high uncertainty in both the scenario narratives and the resulting models, as discussed in Section 1.4. Therefore, this work only suggests possible methods to explore potential paths and outcomes, rather than predicting the future with certainty.

Future research could involve developing and evaluating a broader range of scenarios and their effects on more sectors, considering the complex interrelationships between different industries. Additionally, future studies could incorporate models that include other factors such as GDP, inflation and other macroeconomic variables, taking into account the correlation between each variable. It would also be valuable to assess each country's individual climate initiatives and their capacity to address climate uncertainties.

In conclusion, financial institutions face a critical need to closely monitor regulatory changes and climate ambitions outlined in the Paris Agreement, particularly as the target of achieving net-zero emissions by 2050 approaches. Additionally, the impending regulatory adjustments within the EU, slated for implementation in 2026, require attention. The potential elimination of free allowances for sectors like aviation, cement, and steel, coupled with the introduction of the CBAM, could precipitate sudden shifts in market dynamics. While these regulations are currently slated for gradual implementation, there remains a possibility of policymakers altering these plans. Thus, financial institutions must remain adaptable in navigating these evolving regulatory landscapes to effectively manage associated risks and opportunities.

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