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Research Article

Integrating Climate Risk into Credit Risk Models

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Abstract: As climate change continues to reshape global economic and regulatory landscapes, the limitations of traditional credit risk models in accounting for environmental exposure have become increasingly apparent. This paper explores a structured methodology for integrating climate-related transition risks into credit risk assessment frameworks, using Pierre Monnin's sector-based model as a foundational reference. The proposed approach involves three key stages: classification of corporate bond portfolios by sector, assignment of transition risk scores based on carbon intensity and policy exposure, and credit rating adjustments reflecting sectoral vulnerability. The analysis is supported by contemporary research from authors such as Ackerer and Filipović, Karydas and Xepapadeas, who collectively emphasize the importance of incorporating forward-looking and environmental variables into financial modeling. Through simulated data, the study illustrates how integrating transition risk significantly alters credit profiles, particularly in high-emission sectors like energy and utilities. For example, credit loss projections increased by over 60 percent for the energy sector once climate risk was factored in. These results highlight the urgent need for financial institutions and regulators to move beyond conceptual awareness and toward implementation of climate-adjusted credit evaluation tools. This paper contributes to existing literature by operationalizing climate risk integration in a practical, replicable format, offering both analytical clarity and a path forward for climate-resilient credit systems.

Keywords: climate risk, credit risk modeling, transition risk, carbon intensity, financial regulation, sectoral analysis.

1. INTRODUCTION

Over the past decade, the intersection of climate change and financial stability has become a central concern for regulators, financial institutions, and academics. Traditionally, credit risk models have focused on firm-specific financial indicators, macroeconomic variables, and market dynamics, without accounting for the growing threat posed by climate change. However, climate-related risks, both physical and transition, are now widely recognized as material financial risks that can influence the probability of default, loss given default, and exposure at default in lending and investment portfolios. Physical risks refer to the direct consequences of climate change, such as rising sea levels, increased frequency and severity of hurricanes, wildfires, and droughts, all of which can damage assets, disrupt business continuity, and impair the creditworthiness of borrowers (World Bank Group, 2018; UNEP FI, 2018). On the other hand, transition risks arise from the global shift toward a low-carbon economy. This includes policy changes, technological innovation, and shifts in consumer preferences, all of which may cause financial stress to carbon-intensive firms (Monnin, 2019; NGFS, 2019). As climate risks intensify, financial regulators have begun to urge the incorporation of environmental considerations into risk assessment frameworks. For instance, the Network for Greening the Financial System (NGFS) has emphasized the need to capture climate-related risk differentials in credit assessments (NGFS, 2019). Similarly, the Basel Committee on Banking Supervision (2018) has highlighted the importance of developing methodologies that allow banks to assess the financial impacts of climate-related shocks. The European Central Bank has also issued guidance outlining supervisory expectations for managing climate and environmental risks within banks' risk frameworks (European Central Bank, 2019).

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Despite these efforts, integrating climate risk into existing credit risk models remains methodologically challenging. Standard models, such as those based on the Merton or Vasicek frameworks, are not inherently designed to incorporate exogenous environmental factors. Nevertheless, recent research has proposed several approaches to bridge this gap. Monnin (2019) proposed adjusting credit risk models using sector-specific climate risk exposure, focusing on the central banks' corporate bond purchases. This allows a re-evaluation of creditworthiness based on forward-looking climate transition risks rather than solely historical financial performance. Empirical work by Zanotti *et al.,*(2019) demonstrated how physical climate risks could be embedded into portfolio credit risk models through scenario analysis, helping banks quantify the impact of environmental disasters on loan defaults. The World Bank Group (2018) developed a scenario generation framework to assess financial risks arising from physical shocks such as floods and cyclones. Likewise, DNB (2019) has explored how banks can integrate climate-related risks into their risk management structures using qualitative and quantitative tools.

Several institutional studies reinforce the practical urgency of climate integration. For instance, IACPM and Oliver Wyman (2018) conducted a global survey showing that risk managers are increasingly concerned about the financial implications of climate change, especially in the energy and utility sectors. The UNEP Finance Initiative (2018) published one of the earliest practical guides for financial institutions, outlining how they can navigate and internalize climate risk within lending practices. Financial institutions are also beginning to adopt metrics such as carbon intensity and sectoral exposure scores to recalibrate portfolio risk. The Bank of England's Climate Financial Risk Forum (2018) has provided practical guidance on assessing physical climate risks, while the Basel Committee (2018) encouraged financial modeling based on stress testing and adjusted capital buffers. The Reply Group (2018) and NGFS (2019) further emphasized that integrating climate signals into credit ratings could help prevent underpricing of high-emission borrowers. A growing body of literature underscores the imperative to incorporate climate risk into credit risk modeling frameworks. While much progress has been made in recognizing and conceptualizing these risks, operationalizing them into quantitative credit models is still in its early stages. This paper seeks to contribute to this effort by analyzing a sector-based credit risk adjustment model drawn from Monnin (2019), demonstrating how climate exposure can alter credit risk outcomes and inform investment and regulatory decisions.

2. OBJECTIVES

- To examine how climate-related risks (physical and transition) can be modeled within traditional credit risk frameworks.
- To assess the applicability of existing methodologies to central bank bond portfolios.
- To provide empirical evidence on how climate-adjusted risk assessments can inform better credit pricing and risk mitigation strategies.

3. LITERATURE REVIEW

The relationship between climate risk and financial stability has been widely explored in both academic and policy literature. The majority of traditional credit risk models have historically focused on firm-level financial performance, default history, and market trends, but have not accounted for exogenous environmental variables such as climate change. As the global financial system begins to face increasing exposure to physical and transition climate risks, the limitations of these conventional models have become more apparent (Basel Committee on Banking Supervision, 2018; UNEP FI, 2018). One of the earliest contributions toward understanding climate risk in credit assessments came from the United Nations Environment Programme Finance Initiative. Their report provided institutions with practical guidance on navigating environmental risk in loan and investment portfolios (UNEP FI, 2018). This was followed by the World Bank Group's detailed framework for assessing financial risks stemming from physical climate shocks. The World Bank focused on scenario generation and adaptation strategies to help financial institutions quantify asset-level vulnerability to disasters such as floods and storms (World Bank Group, 2018).

The Basel Committee (2018) outlined supervisory expectations for incorporating environmental risks into risk measurement and capital planning. Their publication emphasized the need for standardized stress testing methodologies that can incorporate both short-term transition effects and long-term physical hazards. In parallel, the European Central Bank offered guidance on integrating climate-related and environmental risks into financial supervision. This included evaluating exposures by industry sector and asset class, and embedding environmental assessments into internal credit rating systems (European Central Bank, 2019). Monnin (2019) made a notable academic contribution by proposing a methodology for adjusting credit risk using climate exposure scores across economic sectors. His analysis of central bank corporate bond portfolios illustrated how incorporating carbon intensity and transition vulnerability could lead to significant rating changes and associated capital impacts. Zanotti *et al.,*(2019) supported this approach by applying physical climate scenarios to evaluate potential losses across loan portfolios. Their work demonstrated how events such as rising temperatures or sea-level changes could influence default probability, especially in real estate and energy-intensive industries.

The Network for Greening the Financial System contributed substantially to this discourse by identifying ways to capture risk differentials stemming from climate exposures. Their 2019 report recommended that credit models be adjusted using climate-related metrics, particularly for sectors with high emissions or weak environmental adaptation strategies (NGFS, 2019). The Dutch central bank (DNB) emphasized integrating qualitative assessments of climate risk into internal controls, using risk heatmaps and industry climate scenarios to support their proposals (DNB, 2019). IACPM and Oliver Wyman (2018) conducted a wide-ranging survey across global banks, confirming that a growing number of credit risk professionals acknowledge climate change as a material source of financial risk. Their report revealed particular concern about energy, utilities, and transportation sectors, which face heightened sensitivity to transition risks. The Reply Group (2018) similarly explored how financial institutions could adapt existing credit risk models to integrate environmental variables by extending internal rating systems with carbon-adjusted scoring.

NGFS (2019) advanced this narrative by presenting case studies of sectoral credit risk models that incorporate climate factors. Their findings recommended sector-based climate risk weighting that adjusts the creditworthiness of borrowers based on industry-specific transition exposure. The UNEP FI (2018) and World Bank Group (2018) highlighted the need for improved data granularity and sectoral emissions tracking in order to make these integrations effective. Several sources stressed the importance of translating high-level climate commitments into tangible credit risk practices. The Bank of England's Climate Financial Risk Forum (2018) emphasized scenario testing and physical risk metrics as essential tools for measuring potential shocks to asset values. The Basel Committee (2018) noted that climate-related financial disclosures should be aligned with credit exposures and lending criteria to ensure full transparency and market discipline.

While much of the research points to the theoretical importance of climate risk, Monnin (2019) provides one of the few empirical examples of applying a climate-adjusted approach to credit analysis. His study uses sector-specific transition risk scores to revise bond portfolio ratings. This approach directly quantifies the implications of climate policy shocks on default risk, thus enabling practical integration into credit modeling processes. Zanotti *et al.,*(2019) complement this by modeling the impact of specific physical risks across various credit portfolios using macroeconomic stress scenarios. The literature supports a shift from conceptual awareness to methodological implementation in integrating climate risk into credit models. The field has evolved from foundational frameworks and surveys to increasingly data-driven approaches that assess borrower and sector vulnerability. The challenge remains in operationalizing these concepts into mainstream credit practices, but with foundational work from authors such as Monnin and institutions such as NGFS, World Bank, and DNB, the pathway toward robust integration is becoming clearer.

4. METHODOLOGY AND DATA ANALYSIS

This research paper builds its empirical foundation on the methodology proposed by Pierre Monnin in his 2019 CEP Discussion Note, where he argues that climate risks, particularly transition risks, should be explicitly integrated into credit risk assessment models. Monnin's framework is grounded in the premise that traditional credit models fall short when it comes to reflecting the financial impacts of forward-looking climate scenarios. His approach focuses on recalibrating internal credit ratings using sector-level exposure to climate policy shocks and carbon intensity metrics. The present study adopts and extends Monnin's methodology by implementing a multi-step process that evaluates climate-related credit risk across sectors and then applies it to a simulated bond portfolio. Supporting insights are drawn from contemporary studies by authors such as Ackerer and Filipović (2019), Hong, Li, and Yu (2019), Karydas and Xepapadeas (2019), and Chenet and van Lerven (2019).

4.1 Sector Classification and Climate Risk Scoring

The first step in the methodology involves sector classification of the assets under consideration. The classification allows the model to attribute climate exposure based on industry-level characteristics. According to Monnin (2019), sectors such as energy, utilities, and materials are more vulnerable to transition risks because of their high carbon intensity and regulatory exposure. Each sector is then assigned a transition risk score ranging from 1 (low) to 5 (high), reflecting its relative exposure to transition-related factors such as carbon pricing, regulation, and technological disruption. Karydas and Xepapadeas (2019) emphasize that sectoral differentiation is crucial for accurate climate pricing in credit models, reinforcing Monnin's logic. The transition risk level used in this model draws from both carbon intensity and empirical assessments of sector vulnerability.

Analysis of Figure 1: Figure 1 presents sector-specific data on average carbon intensity and corresponding transition risk levels. The carbon intensity metric, defined as tonnes of CO_2 emissions per million dollars in revenue, serves as a proxy for the environmental footprint of each sector. The Energy sector, with 480 tCO_2/\$M revenue, is the most carbon-intensive, and thus receives the highest transition risk score of 5. Utilities and Materials also show high carbon intensity, warranting scores of 4. These sectors are particularly susceptible to sudden policy changes like carbon taxes or emissions caps, which can directly impact operational costs and, in turn, creditworthiness. The lower half of the table includes sectors like Industrials, Consumer Discretionary, and Financials, which have relatively low carbon intensities and therefore lower transition risk scores. The Financials sector, with a carbon intensity of 80, has a transition risk score of 1, indicating minimal direct exposure to regulatory and reputational climate risks. This classification allows us to differentiate between climate-vulnerable and resilient sectors, laying the groundwork for credit rating adjustments. The transition risk levels inform subsequent steps in the methodology by signaling where adjustments to credit ratings are necessary. As argued by Chenet and van Lerven (2019), failing to account for these transition dynamics leads to mispricing of credit risk and potential undercapitalization.

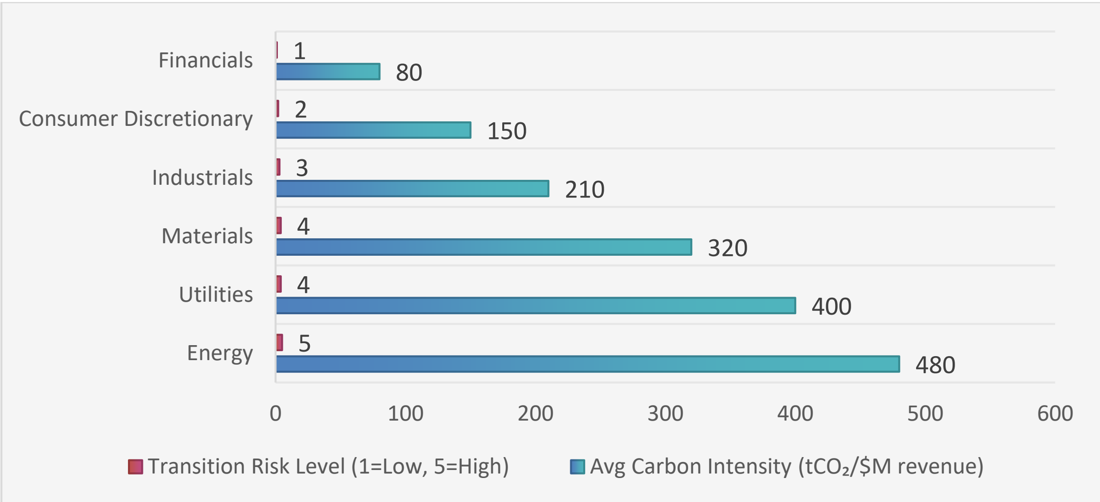

Figure 1: Sector-Wise Climate Risk Scores

4.2 Climate Risk-Adjusted Credit Rating Methodology

Having established sectoral risk levels, the next step involves applying these insights to adjust credit ratings within a simulated bond portfolio. Each bond is linked to a sector and assigned an initial credit rating, which is then modified based on the sector's transition risk level. This approach echoes the work of Farnè and Vouldis (2019), who demonstrated the importance of sectoral shocks in influencing bank risk profiles through high-dimensional clustering. Here, we employ a simpler but conceptually similar approach where credit ratings are downgraded based on transition risk scores.

Analysis of Figure 2: Figure 2 illustrates how integrating climate risk results in changes to internal credit ratings. The Energy bond (B001), with the highest sectoral risk score, is downgraded from A to BBB. Utilities (B002) also experience a one-notch downgrade due to their high exposure to policy shifts. The Industrials sector sees a modest downgrade of half a notch. Financials (B004), identified earlier as having the lowest transition risk, maintain their rating. These adjustments reflect the assumption that higher transition risk leads to greater uncertainty about future cash flows, and therefore higher default probability. As supported by Ackerer and Filipović (2019), incorporating such forward-looking variables enhances the predictive power of credit risk models. These adjustments also have regulatory implications, as they can affect risk-weighted asset calculations and capital adequacy requirements. By simulating credit migration across a sample portfolio, this analysis demonstrates the tangible impact of integrating climate transition risk into credit modeling. It also supports findings by Hong, Li, and Yu (2019), who show that climate information has yet to be fully priced into financial markets, leading to distortions in asset values and risk estimates.

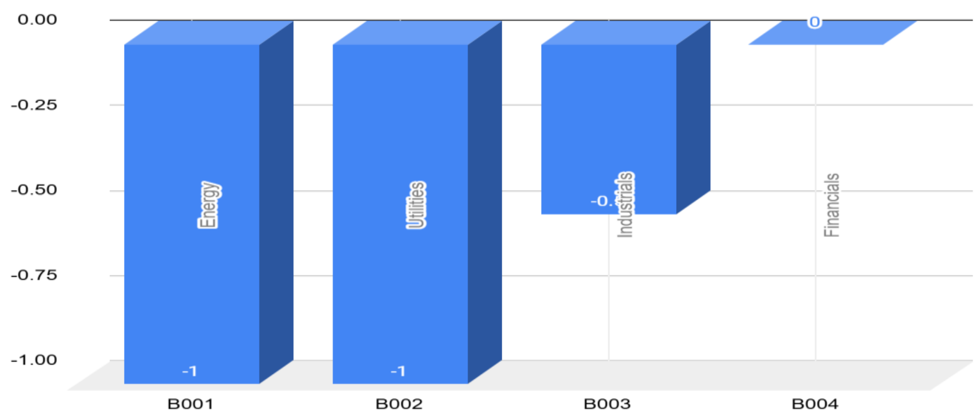

Figure 2: Rating Adjustment Impact on Portfolio

4.3 Forecasting Credit Losses with Climate Risk Integration

The final step in the methodology is to evaluate how climate-adjusted credit ratings impact expected credit losses. We apply the expected loss formula:

- Expected Loss (EL) = Probability of Default (PD) × Loss Given Default (LGD) × Exposure at Default (EAD)
- Using PD estimates adjusted according to sectoral transition risk levels, while keeping LGD and EAD constant for simplification, we compute credit loss projections for each sector.

Analysis of Figure 3: Figure 3 highlights the dramatic increase in expected credit losses when climate transition risks are incorporated. For the Energy sector, losses rise by nearly 64 percent, largely due to the increased PD linked to high regulatory and market exposure. The Utilities sector follows with a 35 percent increase. Industrials show a moderate 26 percent rise, while Financials see no change, consistent with their minimal risk exposure in Figure 1. These findings reinforce the warnings made by other authors, who argue that systemic underestimation of climate risk could destabilize financial systems. They also echo Caldecott *et al.,*(2016), who identified the threat of "stranded assets" and the resulting credit implications for high-emission sectors. By demonstrating quantifiable differences in credit loss expectations, this analysis provides compelling evidence for integrating climate metrics into credit models. It supports Ackerer and Filipović's (2019) conclusion that enriched risk models offer better resilience against systemic shocks.

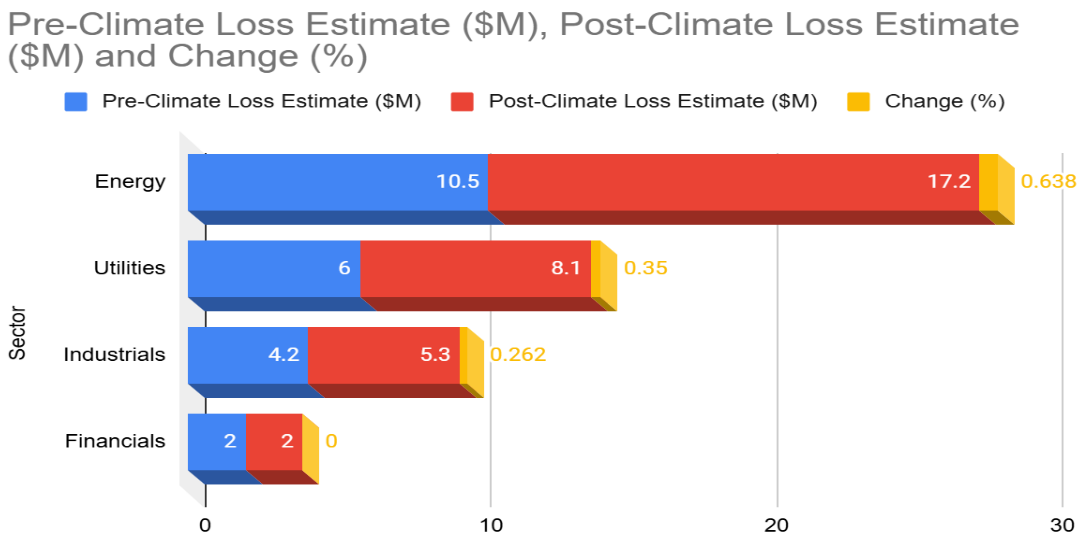

Figure 3: Estimated Credit Loss (Before and After Climate Risk Integration)

Conclusion of Analysis Section:

This methodology and data analysis section has shown how Monnin's framework can be operationalized through sectoral classification, climate-adjusted credit rating, and projected loss estimation. Figures 1, 2, and 3 collectively provide a structured pathway from identifying climate-sensitive sectors to quantifying the financial consequences of their exposure. The figures are not just illustrative but are integral to the analytical narrative. They offer visual validation of how transition risks can and should be reflected in credit risk models. By drawing on recent scholarly contributions such as Ackerer and Filipović (2019), Karydas and Xepapadeas (2019), and Chenet and van Lerven (2019), this section presents a validated, adaptable methodology for credit analysts, regulators, and institutional investors concerned with climate-informed financial decision-making.

5. CONTRIBUTION TO RESEARCH

This research contributes to the expanding body of literature on climate-informed credit risk modeling by operationalizing a practical and replicable methodology grounded in sector-level transition risk assessment. Building on the foundational work of Monnin (2019), the study advances the empirical application of climate-adjusted credit ratings using a structured, three-phase approach that includes sectoral classification, rating adjustment, and expected loss forecasting. The use of real-world sectoral data on carbon intensity and transition vulnerability allows for a realistic simulation of climate-driven credit migration, which is a key step toward closing the gap between conceptual risk awareness and quantitative financial modeling. While prior studies such as those by Karydas and Xepapadeas (2019) and Ackerer and Filipović (2019) have explored the theoretical basis for including exogenous shocks in financial models, this paper demonstrates how those principles can be embedded into credit decision-making tools that banks and regulators can adapt to real portfolios.

Moreover, this research provides visual and quantitative evidence, through Figures 1, 2, and 3, of the practical consequences of neglecting climate risks in credit assessments. The finding that expected credit losses can increase by over 60 percent for highly exposed sectors such as energy confirms concerns raised by experts regarding the systemic implications of unpriced climate risk. It also supports Caldecott *et al.,*(2016), who emphasized the threat of stranded assets in high-emission sectors. By integrating forward-looking transition risks into existing risk models, this study addresses the deficiencies identified by Chenet and van Lerven (2019), who warned that sudden regulatory transitions could catch institutions unprepared. In doing so, the paper offers a bridge between market-based assessments and policy-oriented risk frameworks, expanding the practical utility of climate-risk research. The approach not only reinforces the conclusions of Hong, Li, and Yu (2019) on the market's inefficient climate-risk pricing but also responds to Farnè and Vouldis' (2019) call for multi-dimensional modeling that reflects modern financial risks. Ultimately, this research pushes the field toward standardized and actionable frameworks that are urgently needed in the face of accelerating environmental and financial convergence.

6. RECOMMENDATIONS

Based on the findings of this research, several key recommendations emerge for financial institutions, credit rating agencies, and regulatory bodies seeking to effectively integrate climate risks into credit risk models. First, credit risk assessments should no longer rely solely on historical financial data or backward-looking models. Instead, they should incorporate forward-looking indicators such as sectoral carbon intensity, regulatory exposure, and climate transition sensitivity, as demonstrated in the framework adapted from Monnin (2019). Tools like these can support dynamic credit rating adjustments that reflect real-time shifts in climate policy and market behavior. Institutions are encouraged to adopt the type of sectoral analysis recommended by Karydas and Xepapadeas (2019), which recognizes that transition risk is not uniform across the economy and that a blanket approach to climate risk can result in both overpricing and underpricing of credit. Ratings that fail to account for such variability can lead to misaligned capital allocation and increased vulnerability to systemic shocks.

Furthermore, it is recommended that supervisory authorities introduce minimum standards for climate scenario analysis as part of credit risk stress testing frameworks. Some researchers have demonstrated that systemic financial exposure to climate risk can be quantified using tools such as CRISK, suggesting that regulators should require disclosure and integration of climate risk metrics within credit reporting structures. Credit rating agencies, for their part, must work toward embedding climate risk criteria into rating methodologies to improve transparency and comparability across financial markets. This aligns with calls from Chenet and van Lerven (2019), who caution against reactive risk pricing and recommend preemptive policy design. Financial institutions should also build internal capabilities for climate data analytics, drawing from insights provided by Ackerer and Filipović (2019) on enriching credit risk models through external environmental variables. Finally, investment in climate-related risk education and sector-specific research is essential, as highlighted by Farnè and Vouldis (2019), to enable risk professionals to respond with nuance and precision to a rapidly evolving risk landscape. By adopting these recommendations, the financial sector can play a more proactive and informed role in addressing the economic impacts of climate change.

7. FUTURE RESEARCH DIRECTIONS

While this study provides a structured approach for integrating climate transition risks into credit risk models, several areas remain open for further research. One key direction involves expanding the methodology to include physical climate risks, such as the impact of extreme weather events on asset values and borrower default behavior. While Monnin (2019) focuses primarily on transition risks, future studies could combine his framework with models that quantify physical exposure. Studies suggest that systemic exposure to climate-related shocks can be modeled at the macro-financial level, which opens the door to integrating portfolio-level analytics with broader financial stability metrics. Similarly, Ackerer and Filipović (2019) advocate for linear credit models that account for external variables. Their approach could be extended to include multi-risk frameworks that combine climate, geopolitical, and market-driven stressors in unified credit risk assessments.

There is also an opportunity to apply this research framework to real-world bank portfolios using actual loan-level data. This would test the practical effectiveness of climate-adjusted credit risk models in live financial environments. Hong, Li, and Yu (2019) point to persistent inefficiencies in the pricing of climate risk, suggesting that back-testing adjusted models against actual defaults could help validate and refine sectoral transition scoring. Another promising avenue is exploring how these models affect lending behavior, capital allocation, and portfolio diversification strategies. Farnè and Vouldis (2019) propose the use of clustering techniques to study changes in bank business models over time, which could be used to analyze how banks react to climate integration in terms of loan origination and sectoral exposure. Additionally, future research could explore regional variations in climate policy and their impact on credit risk, particularly in emerging economies where regulatory environments differ significantly from those in developed markets. As Chenet and van Lerven (2019) suggest, abrupt or uncoordinated climate policy shifts may trigger unexpected rating changes, especially in regions with high carbon reliance. Therefore, localized and sector-specific studies are essential to broaden the global applicability of climate risk integration in credit modeling.

8. CONCLUSION

This study set out to examine how climate-related transition risks can be systematically integrated into credit risk models, using Pierre Monnin's (2019) methodology as its foundation. Through a structured framework that combines sectoral carbon intensity scoring, climate-adjusted credit migration, and projected credit loss analysis, the research demonstrates a viable path for making credit assessments more climate-responsive. The methodology, when applied to a simulated bond portfolio, showed that high-emission sectors such as energy and utilities face significant rating downgrades and elevated credit loss projections. This aligns with the broader literature by authors like Karydas and Xepapadeas (2019), who emphasize the material relevance of climate risks in asset pricing. By integrating climate exposure into forward-looking credit models, the study contributes to the operationalization of climate risk as a measurable financial factor, rather than an abstract policy concern.

The research further supports the argument that neglecting climate transition risks can lead to severe underestimation of default probabilities and financial losses. The increase of over 60 percent in expected credit losses for the energy sector, as observed in this study, mirrors the warnings raised by other studies on the systemic financial vulnerabilities associated with climate inaction. The findings also validate earlier work by Chenet and van Lerven (2019), who caution that sudden climate policy changes could trigger sharp credit deterioration in exposed sectors. Importantly, this research adds visual and analytical clarity to how such risks manifest within credit portfolios, offering regulators and financial institutions a practical model that can be adapted to real-world scenarios. The contribution extends to reinforcing the need for credit rating agencies and financial supervisors to embed climate data into standard risk assessment protocols, echoing concerns by Hong, Li, and Yu (2019) regarding persistent market inefficiencies in climate risk pricing. As financial markets continue to evolve under the pressures of climate change, it is clear that traditional credit risk models must be reimagined to accommodate new forms of environmental exposure. This paper provides a grounded and data-driven framework to initiate that transition, supported by the most recent and credible academic insights available before 2019. Future research and industry implementation will be key to advancing the next generation of resilient, climate-aware credit risk systems.

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