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Reduction of Climate Risk as a Key to Business Performance – Framework for Sustainable Corporate Treasury Management (CTM)

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Abstract

Aim: The article aims to examine the impact of climate instability risk on Corporate Treasury Management (CTM) and demonstrate that sustainable strategies can effectively mitigate this risk while enhancing corporate financial performance.

Methodology: A theoretical and empirical approach is employed, including econometric modelling, case study analysis, and literature review, with a focus on the use of financial instruments – particularly climate derivatives – within CTM.

Results: Effective management of climate risk through sustainable policies and financial instruments raises treasury levels and strengthens corporate competitiveness by reducing unexpected losses and the costs of maintaining high liquidity reserves.

Implications and recommendations: The study recommends incorporating environmentally conscious strategies into CTM and implementing fiscal incentives and regulatory frameworks to support climate risk hedging tools. Further research should explore sector-specific applications of sustainable CTM, especially in climate-sensitive industries.

Originality/value: The article offers a novel integration of sustainability and treasury optimisation, showing that environmental responsibility can directly support and enhance core financial goals within CTM frameworks.

Keywords: climate risk, sustainable treasury management, effectiveness of the entity, Corporate Treasury Management (CTM)

1. Introduction

The study examines how climate risks affect corporate treasury management, and demonstrates that sustainable management strategies can mitigate these risks while enhancing financial performance.

It is shown that increasing the level of treasury is not at odds with adopting sustainable Corporate Treasury Management (CTM) principles. On the contrary, effectively assessing and managing the risks of climate instability can enhance financial efficiency by minimising unexpected losses caused by extreme weather conditions. The article highlights that the absence of strategies regarding climate instability risks results in higher operating costs, a greater need for inventory and cash reserves, and heightened uncertainty in financial flows.

The empirical section explores the application of financial instruments, such as climate derivatives, in CTM to mitigate the adverse impacts of climate change. The paper also examines the link between corporate competitiveness and climate instability risk, emphasising that effectively managing these risks can enhance the company's treasury level and strengthen its market position.

The paper concludes by pointing out that integrating environmental considerations and climate risk management into corporate treasury activities enhances financial stability and strengthens sustainability. It also highlights the necessity of macroeconomic regulations and cultural shifts to encourage companies to adopt environmentally friendly strategies in CTM.

The root of many challenges related to a cleaner and improved environment impacting modern businesses lies in pre-existing conditions. One such factor is global warming, which leads to specific climate impacts (Kupczyk 2006, pp. 24-26; Muller et al., 2015; Field, 2012; Ender & Zhang, 2015). In mitigating risk exposure for full-cycle agribusiness firms, Ender and Zhang (2015) investigated the effectiveness of temperature-based climate derivatives. The results (Soltes, 2010) indicated that temperature-based put options are effective in offsetting yield shortfalls (Ender & Zhang, 2015). According to Linnenluecke et al. (2013), businesses and industries play a key role in fostering social adaptation to the impacts of climate change. Linnenluecke et al. (2013) asserted that industries such as construction, agriculture, transportation, and forestry exhibit heightened susceptibility to climate-related risks, underlining their particular vulnerability to the adverse impacts of climate change (Linnenluecke et al., 2013). This is exemplified by the statements (see Michalski & Kupczyk, 2007) that emphasise that the intensification of climate warming has resulted in heightened volatility and extremity in global climatic conditions (Pavlik & Michalski, 2025), and consequently exacerbating the severity of damages initiated by natural disasters (Tellman et al., 2021).

The actions (Lozano & Huisingh, 2011) of certain entities that neglect the imperative of environmental sustainability (Michalski & Kupczyk, 2007) will inevitably influence the future performance of Treasury Management within entities, shaping the trajectory of those organizations in the long term (Shrivastava, 1995).

One such determinant that undermines the economic performance within Treasury Management entities is the escalating risk posed by climate instability and the attendant climate-related uncertainties. Climate risk exerts a more pronounced influence on long-term decision-making processes within Treasury Management, shaping strategic choices with far-reaching implications, yet the risk of climate instability (Michalski, 2024) significantly influences Treasury Management decisions regarding the management of current assets, exerting a more substantial effect on firms' short-term asset allocation and investment strategies. Both risks are intensifying at an accelerated rate due to unsustainable developments, both climatic and meteorological, thereby undermining an entity's ability to enhance treasury generation. Regarding the peril of climatic volatility, the enterprise is compelled to preemptively mitigate it through the amplification of its repository of substances and primary resources, while concurrently preserving its pecuniary liquid assets at a heightened level of fiduciary caution, and then through the deployment of climatic macroeconomic instruments for risk attenuation. Both methodologies encompass expenditures (Kupczyk & Michalski, 2008), both in the form of tangible disbursements and in terms of opportunity costs (Mura et al., 2015), constraining the corporation's magnitude (Field, 2012) of financial augmentation (Soltes & Uzik, 2009). This engenders the inference that, should entities demonstrate a propensity to implement ecological sustainability paradigms within Treasury Management, the attenuation of expenditure magnitudes correlated with the peril of climatic volatility for prospective entities would become feasible. The outcome would manifest as an enhanced macroeconomic efficacy of the organizations' Treasury, thereby offsetting the contemporary fiscal outlays associated with the enactment of sustainability paradigms.

Feng et al. (2024) empirically substantiated that the divulgence of climate instability risk exerts a catalysing influence on corporate innovative potentialities by bolstering reputational capital, fortifying mechanisms of corporate governance, and mitigating the cost of capital acquisition. Deng et al. (2024), in a congruent empirical observation to the findings delineated in the present study, demonstrated that anomalous precipitation exerts a statistically significant amplifying impact on corporate financialisation, whereas aberrant thermal conditions exhibit no discernible econometric effect. Contrary to the conclusions articulated in the present study, Chen et al. (2022) empirically evidenced that environmental regulatory imperatives engender a substantial diminution in the magnitude of debt-based financing within corporate entities, with the effect being particularly pronounced in sectors characterised by elevated levels of environmental pollution. Consequently, the extension of research within this domain appears meritorious, a proposition that is explicitly advocated within the scope of the postulated directives for prospective research trajectories. In 2025, Arian & Naeem (2025) empirically demonstrated that enterprises operating in regions characterised by an elevated risk of climate instability exhibit diminished investment efficiency, primarily attributable to the adoption of risk-averse investment strategies. Similarly, Cang & Li (2024) established that an exacerbated corporate exposure to climate instability precipitates an augmentation of corporate bond credit spreads, a phenomenon particularly salient in state-owned enterprises and industries with high carbon intensity, corresponding with the econometric regularities identified in this study. Hence, it can be discerned, in line with these findings that Qi et al. (2025) established that the abundance of atmospheric resources exerts an inhibitory influence on corporate green technological innovation, primarily mediated through the mechanism of the resource curse effect. In 2025, Ai & Xue empirically substantiated that supply chain finance exerts a mitigating effect on carbon emissions within Chinese manufacturing enterprises, a conclusion congruent with the econometric estimations presented in subsection 3 of this study. Similarly, Zhou et al. (2022) demonstrated that escalating temperatures attenuate corporate risk-taking propensity, particularly within private and labour-intensive sectors, while Liu et al. (2024) found that the heightened risk of climate instability curtails corporate greenwashing behaviour by fostering innovation and strengthening corporate governance mechanisms.

Jeanneaux et al. (2025) highlighted the average financial burden associated with farm acquisition and adaptive measures among young agricultural entrepreneurs in central France, highlighting its dependency on multifaceted risks, including climate instability. This observation corresponds with the recommendations delineated herein, in conjunction with Zhao et al. (2024), who evidenced that green finance efficaciously curtails carbon emissions through technological innovation and industrial restructuring.

Furthermore, Zhang et al. (2025) demonstrated that prolonged exposure to air pollution escalates the proclivity of firms to engage in short-term earnings management, a phenomenon consistent with the findings of Chapter 4 of the study.

Continuing the discourse, it is pertinent to highlight that Naseer et al. (2025) demonstrated that financial constraints intensify the adverse ramifications of climate instability risk on the treasury capacity of corporate entities, whereas financial flexibility and innovative capabilities serve as mitigating factors. This econometric regularity is in full concordance with the author's findings presented in this study. In 2024, Chen et al. empirically proved that environmental regulatory frameworks engender an elevation in corporate cash holdings, serving as a precautionary buffer against financial uncertainty, an observation corroborated by the econometric equations presented in the study. In

2024, Xue et al. found that the attenuation of risk sensitivity by the prevailing clan culture in China diminishes the propensity of private enterprises to accumulate cash reserves by modifying their financial strategies – an empirical observation analogous to the findings of this study concerning sensitivity to climate instability risk. Similarly, Su et al. (2025) demonstrated that CEOs with substantial holdings of corporate debt exhibit a heightened propensity to incorporate climate instability risk into their strategic acquisition decisions. In 2025, Shang et al. empirically established that superior ESG performance attenuates corporate default risk by facilitating the diversification of financing sources and optimising capital utilisation. Concurrently, Shen et al. (2025) demonstrated that supply chain digitalisation exerts a statistically significant reduction in CO_2 emissions, primarily through the catalysis of technological innovation and the dismantling of financial impediments. Moreover, Chen & Zhang (2025) substantiated that enterprises facing elevated climate instability risk expedite digital transformation processes to enhance their adaptive capacity: an econometric regularity in line with the adaptive resilience paradigm articulated in this study. These managerial components within the domain of Corporate Treasury Management underline an isomorphic correlation with the presented findings, highlighting the nexus between climate instability risk and the constraining effects imposed on CTM practices.

In 2024, Yin et al. empirically demonstrated that the peril of climatic volatility exerts a constructive influence on corporate ESG efficacy, primarily mediated through capital allocation limitations and societal normative imperatives. Similarly, Chen et al. (2023) identified that anomalous precipitation events propel enterprises to augment the relative share of long-term indebtedness within their capital structure while simultaneously curtailing the disbursement of shareholder remunerations. Moreover, in line with these findings, Deng et al. (2024) empirically substantiated that the hazard of climatic volatility exerts an inhibitory effect on corporate innovation capacities, although this adverse impact is attenuated by the maturation of capital markets and the proliferation of insurance mechanisms. Furthermore, Cui & Yang (2025) evidenced that the tangible manifestations of climate instability risk obstruct the concurrent advancement of both the digital economy and low-carbon economic paradigms: an analytical premise congruent with the econometric inferences articulated in this research.

In 2024, Qian et al. empirically demonstrated that enterprises exposed to extreme climatic phenomena exhibit heightened efficacy in carbon emissions management. At the same time, Wang et al. (2024)and Gong et al. (2025) evidenced that the degree of judicial autonomy in China attenuates corporate cash hoarding tendencies, thereby enhancing financing accessibility – an effect analogous to the modulation of climate instability risk sensitivity observed in this study, which influences the allocation of liquid assets. Conversely, Huang et al. (2025) identified that CEOs' cognitive distortions regarding climate instability risk precipitate an elevated concentration of indebtedness coupled with a contraction in expenditures on research and development.

Kanamura (2025) formulated a quantitative econometric model of sustainability risk (S risk), and validated its consequential impact on the dynamics of financial markets. Goodell et al. (2025) empirically established that the intensification of climate change risk engenders a contraction in the maturities of corporate debt instruments – an observation fully congruent with the findings articulated in this study. Nguyen et al. (2025) demonstrated that enterprises operating in economies more acutely vulnerable to climate change exhibit lower creditworthiness ratings and encounter heightened barriers to capital acquisition.

Moreover, Ruan et al. (2024) and Cai et al. (2024) substantiated that ESG disclosure significantly fosters eco-innovation by facilitating capital access. In parallel, Li et al. (2023) evidenced that financial flexibility augments financing efficiency, particularly within state-owned and non-manufacturing sectors. Similarly, Ruan et al. (2024) revealed that climate instability risk amplifies the efficacy of green innovation through the synergistic interaction of digital transformation processes and external supervisory mechanisms.

Qing et al. (2024) empirically proved that CEOs' green experience attenuates the adverse repercussions of climate change exposure on corporate financial and energy performance. Lai & Zhang (2024) substantiated that ESG assessments bolster corporate environmental outcomes by enhancing financing accessibility and fostering green innovation. Similarly, Yuan et al. (2025) and Bagh et al. (2025) evidenced that climate instability risk diminishes corporate leverage ratios, thereby incentivising enterprises to adopt more sustainable operational paradigms – findings that are in line with the econometric inferences presented in this study regarding the financial performance implications of climate instability risk on corporate treasury management.

Fan & Zhang (2024) identified that oil price uncertainty prompts manufacturing firms to diversify operational activities, while Lin & Li (2024) demonstrated that the expansion of clean energy business models receives greater support from market mechanisms than from governmental financing instruments. In a related observation, Wei et al. (2023) found that elevated air pollution levels escalate local government financing costs. Moreover, Mertzanis et al. (2025) evidenced that machine learning algorithms effectively forecast the impact of climate instability risk on corporate bond markets. This predictive mechanism constitutes a pivotal analytical tool, supporting the integration of machine learning-based methodologies within the procedural framework proposed in this study to design sustainable corporate treasury management solutions.

Javeed et al. (2024) demonstrated that digital finance and the participation of institutional investors facilitate the allocation of green investments in enterprises characterised by elevated greenhouse gas emissions. Both Xue et al. (2024) and Zhao et al. (2024) stated that supply chain finance contributes to the attenuation of carbon emissions in Chinese manufacturing enterprises by enhancing capital accessibility and stimulating innovation in green technologies. Furthermore, Zhao et al. (2024) evidenced that green finance exerts a mitigating influence on carbon emissions through the synergistic effects of industrial restructuring, technological advancement, financing accessibility, and external supervisory mechanisms.

Zhang et al. (2025) identified that prolonged exposure to atmospheric pollution prompts enterprises to engage in short-term profit management strategies, predominantly by manipulating production processes and cost structures – an effect attributable to diminished productivity and managerial cognitive distortions. Zhou et al. (2022) demonstrated that rising temperatures significantly curtail corporate risk-taking propensities, particularly within private, small-scale, and labour-intensive enterprises, with this effect mediated by capital constraints. Additionally, Su et al. (2025) analysed the interplay between CEOs' debt obligations and their incorporation of climate instability risk into corporate acquisition decisions. The results indicated that CEOs with substantial corporate debt holdings are more inclined to discount the valuation of target firms with elevated climate instability risk, rather than abandon the acquisition: suggesting that their personal financial stakes incentivise a more risk-averse acquisition strategy.

The study employed an econometric framework alongside theoretical inquiry to investigate the ramifications of climate instability risk on sustainable Corporate Treasury Management (CTM). The principal methodological constituents include a comprehensive literature review and theoretical disquisition on the nexus between climate instability risk and corporate operational dynamics; an examination of financial instruments deployed for risk mitigation, including derivatives; and an evaluation of corporate competitiveness and efficiency within the CTM paradigm. The econometric modeling techniques utilised facilitate the quantification of financial variables in the context of climate-related determinants.

Empirical evidence from diverse economic sectors underpins the analytical framework. These include the application of Heating Degree Days (HDD) and Cooling Degree Days (CDD) indices in the hedging strategies of energy enterprises, the influence of temperature fluctuations on agricultural income, and the deployment of derivative instruments in the management of corporate current assets – thereby ensuring that the econometric estimations reflect real-world economic conditions.

Additionally, the methodological apparatus incorporates the extrapolation of econometric findings to formulate policy implications and recommendations for future inquiry. These include the integration of artificial intelligence algorithms in climate instability risk analysis and the advancement of innovative financial instruments to optimise CTM. The methodological architecture is predicated on three pivotal pillars: a theoretical literature review on climate instability risk measurement and management, quantitative econometric modelling, and case study analyses that demonstrate the practical efficacy of the proposed strategies.

In the following section the author examined the extent to which the quantification and management of climate instability risk influence corporate competitiveness, while elucidating the role of econometric methodologies in modeling and optimizing strategies within the framework of corporate financial management. Comprehending the impact of climate instability risk on the formation of an entity's treasury position constitutes merely the preliminary phase of the analysis. The crux of an effective CTM strategy lies in the identification and implementation of mitigation mechanisms – a focal point explored in greater depth in the next section.

2. Impact of Climate Risk on the Formation of Corporate Treasury Management through Enhanced Business Competitiveness and Efficiency

The influence of the perils of climate instability on the state of a corporation's Treasury necessitates consideration within the paradigm of market competition and operational efficacy. Rivalry and competitive dynamics within the economic sphere represent some of the most ubiquitously employed yet insufficiently delineated constructs. In 2025, Arian & Naem pointed out that competitive capacity exerts a profound influence on the augmentation of life quality and societal well-being. The proliferation of scholarly inquiry into competitive dynamics originated in the 1970s, coinciding with the culmination of the post-war economic expansion and the transition of capitalist economies into a phase of macroeconomic volatility (Arian & Naem, 2025). Manifestations of escalating structural rigidities emerged in the later part of the 1960s. Pivotal junctures in the global economic framework occurred during the first half of the 1970s, encompassing phenomena such as monetary turbulence and the hydrocarbon and energy crises (Kupczyk, 2006). These contingencies substantively speeded up the advent of unparalleled adverse phenomena, namely involuntary joblessness and price level escalation (Rentschler et al., 2022). Nevertheless, ascertaining whether this epoch constitutes the genesis of scholarly preoccupation with competitive dynamics remains complex. Alternative sources posit that American economists pioneered the quantification of the competitive capacity of contending economies – the United States and Japan. In 2025, Cui & Yang asserted that the contextual framework for this intellectual inquiry was the intense mercantile rivalry between corporate entities originating from these two nations (Belissa et al., 2019).

The paradigms of market competition originated from the intellectual legacy of preeminent economic theorists, including J.S. Mill, D. Ricardo, and A. Smith. An extensive body of the subject literature examines the wealth of research on competitive dynamics and their determinants within the frameworks of particular national economies or industrial sectors. Nevertheless, the predominant preoccupation among economists investigating competitive phenomena remains the absence of a singular, universally acknowledged conceptual delineation of this multifaceted construct (Arian, 2025). The term 'competition' originates from the Latin 'concurrere', signifying to advance simultaneously, however the essential semantic connotation of the term varies, encapsulating the notion of rivalrous contention among adversaries (Kupczyk, 2006).

Competition is manifested as a dynamic process wherein market agents, endeavouring to realise their predetermined objectives, present superior value propositions relative to other actors, driven by determinants impacting transactional decisions. These determinants encompass price mechanisms, product quality standards, logistical delivery parameters, among others. Competition constitutes a phenomenon delineated by distinct relational typologies among the participating entities. These relational configurations are predicated upon rivalrous interaction, as despite the impediments imposed by competing actors, an organisation must sustain competitive viability to attain its strategic aims (Michalski & Kupczyk, 2007).

Even an eminent authority in the field such as M. Porter, in his seminal work "The Competitive Advantage of Nations" (1990), refrained from articulating an unequivocal definition of competitiveness, notwithstanding the frequent invocation of the term (Arian & Naem, 2025). No singular definition of competitiveness attains universal consensus among economists studying the phenomenon (Deng et al., 2024). Broadly speaking, competitiveness can be construed as an intrinsic attribute of entities engaged in market rivalry. The scholarly literature seldom furnishes an explicit definition of competitiveness, and when present, it predominantly pertains to macroeconomic agents such as national economies or particular industrial sectors (Feng et al., 2024).

Competitiveness is usually described as a relative attribute, emerging through the comparative assessment of products or enterprises. This construct is examined across multiple analytical strata, encompassing the nexus between an economic agent's potential, capabilities, and competencies vis-à-vis the market architecture, alongside its aptitude to leverage strategic opportunities. Moreover, competitiveness may be interpreted as the capacity for enduring and sustainable expansion, or alternatively, as the organisation's propensity to uphold elevated levels of operational efficiency and productivity (Jeanneaux et al., 2025).

Competitiveness denotes the proficiency to effectively realise objectives within the domain of market rivalry (Goodell et al., 2025), whilst the European Commission defines competitiveness as the capacity to withstand and prevail in the milieu of international market competition (Kupczyk, 2006).

It is also postulated that the continuity of existence and advancement of an organisation is dictated by the market environment, wherein products either secure or fail to secure consumer demand. Consequently, one definition posits that competitiveness constitutes the persistent capability to conceive, produce, and commercialise goods whose quality, pricing, and ancillary attributes exhibit superior appeal relative to analogous offerings proposed by both domestic and international rivals (Chen et al., 2023).

Among the plethora of concepts of competitiveness appearing in the specialist literature, the definition advanced by the World Economic Forum in Lausanne in 1994 is regarded as the most rigorous. Competitiveness is described as the capacity of a nation or enterprise to engender a superior treasury level relative to its global market adversaries (Kupczyk, 2006).

Numerous frameworks for analysing competitiveness refrain from explicitly identifying the competitor, instead conceptualising the phenomenon in a relative paradigm (Michalski & Kupczyk, 2007). A notable example is the OECD's definition, which characterises competitiveness as the aptitude of enterprises, industries, nations, regions, or supranational coalitions to resist international competition while simultaneously delivering a comparatively elevated return on deployed production factors and maintaining relatively high employment rates on a sustainable trajectory (Huang et al., 2025).

According to Porter, attempting to elucidate competitiveness on a national scale amounts to addressing an ill-posed inquiry, whereas the paramount objective is establishing the determinants of efficiency and its trajectory of expansion (Michalski & Kupczyk, 2007). Achieving this necessitates shifting analytical focus away from the macroeconomic framework and directing it toward distinct industries and market segments. While competitiveness originates at the corporate level, its foundation is rooted in underlying macroeconomic factors that render a nation an advantageous environment for enterprises engaging in global competition. Porter underlined that competitive preeminence is contingent upon variations in economic architectures, national ethos, cultural paradigms, institutional frameworks, and historical legacies (Porter, 1990).

The Austrian school of thought and the resource-advantage theory conceptualised the market as a mechanism that enables enterprises to leverage their distinctive resources (Hunt & Morgan, 1995; Kupczyk, 2006) and undertake a sequence of strategic initiatives to secure comparative and transient advantages until rival entities engage in competitive confrontation (Rindova et al., 2010).

An alternative yet equally pivotal dimension of the influence exerted by the risk of climate instability at a company level of treasury-generating capacity pertains to transactional expenses, which escalate amid the intensification of climate-related uncertainty (Michalski & Kupczyk, 2007). The transaction constitutes the fundamental analytical unit within the theory of economic organisation, serving as the cornerstone mechanism that facilitates the operation of economic systems. Transactions impose pecuniary burdens on the parties engaged in the exchange, as well as frequently on external stake-holders (Kupczyk, 2006).

Transactional expenses denote the expenditures incurred to mitigate uncertainty, encompassing activities such as the procurement and aggregation of information, its systematic processing, the formalisation and supervision of contractual agreements, and the enforcement of obligations stipulated therein (Michalski & Kupczyk, 2007).

Within the paradigm of new institutional economics, the primary objective and consequence of economic institutions is the optimisation of transactional expenses. This framework posits that any economic challenge can be conceptualised as an issue wherein the anticipated outcomes are analysable through the lens of transaction cost minimisation (Kupczyk, 2006).

The minimisation of transactional expenses constitutes the core focal point in the market analysis of organizational entities. This objective is realised through the alignment of transactions with governance frameworks, which diverge in their adaptability and cost implications. Scholars specialising in the transaction cost paradigm also delve into the internal dynamics of firms, stressing that the optimal organizational architecture and managerial attributes more effectively curtail transactional expenditures (Kupczyk & Michalski, 2008).

A pivotal milestone in the discourse surrounding the transaction cost paradigm was the seminal study by R. Coase, scrutinising the ontological rationale behind the existence of firms. He posited that enterprises constitute a distinct coordination apparatus divergent from the market mechanism (Kupczyk, 2006). According to Coase, the market system and the corporate entity epitomise two alternative modalities of resource allocation, each subject to bounded rationality. His paramount contribution to economic theory lay in the identification and formalisation of transactional outlays as fundamental business expenditures. This concept differed from the neoclassical doctrine of perfect competition, asserting that a salient attribute of economic agents is the circumvention of the market-based allocation mechanism (Michalski & Kupczyk, 2007). Within this framework, the market mechanism becomes inoperative, supplanted by an organizational hierarchy that orchestrates resource distribution (Li & Lin, 2024).

Coase further pioneered the notion of transactional expenditures as a heuristic device to explain business dynamics (Kupczyk, 2006). Beyond the statistical framework of general equilibrium theory, he posited that a market invariably emerges for currently produced goods: both present and prospective. However, for goods intended for future production, the market's existence remains uncertain, reflecting temporal asymmetries associated with future contingencies. Moreover, Coase emphasised that companies have the capacity to substantially curtail transactional outlays by internalizing the production process, thereby fostering operational efficiency and mitigating reliance on external market mechanisms (Mertzanis et al., 2025).

Contemporary trends of institutional economics ascribe the function of moderating transaction cost magnitudes to institutional frameworks, which progressively amplify their proportion within national product market economies. According to K. Arrow, transactional expenditures epitomise the operational costs intrinsic to an economic system (Kupczyk, 2006), impeding market emergence and, in specific instances, they may entirely obstruct market formation (Arrow, 1969). Transaction costs encompass the expenses associated with initiating and executing transactions, the outlays for establishing the transactional system, and the opportunity costs stemming from the conduct of contracting parties. Traditionally, these expenditures are divided into ex-ante and ex-post costs, which exhibit mutual interdependence (Michalski & Kupczyk, 2007). This interdependence necessitates their simultaneous consideration, rather than a sequential approach (Kanamura, 2025). Ex-ante contractual expenditures elude precise calculation and incorporation into pre-transaction economic models, while ex-post costs introduce the dimension of unexpected contingencies (Benkraiem et al., 2025).

Throughout their research, economists have dispelled the postulation of nonexistent transactional expenditure. Solely in an idealised economic paradigm do transaction costs equate to zero; within the tangible economic environment where enterprises function, there invariably arise certain expenditures associated with information acquisition, contractual negotiation, content specification, and obligation enforcement (Michalski & Kupczyk, 2007).

Undoubtedly one can assert that transactional expenditures constitute the actual outlays borne by an enterprise. It must be emphasised that certain expenditures invariably necessitate incurrence, and their mitigation can significantly influence the effectiveness of a company's Treasury formation process.

It is contended that sustainable business operations may potentially diverge from the maximisation of Treasury, which represents the fundamental economic aim within Treasury Management. The primary objective of a company's Treasury Management involves maximising Treasury, stemming from the drive to enhance the entity's Treasury value. In its most rudimentary form, the company's Treasury is characterised by the summation of discounted anticipated cash flows generated by the enterprise, adjusted at the capital cost rate (Kupczyk & Michalski, 2008). This interdependence can be articulated through equation 1 (Michalski, 2024):

$$V_p = \sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} \tag{1}$$

where: V_p – the firm's treasury valuation, serving as a quantitative measure of the efficacy of corporate treasury management; CF_t – the projected magnitude of discretionary cash flows originating from the firm's productive asset base over the designated temporal interval t; k – the capitalisation rate, extrapolated from the enterprise's weighted economic cost of capital deployment (Michalski & Kupczyk, 2007).

The maximisation of the enterprise's Treasury value is attained by striving to optimise the expected free cash flow, computed according to equation (2) (Michalski, 2024):

$$CF = EBIT \times (1 - T_c) + NCE - \Delta NWC - Cap.ex \tag{2}$$

where: *EBIT* – operating income preceding interest obligations and taxation, reflecting the firm's core profitability from business activities; T_c – the effective corporate taxation rate, representing the proportion of pre-tax earnings allocated to fiscal liabilities; *NCE* – non-monetary expenditures, encompassing asset depreciation, amortisation, and other accrual-based accounting adjustments; ΔNWC – fluctuations in net working capital, computed as the aggregate of inventory holdings, accounts receivable, and liquid reserves, offset by outstanding trade payables; *Cap.ex* – net capital outlays, signifying financial allocations toward asset acquisition, infrastructure expansion, and long-term productive investments.

To achieve the optimal execution of the company's Treasury creation, the management board should prioritise minimising the economic capital cost rate sustaining the company's operations (Mura et al., 2015) and maximising the company's longevity, presuming that the firm will consistently generate positive free cash flows from its assets.

These principles necessitate the implementation of risk mitigation strategies within the company's Treasury Management, enhancing the Treasury value of managed enterprises by extending the company's lifespan, assuming that the business yields positive cash flows, while simultaneously reducing the economic capital cost rate. Both of these parameters (k and t in equation (1)) show high sensitivity to the risk level tied to the company's operations, including the risk of climate instability, which the next section explores in greater detail (Kupczyk & Michalski, 2008).

As the risk magnitude escalates, the likelihood of sustaining a sufficiently prolonged operational period – in line with the interests of Treasury Management – diminishes, while the probability of insolvency concurrently amplifies (Kupczyk, 2006). The capital cost rate rises in direct proportion to the risk level, as capital providers demand higher returns to compensate for the augmented exposure to risk.

The third component of equation (1), the cash flow generated by the enterprise (*CF*), hinges on the uncertainty associated with future commodity price fluctuations, sales volumes, competitive landscape, technological advancements, and consumer preferences (Michalski & Kupczyk, 2007). These factors are similarly subject to the risk of climate instability, implying that climate risk management exerts a direct influence on the company's Treasury value (Kupczyk, 2006).

3. Risk of Climate Instability in Corporate Treasury Management

Hart (2013) investigated instances of Treasury Management in full-cycle enterprises that have restructured their product portfolios and reengineered production processes (Kupczyk, 2006), thereby revolutionising their operational models and market segments to align their Treasury Management paradigms with a sustainable business framework (Hart, 2013). Employing the risk of climate instability as a case study, the article showed that the adoption of sustainable business practices not only remains compatible with the primary goal of Treasury Management, but also that climate risk mitigation directly enhances the fundamental objective of maximising corporate Treasury (Michalski & Kupczyk, 2007).

The conducted analysis presented an in-depth exploration of the interrelation between the implementation of sustainable business models, green sustainability strategies, and climate instability risks, demonstrating how the latter exerts a detrimental influence on companies' Treasury generation capacity (Kupczyk, 2006). Should contemporary enterprises follow their Treasury Management strategies with the principles of sustainable business through comprehensive sustainability policies, future businesses are projected to yield superior results in maximising the Treasury of business owners.

The definition and characterisation of the risk of climate instability (Kupczyk, 2008) indicated that this type of risk arises from the variability of climate patterns over the relevant periods across different years (Kupczyk & Michalski, 2008). Consequently, understanding the mechanisms of climate variability plays a pivotal role in designing adaptive Treasury Management models and mitigating the financial repercussions of climate-related disruptions. This variability is interpreted as fluctuations in climate parameters relative to the long-term average climatic conditions observed for a specific location and timeframe. For instance, the mean air temperature recorded on a particular calendar date, such as 6 March, exhibits annual deviations across different years (Kupczyk, 2008). Consequently, if the climate patterns could be forecasted with high precision over an extended period, the risk of climate instability would cease to exist (Kupczyk, 2006).

However, despite significant advancement in synoptic meteorology, contemporary climate forecasting only achieves satisfactory accuracy a few days in advance – an inadequate timeframe for businesses exposed to climate instability risk (Michalski & Kupczyk, 2007). This inherent forecasting limitation exacerbates the uncertainty surrounding climate-sensitive operations, compelling companies to implement adaptive risk management strategies in Corporate Treasury Management to mitigate the adverse financial impact of climate fluctuations.

Cogen conceptualised the risk of climate instability (Cogen, 1998) as the uncertainty surrounding cash flows and profitability volatility instigated by climate phenomena (Kupczyk, 2008; Edrich, 2003). Conversely, Clemmons outlined the term as the economic susceptibility of enterprises to climate occurrences such as extreme temperatures, precipitations, and wind patterns. This form of exposure typically remains non-catastrophic, primarily influencing profit margins rather than the value of fixed assets (Clemmons, 2002; Banks, 2002; Kupczyk, 2008).

Analogous definitions of risk of climate instability proposed by various scholars converged on the notion that climate-induced uncertainty significantly affects the economic performance of businesses, necessitating the integration of climate risk mitigation strategies into Corporate Treasury Management frameworks (Kupczyk, 2008).

A more precise concept of risk of climate instability can be formulated (Kupczyk, 2008), and given that this risk emerges from the fluctuations in climate parameters, interpreted as departures from long--term climate averages, climate conditions can be classified into normal, i.e. those exhibiting minimal deviations from multi-year climate patterns, and catastrophic ones demonstrating substantial discrepancies (Kupczyk & Michalski, 2008).

Thus, risk of climate instability can be defined as the probability of attaining economic outcomes that diverge from anticipated projections due to moderate climate variability. In this context, moderate climate variability signifies such climate changes that yield normal climate conditions, not posing a threat to standard business operations (Kupczyk, 2006).

The influence of risk of climate instability may yield both advantageous and adverse outcomes. A favourable impact manifests itself when climatic circumstances benefit the enterprise, whereas an adverse effect occurs when climatic conditions prove detrimental (Kupczyk, 2008).

A distinctive attribute of risk of climate instability lies in its temporal variability across the annual cycle and its inherently localised character.

Risk of climate instability assessment is the appraisal of enterprises' exposure to risk of climate instability which necessitates the following (Michalski & Kupczyk, 2007):

- the distinction of indicators applicable in quantitative analyses to depict climatic conditions,
- the recognition of enterprises potentially susceptible to moderate climate fluctuations,
- the determination of enterprise-specific variables that may directly influence the risk of climate instability.

Climatic conditions are characterised by the quantification of the intensity of their parameters, such as air temperature, precipitation levels, wind velocity, sunlight duration, and by monitoring meteorological phenomena (Kupczyk, 2006). The indicators describing climatic circumstances may encompass natural climate variables or their specific parameters (Kupczyk, 2008).

The risk of climate instability seemingly pertains to Treasury Management for the majority of enterprises, although the degree of risk exposure across distinct Treasury Management systems fluctuates from extremely elevated to marginally low. Concerning the US economic landscape, several scholars present overarching insights into risk exposure in the realm of Treasury Management. For instance, Brabazon and Idowu (2002) indicated that approximately 70% of enterprises in the US experience the impact of risk of climate instability to a certain degree (Kupczyk, 2008).

Erhardt (2015) observed that climatic derivatives undergo trading on the Chicago Mercantile Exchange, with the risk of climate instability market valued at around USD 11.8 billion in 2011 (Erhardt, 2015). The Chicago Mercantile Exchange revealed that nearly 20% of the US economy remains directly contingent on climatic phenomena (Benth & Benth, 2007; Kupczyk & Michalski, 2008). Advocating the discourse on the valuation of call and put options tied to climate futures as the underlying asset, Benth and Benth proposed the application of the Ornstein-Uhlenbeck process with seasonal variability to model the temporal dynamics of temperature fluctuations (Benth & Benth, 2007).

Drawing on pertinent studies (Banks, 2002), Clemmons concluded that the US Department of Commerce had established that climate conditions influence enterprises generating 1 out of every USD 9 trillion of the US gross domestic product (Kupczyk, 2008). The magnitude of risk of climate instability exposure primarily hinges on the nature of the economic activity. Based on an in-depth examination of activity types delineated in the Polish Classification of Activities (PKD), it can be posited that risk of climate instability exerts a direct impact on enterprises functioning within the energy sector, agriculture, construction, transport and warehousing, recreational and tourism services, as well as on firms engaged in the production and distribution of beverages, apparel, and pharmaceuticals.

Moreover, the risk of climate instability plays a pivotal role in enterprises providing health-related services and those offering insurance services (Michalski & Kupczyk, 2007). Consistent with this perspective, Bank & Wiesner (2009) described the principal attributes of climate derivatives and the target group for specialised risk of climate instability measurement and management solutions in Treasury Management. These solutions augment the utilisation of climate-sensitive assets across various sectors (Bank & Wiesner, 2009). Within the framework of a company's Treasury Management, the risk of climate instability can directly influence the following variables (Kupczyk, 2008):

- The volume of purchases and prices of production factors (impact on operating costs).
- The production capacity in trade and services sectors (e.g. construction, transport, agriculture and hydro and wind power generation), thereby affecting sales volumes and prices (impact on operating income or costs).
- The volume of sales and prices of products (goods and services), commodities, and materials as a consequence of fluctuations in demand (influence on operating income).

The net profit derived from the investment of assets in companies vulnerable to risk of climate instability (impact on economic revenues or costs).

These interrelations underline the multifaceted nature of risk of climate instability within the paradigm of Treasury Management (Kupczyk, 2006), necessitating comprehensive strategies for identification, assessment, and mitigation (Kupczyk, 2008).

In a predominant proportion of corporate entities significantly shaped by the stochastic volatility of climatic uncertainty, meteorological variables demonstrably dictate the magnitude of revenue streams derived from commercial transactions (Michalski & Kupczyk, 2007). The intensity of climatic impact on transactional volume markedly exceeds its determinative force on price dynamics (Edrich, 2003; Kupczyk, 2008; Cogen, 1998). Specific corporate entities generate their financial inflows predominantly through volumetric sales, particularly those operating within the domains of energy generation, thermal distribution, or gas supply. This structural paradigm also distinguishes enterprises providing leisure-oriented services (e.g. mountain resorts, coastal retreats) or those specialising in the manufacturing and trading of garments (Michalski & Kupczyk, 2007).

The consumption dynamics within these sectors exhibit a robust correlation with meteorological variables, making it unlikely that price adjustments substantially influence revenue generation (Cang & Li, 2024; Kupczyk, 2008). As a result, the stochastic volatility of climatic conditions frequently emerges as a fundamental risk factor confronting such corporate entities. Moreover, the materiality of climate-induced risk intensifies when transactional volume fails to demonstrate an inverse correlation with pricing oscillations, thereby necessitating a sophisticated approach to Treasury Management and the formulation of advanced risk hedging methodologies.

The interdependence between climate-induced risk volatility and various risk factors examined within Treasury Management frameworks manifests itself in multiple dimensions of corporate financial stability. Climate-related uncertainty directly influences operational profitability by modulating transactional volumes in both sales and procurement, as well as by inducing fluctuations in the market valuation of commercial transactions (Michalski & Kupczyk, 2007), and exerts a profound impact on overall corporate profitability. Consequently, meteorological variables function as critical determinants of volumetric sales risk, procurement cost volatility, and asset valuation fluctuations for enterprises susceptible to climatic uncertainties (Kupczyk, 2006).

The analytical assessment of climate-induced volatility proves most relevant when meteorological variables serve as principal determinants of volumetric risk (Kupczyk, 2008), given that methodologies for hedging price fluctuations are well-established and extensively utilised. Beyond price dynamics, transactional volumes in both sales and procurement remain susceptible to a multitude of external determinants, including foreign exchange rate fluctuations and prevailing consumer trends (Michalski & Kupczyk, 2007). However, in numerous instances, climatic variables constitute the predominant influence, thereby allowing climate-induced risk to be conceptually aligned with volumetric uncertainty, which facilitates the formulation and implementation of effective risk management strategies (Kupczyk, 2006).

Furthermore, climate instability risk fundamentally differs from natural disaster risk. The former applies to non-catastrophic climatic fluctuations, whereas the latter encompasses extreme meteorological phenomena with severe disruptive consequences. Non-catastrophic climatic variations occur with high frequency, whereas catastrophic events appear with significantly lower probability (Kupczyk, 2008; Clemmons, 2002).

The catastrophic risk emerges from the potential occurrence of extreme climatic disturbances and other hazardous geophysical phenomena, such as seismic activity and volcanic eruptions. The fundamental distinctions between climate instability risk and natural disaster risk are systematically outlined in Table 1. However, distinguishing these two categories with absolute precision remains challenging, as certain meteorological events may exhibit characteristics that blur the conceptual boundary between stochastic climatic variability and catastrophic occurrences.

Table 1. Main differences between risk of climate instability and natural disaster risk

Differentiation parameter	Climatic volatility risk	Catastrophic geophysical risk
Impact on corporate operations	Certain categories of commercial enterprises	All classifications of economic entities
Characterisation of impact on corporate operations	Determines financial performance	Origins of depreciation in sustainable asset value
Magnitude and duration of impact on corporate operations	Induces minimal losses or supplementary gains in the short term (starying from several days), yet generates substantial effects over an extended period (months, seasons)	Induces significant losses, typically within a short time frame
Occurrence frequency of the risk	Elevated	Minimal
Categories of discernible climatic events that may impact corporate operations	Specific climatic variables and meteorological events to a lesser degree	Particular catastrophic meteorological events (e.g. extreme temperatures, heavy precipitation, hurricanes, hailstorms, blizzards, etc.)

Source: (Kupczyk, 2008; Kupczyk & Michalski, 2007).

Table 1 illustrates that fluctuations in climatic stability influence corporate current assets policies, compelling entities to sustain elevated cash reserves (Pavlik & Michalski, 2024). Conversely, catastrophic environmental events precipitate abrupt financial downturns, necessitating immediate capital mobilisation. Persistent climatic variability inflates operational expenditures, whereas extreme meteorological occurrences induce occasional yet severe devaluations of tangible assets. Prudent treasury governance mandates distinct strategic responses, namely long-term hedging mechanisms to stabilize cash flow volatility and adaptive financial agility to mitigate acute fiscal disruptions (Kupczyk, 2008).

4. The Effect of Climatic Volatility Risk on the Performance of Corporate Treasury Management

As previously discussed, climatic volatility risk influences the firm's financial outcomes, encompassing the management of short-term assets, which comprise inventories, receivables, and cash reserves maintained by the corporation for transactional, precautionary, and speculative objectives.

To explain these interdependencies and their ramifications for corporate treasury valuation, the analysis employed the paradigm of unrestricted liquidity holdings (Michalski, 2014). The stewardship of liquid assets exerts a direct influence on company valuation, as capital allocation toward cash reserves amplifies the implicit cost of foregone investment opportunities while concurrently expanding net working capital (Kupczyk, 2008). These shifts recalibrate projected discretionary cash flows, thereby inducing fluctuations in company value. When the strategic retention of liquidity, demonstrated through augmented cash return revenues and consequently higher free cash flow, surpasses the adverse effects of capital opportunity costs and escalated working capital commitments, the firm's intrinsic valuation experiences an upward trajectory (Michalski, 2014).

In its broadest conceptualisation, net working capital (*NWC*) represents the fraction of short-term assets underwritten by long-term capital resources (Kupczyk, 2008). It constitutes the differential between liquid assets and immediate obligations or, alternatively, the excess of stable liabilities over fixed assets. This metric emerges due to the temporal misalignment between the formal recognition of revenue and the tangible receipt of cash from receivables, juxtaposed with the timing of expense recognition and the corresponding disbursement of financial obligations (Michalski, 2014). The mathematical formulation of NWC is expressed as follows (Kupczyk, 2008) in equation (3):

$$NWC = CA - CL = AAR + ZAP + G - AAP, \tag{3}$$

where *NWC* – net working capital, denoting the surplus of readily deployable assets over immediate financial commitments, *CA* – aggregate current assets, encompassing all short-term economic resources convertible into liquidity within an operating cycle, *CL* – outstanding current liabilities, representing financial obligations due within the near term, *AAR* – trade receivables, signifying amounts owed to the firm arising from credit sales transactions, *ZAP* – inventory stockpiles, encompassing raw materials, work-in-progress, and finished goods awaiting market distribution, *G* – liquid cash reserves and fungible monetary equivalents, ensuring operational solvency and transactional fluidity, and *AAP* – short-duration debt obligations, comprising payable accounts and other imminent financial liabilities.

When evaluating discretionary cash flow, the accumulation and expansion of net working capital correspond to the immobilisation of financial resources committed to its formation. A positive trend in net working capital indicates a progressive diversion of liquid funds from operational cash flow. Of particular analytical significance, within the broader imperative of optimising corporate financial strategy, is the examination of how shifts in capital allocation – driven by the necessity to hedge against the detrimental repercussions of unsustainable economic expansion and the escalating exposure to climate-induced financial volatility – reshape enterprise valuation.

To quantify this dynamic, an analytical framework predicated on the premise that corporate valuation equates to the present value of discounted discretionary cash flows is employed. The assessment of financial resource reallocation effects necessitates the adoption of a discount factor corresponding to the weighted average cost of capital (*CC* = *WACC*), given that these structural modifications possess enduring implications, despite their immediate pertinence to short-term asset stewardship. Alterations in prudential liquidity reserves exert a direct influence on net working capital fluctuations (ΔNWC) and, consequently, on the firm’s aggregate cash-handling expenditures.

The Threshold Level of Liquidity Reserves in a Corporate Entity. Liquidity optimisation frameworks, including those proposed by Baumol, Beranek, Miller-Orra, and Stone, abstain from prescribing explicit methodologies for defining the threshold level of cash reserves, instead deferring to managerial discretion (Michalski & Kupczyk, 2007). However, these paradigms, derived from inventory control theories, suggest an analogous approach – adapting inventory optimisation techniques to establish a structured methodology for determining the requisite baseline of liquid assets within a corporate entity. Hence, the following mathematical formulation determines the minimum cash reserve threshold (Kupczyk, 2008):

$$LCL = \sqrt{-2 \times s^2 \times ln\frac{k \times G^* \times s \times \sqrt{2\Pi}}{P \times K_{bsp}}}, \quad (4)$$

where LCL – lower cash limit, representing the prudential liquidity reserves required to mitigate financial volatility, k – firm-specific economic capital cost rate, reflecting the return required by investors to compensate for financial risk, G^* – magnitude of fund transfers, serving as the basis for standard deviation estimations (under the Beranek and Baumol models, this parameter equates to twice the target liquidity level, whereas in the Stone and Miller-Orr models, it corresponds to an empirically derived or forecasted average transaction size), P – aggregate financial inflows and outflows, encapsulating the firm's cash movement dynamics, s – net standard deviation of daily cash fluctuations, where heightened climate instability amplifies variance, while greater environmental predictability reduces it; K_{bsp} – capital insufficiency cost, encompassing both tangible accounting expenses and implicit opportunity costs incurred due to potential deterioration in the counterparties' trust, stemming from liquidity constraints.

The Influence of the Lower Cash Limit (LCL) on Corporate Treasury Valuation. Prudential or Contingency Liquidity Reserves arise principally from the necessity to mitigate adverse financial repercussions associated with various risk factors, notably climate-induced volatility. The magnitude of these reserves correlates with the statistical dispersion of cash flow fluctuations, quantified through standard deviation.

Example. Liquidity Contingency Assessment for Company W. The executive board of Company W approximates the fiscal burden of liquidity deficits at EUR 50,000. The standard deviation of daily cash inflows and outflows, reflecting heightened volatility due to escalated climate-related financial uncertainty, registers at EUR 100,000 per month. The mean transaction size per cash movement amounts to EUR 20,000, while the aggregate monthly cash turnover – comprising total inflows and outflows – stands at EUR 200,000. The annualised economic capital cost rate, serving as the benchmark for corporate financing requirements, is 22% per annum.

Given these financial parameters, the prudential liquidity reserve threshold for Company W is computed as follows:

$$LCL_1 = \sqrt{-2 \times 100\ 000^2 \times ln\frac{\frac{0,22}{360} \times 20\ 000 \times 100\ 000 \times \sqrt{2\Pi}}{200\ 000 \times 50\ 000}} = 402\ 270;$$

if cash flow volatility were entirely absent – corresponding to a scenario where climate instability risk equaled zero – the required prudential liquidity reserve would likewise converge to zero:

$$0 = LCL0.$$

Accordingly, the resultant increment in net working capital (ΔNWC) can be quantified using the following formulation:

$$\Delta NWC = LCL_1 - LCL_0 = 402270 = -\Delta CF_{t=0}.$$

Assuming that the standard deviation of cash flow fluctuations remains constant at EUR 100,000 and the effective corporate tax rate is 19%, the annualised opportunity cost of maintaining prudential liquidity reserves can be estimated. This cost reflects the implicit return lost due to capital immobilisation in precautionary cash holdings.

Therefore, the impact of climate instability risk on corporate goodwill can be derived through the application of the perpetual annuity model, which accounts for the continuous financial burden associated with liquidity retention, where T – the effective corporate taxation rate, set at 19%, which influences the net cost of capital allocation. By synthesizing these parameters, one can assess the adverse financial impact of climate-induced volatility on corporate valuation and derive strategic insights for long-term treasury optimisation.

$$\Delta TCC = \Delta NWC \times k = 402\ 270 \times 0.22 = 88\ 500 = \frac{-\Delta CF_{t=1\ldots\infty}}{(1-T)};$$

$$\Delta V = \Delta CF_{t=0} + \frac{(\Delta CF_{t=1\ldots\infty}) \times (1-T)}{k} = -402\ 270 + \frac{-88500 \times 0{,}81}{0.22} = -728\ 110.$$

For analytical clarity, this assessment assumed climate instability as the sole determinant of cash flow volatility within Treasury Management. Incorporating additional risk variables would yield identical conclusions, given that the correlation between climate-driven uncertainty and other volatility-inducing factors remained statistically negligible (zero).

The prudential liquidity reserve, dictated by a cash flow standard deviation of EUR 100,000, directly diminishes the firm's valuation by EUR 728,110. If the executive team circumvents this capital constraint – by, for instance, leveraging a bank credit facility to access liquidity as needed – this strategy remains financially advantageous, provided that the total cost of maintaining and utilising the credit line does not surpass EUR 728,110.

This example points out that firms implementing sustainability-oriented risk mitigation strategies against climate instability can liberate capital otherwise immobilised in precautionary reserves, thereby enhancing enterprise valuation. However, this approach represents just one of several viable financial optimisation methods. Toeglhofer et al. (2012) introduced Climate-VaR as a quantitative framework for policymakers, enabling them to determine an optimal threshold of climate-related financial exposure (Kupczyk, 2008). This model facilitates a data-driven assessment of climate risk, balancing financial stability with sustainable corporate treasury management. Toeglhofer et al. (2012) presented a streamlined methodology for quantifying climate instability risk, integrating both risk exposure and business sensitivity within a firm's full operating cycle (Kupczyk, 2006). Their approach incorporates economic and financial indicators, enabling a comprehensive evaluation of a company's vulnerability to climatic fluctuations and facilitating strategic treasury adjustments in response to environmental volatility (Toeglhofer et al. 2012). Energy corporations employ climate-linked derivatives indexed to Heating Degree Days (*HDD*) and Cooling Degree Days (*CDD*) as hedging instruments to mitigate financial losses stemming from anomalous climatic patterns. These structured financial instruments enable firms to stabilise revenue streams by offsetting weather-induced demand fluctuations in energy consumption (Kupczyk, 2008). Furthermore, econometric investigations could empirically assess whether agricultural enterprises leveraging climate options exhibit reduced income volatility. Such hypotheses can be rigorously tested through Vector Autoregression (VAR) models applied to farm-level financial data, offering quantitative validation of the risk-mitigating efficacy of climate derivatives in the agribusiness sector (Kupczyk, 2006).

5. Mitigation of Climate-Induced Financial Volatility – Strategic Deployment of Weather-Linked Derivatives in Corporate Treasury Optimisation

In their study, Caporin & Pres (2012) examined climate-induced financial volatility from a managerial risk-assessment perspective and conceptualised quantitative modelling frameworks as strategic instruments for financial governance. These models, in the author's assessment, offer substantial applicability within Corporate Treasury Management, particularly in the valuation of climate-contingent financial derivatives (Kupczyk, 2006). Caporin & Pres (2012) demonstrated the methodological integration of quantitative models into Corporate Treasury Management, emphasising their empirical calibration using real-world financial data. They further illustrated statistical benchmarking techniques, enabling a comparative evaluation of model efficacy through density forecast analysis (Caporin & Pres, 2012). In another study, Development of Climate-Linked Financial Instruments in Corporate Treasury Management (Kupczyk, 2006), climate derivatives, alongside climate bonds, structured hybrid instruments integrating fixed-income securities with weather-contingent financial contracts, serve as pivotal mechanisms for mitigating climate-induced financial volatility (cf. Michalski & Kupczyk, 2007). Janczura (2014) formulated analytical expressions for electricity derivatives contingent on climate-induced financial volatility, incorporating the theoretical construct of risk premia. In (Kupczyk, 2008), the findings reveal a dynamic, time-sensitive structure of risk compensation, with empirical validation indicating the presence of a negative risk premium among full-cycle energy corporations (cf. Janczura, 2014). A climate derivative is an instrument whose value depends on a climate index. A climate-linked derivative constitutes a financial instrument whose valuation fluctuates in response to variations in a predefined climate index (Kupczyk, 2008). These climatic indices – fundamental reference metrics for structuring weather-contingent financial contracts – derive from empirically recorded climatic variables, quantifying meteorological fluctuations through standardised parameterisation (Girgibo et al., 2024). Muller et al. (2015) incorporated climate-induced financial volatility, specifically temperature fluctuations, as an additional exogenous determinant within their analytical framework. Integrating climate-induced financial volatility, represented by temperature fluctuations (Kupczyk 2008), into the modelling framework enhances the empirical robustness of swing option valuation and optimises the assessment of storage economics, yielding more precise and realistic financial projections (Muller et al., 2015). Erhardt (2015) analysed long-term trends in the forecasted annual count of Heating Degree Days (HDD) and Cooling Degree Days (*CDD*), leveraging projections derived from a regional climatic simulation framework. The study employed both an empirical, data-driven estimation technique and an alternative methodology grounded in spatial econometric modelling, thereby enhancing the precision of climate risk assessment (Erhardt, 2015). Pres (2009) conducted a comprehensive assess-ment of existing methodologies for identifying and quantifying the financial implications of non-catastrophic climatic variability on commercial enterprises. Through empirical validation of prevailing modelling techniques, the study introduced an enhanced econometric framework for assessing cli-mate-induced financial volatility, offering a more precise approach to measuring climate instability risk (Pres, 2009). Stojanovic & Goncu (2014) developed pricing models for individual instruments within a portfolio of temperature-linked climate derivatives, alongside corresponding risk-hedging strategies. Their analysis employed the contemporary general framework of neutral and indifferent pricing, specifically tailored for incomplete financial markets. Furthermore, they formulated a structural representation of the climate-related risk premium, refining its theoretical underpinnings within the context of weather-contingent financial instruments (Stojanovic & Goncu, 2014).

Kupczyk (2008) identified the Heating Degree Day (*HDD*) index as the predominant climate-based financial metric, designed to quantify negative thermal deviations from a standardised baseline temperature of 65°F (18.3°C) over a specified temporal horizon. Alternative threshold values may be employed in place of the conventional 65°F benchmark, contingent on regional climatic conditions and sector-specific applications. The *HDD* index valuation after *n* trading sessions adheres to the following mathematical formula (Kupczyk & Michalski, 2008):

$$HDD_n = \sum_{i=1}^{n} HDD_i \tag{5}$$

where the mean daily air temperature (T_i) is computed as the arithmetic average of the recorded minimum and maximum temperatures within a given 24-hour period (Kupczyk, 2008). A less frequently utilised metric is the Cooling Degree Day (*CDD*) index, which quantifies positive deviations of the average daily temperature from the 65°F (18.3°C) baseline over a specified timeframe. The *HDD* and *CDD* indices emerged as essential tools in climate risk assessment and financial hedging strategies, initially devised by US energy sector firms to mitigate the financial volatility associated with temperature fluctuations (Kupczyk & Michalski, 2008). These indices reflect the correlation between temperature deviations and energy consumption patterns – a temperature drop below 65°F significantly escalates heating demand, whereas a rise above this threshold amplifies air conditioning usage (Kupczyk 2008). Accordingly, the *HDD* index applies primarily to winter months, where colder conditions yield higher index values, while the *CDD* index is relevant to the summer season, where increased temperatures elevate its numerical magnitude. Beyond *HDD* and *CDD*, additional climate-based indices are employed for specialised applications (refer to Table 2).

Table 2 presents a systematic classification of climate-related financial indices employed in corporate treasury management, along with their sector-specific applications across various economic domains. The key insights from Table 2 are diversity of the climate indices, beyond the conventional *HDD* (Heating Degree Days) and *CDD* (Cooling Degree Days) benchmarks, the table incorporates specialised indicators such as *GDD* (Growing Degree Days), essential for agricultural productivity assessments, and *WPI* (Wind Power Index), instrumental in optimising wind energy operations. Climatic Parameters, while the majority of indices rely on ambient temperature metrics, select some indicators including *CPD* (Critical Precipitation Day), integrate precipitation variables such as rainfall and snowfall, broadening the scope of climate-related financial analysis. Industrial and Commercial Applications – climate indices – serve as quantitative risk management tools within multiple industries, encompassing energy production, agribusiness, beverage manufacturing, construction, and transportation. Their implementation underlines the necessity of climate-informed financial strategies across diverse sectors. By offering a structured overview of climate indices pertinent to corporate treasury management, Table 2 enables firms to refine predictive financial models and enhance climate risk hedging mechanisms, thereby fostering resilience against climate-induced economic uncertainties.

Table 2. Comprehensive taxonomy of climate-based financial indices and their strategic utilisation in corporate risk mitigation frameworks

<table>
<tr><th colspan="2">Meteorological Benchmark for Quantitative Risk Assessment</th><th colspan="2">Atmospheric Variable for Deriving Meteorological Risk Metrics</th><th>Strategic Utilisation of Meteorological Indices Across Corporate Sectors</th></tr>
<tr><td colspan="2">HDD (heating degree day)</td><td colspan="2">Atmospheric Thermal Gradient</td><td rowspan="3">Power Industry and Extractive Resources Sector</td></tr>
<tr><td colspan="2">CDD (cooling degree day)</td><td colspan="2">Atmospheric Thermal Gradient</td></tr>
<tr><td colspan="2">EDD (energy degree day)</td><td colspan="2">Atmospheric Thermal Gradient</td></tr>
<tr><td colspan="2">CAT (cumulative average temperature)</td><td colspan="2">Atmospheric Thermal Gradient</td><td rowspan="2">Extensive Scope, Encompassing Sectors from Leisure Industries to Beverage Manufacturing and Supply Chains</td></tr>
<tr><td colspan="2">AT (average temperature)</td><td colspan="2">Atmospheric Thermal Gradient</td></tr>
<tr><td colspan="2">GDD (growing degree day)</td><td colspan="2">Atmospheric Thermal Gradient</td><td rowspan="3">Agroeconomic Sector</td></tr>
<tr><td colspan="2">CDH (chilling degree hour)</td><td colspan="2">Atmospheric Thermal Gradient</td></tr>
<tr><td colspan="2">FD (frost day)</td><td colspan="2">Atmospheric Thermal Gradient</td></tr>
<tr><td rowspan="2">CD (critical day)</td><td>CTD (critical temperature day)</td><td rowspan="2">Any</td><td>Atmospheric Thermal Gradient</td><td rowspan="2">Broad Applicability Across Agroeconomics, Infrastructure Development, Logistics, and Leisure Industries</td></tr>
<tr><td>CPD (critical precipitation day)</td><td>Precipitation (rain, snow)</td></tr>
<tr><td colspan="2">WPI (wind power index)</td><td colspan="2">Wind (speed)</td><td>Aeolian Energy Facilities</td></tr>
</table>

Source: (Kupczyk, 2008; Kupczyk & Michalski, 2008).

Table 2 highlights the diverse climate indices essential for corporate treasury management, illustrating their role in financial risk mitigation across industries. These indices, ranging from temperature-based measures like *HDD* and *CDD* to precipitation-sensitive metrics such as *CPD*, enable firms to quantify climate variability's financial impact. Their application spans energy, agriculture, construction, and transportation, stressing their strategic relevance. By integrating these indices into financial modelling, companies can enhance forecasting accuracy and optimise risk-hedging strategies. A structured approach to climate risk management strengthens corporate resilience, ensuring adaptability in the face of increasing climate-related economic volatility.

Yuan et al. (2015) stated that financial instruments linked to climatic variables, employed within Corporate Treasury Management, diverge fundamentally from traditional derivatives due to their reliance on meteorological indices as underlying reference metrics (Kupczyk, 2008). Elias et al. (2014) constructed four distinct modeling frameworks to evaluate regime-switching methodologies in capturing the stochastic dynamics of temperature fluctuations, facilitating the valuation of temperature-linked climate derivatives (Elias et al., 2014). Mraoua et al. (2013) conducted an empirical investigation into the interdependencies between climatic variables and stock market performance, analysing both return fluctuations and volatility dynamics. Utilising climate-sensitive sectoral indices over a complete business cycle, they assess the macroeconomic ramifications of climate variability and its implications for strategic Treasury Management. Apart from temperature, their study incorporated two additional climatic parameters, both widely employed as underlying benchmarks for climate-linked financial instruments. Their findings substantiate the efficacy of climate derivatives as robust hedging mechanisms against climate-induced financial volatility (Mraoua et al., 2013). Yuan et al. (2015) used temperature datasets from New York, Atlanta, and Chicago to derive quantitative estimators that measure the sensitivity of temperature-linked climate derivatives. These estimators provide investors with a decision-making framework for selecting the most optimal climate-based financial contracts (Yuan et al., 2015).

Since the climate index remains a non-tradable metric and thus lacks a market-driven valuation, its numerical value is predetermined within the contractual framework. Given that the unit valuation of the climate index is fixed at 0 > a, the payoff function for a long climate position in a put option is expressed as follows (Kupczyk, 2008):

$$h_K(x) = \begin{cases} \alpha(K - x) & \text{for } x \leq K \\ 0 & \text{for } x > K \end{cases}, \tag{6}$$

where K – strike price, representing the predetermined threshold at which the climate option activates.

A climate option serves as a financial instrument enabling the transfer of adverse financial repercussions stemming from climate instability, while concurrently allowing the hedging entity to retain potential upside gains from favourable climatic deviations (Kupczyk & Michalski, 2008. The hedger remits a premium—constituting the option's market price—to offload downside risk exposure (Girgibo et al., 2024). A put option safeguards against depreciation in the value of a climate index, offering a structured risk mitigation mechanism. Erhardt empirically proved that temperature-linked climate derivatives provide full-cycle enterprises with effective hedging solutions against climate-induced financial volatility (Erhardt, 2015). For the hedging entity, a decline in the index's valuation correlates with economic losses, necessitating a long position in a put option to counterbalance the adverse financial impact. The gains obtained from this position serve to offset operational losses arising from climate-induced economic fluctuations. Alternative climate derivatives operate under analogous principles, facilitating structured financial protection against climate risk exposure (Kupczyk, 2008).

Climate-linked financial instruments predominantly correspond to a singular cash flow event, rendering them, in most instances, non-multi-period contracts (Kupczyk & Michalski, 2008). Given their design, climate options typically conform to the European-style framework, meaning that contract holders can execute the option exclusively upon its expiration date, rather than at any prior point within the contract's lifespan (Kupczyk, 2006). Econometric assessments confirm that climate-induced volatility profoundly influences corporate treasury governance and operational efficacy. This study employed quantitative models to measure its impact on financial liquidity, asset allocation, and hedging precision.

The findings indicate that integrating sustainability-oriented treasury policies that incorporate climate-induced financial volatility enhances asset efficiency and mitigates liquidity uncertainty.

From a quantitative finance perspective, the absence of structured climate risk assessment correlates with heightened net working capital volatility and escalated hedging expenditures. Forecasting models confirm that firms adopting climate risk mitigation frameworks exhibit superior resilience, reinforcing long-term enterprise valuation.

This study substantiates the efficacy of econometric methodologies in climate risk modelling, demonstrating that embedding risk assessment within treasury operations not only dampens climate-induced disruptions but also fortifies competitive positioning and fiscal stability.

Given the econometric paradigm employed, future research should emphasise dynamic stochastic modelling, incorporating GARCH and VAR techniques to quantify the transmission of climate fluctuations into corporate cash flow volatility across industries. Additionally, machine learning algorithms can enhance predictive precision regarding climate-driven financial decision-making.

Advancing hybrid econometric-artificial intelligence models to optimise treasury policies under climate uncertainty remains a strategic priority. Further investigations should evaluate the effectiveness of financial hedging mechanisms, leveraging panel-data econometric frameworks to assess corporate fiscal stability amid climate risk.

Moreover, the macroeconomic repercussions of climate regulation on corporate financial strategy necessitate econometric scenario modelling via DSGE frameworks. Structural modelling and Bayesian inference can refine treasury optimisation strategies, particularly in analysing the impact of liquidity and working capital management under projected climate changes.

Econometric findings inform key recommendations for Corporate Treasury Management (CTM) policymakers, emphasising regulatory frameworks for climate risk disclosure, fiscal incentives for firms adopting hedging mechanisms, and tax exemptions for entities utilising climate derivatives or investing in climate-resilient technologies. Additionally, fostering public markets for climate derivatives and implementing government-backed financial support structures would enhance the liquidity of climate risk mitigation instruments.

The study underlines the pivotal role of econometrics in modelling climate-induced financial volatility and its systemic implications for CTM. Empirical evidence confirms that firms employing proactive risk management strategies achieve superior financial resilience. Future research should prioritise the development of dynamic econometric forecasting models, further refining risk mitigation frameworks for enhanced treasury optimisation.

6. Conclusions

The findings derived from the analysis presented in the article unequivocally demonstrate that assessing and mitigating climatic volatility risk within the framework of sustainable Corporate Treasury Management (CTM) not only is in line with optimising the corporate treasury function, but also serves as a vital catalyst for enhancing organizational growth and financial stability. Corporations that integrate risk measurement and management strategies for climatic instability effectively diminish the unpredictability of financial flows, reduce the expenses tied to sustaining elevated levels of inventory and cash reserves, and bolster their market competitiveness.

The article demonstrates that the application of financial instruments such as climate derivatives, can proficiently alleviate the adverse effects of extreme climatic events. Additionally, it points out that firms neglecting climate-related risks face heightened operational expenses and a potential decline in market valuation.

These conclusions further stress the necessity of adopting environmentally-conscious strategies, along with the imperative for macroeconomic and cultural frameworks that would compel organizations to integrate pro-environmental solutions within Corporate Treasury Management (CTM).

In the future it will be crucial to concentrate on several key research avenues, for which this article provides a solid basis. Expanding the study to encompass various sectors of the economy would be valuable, with particular emphasis on assessing the influence of climatic risks on Corporate Treasury Management (CTM) within industries acutely vulnerable to changing environmental conditions, such as agriculture, energy, transportation, and construction. Additionally, the development of climate instability risk hedging instruments should be explored, alongside an analysis of the efficiency and optimisation of utilising climate derivatives and other hedging strategies across different CTM business models. A further area of research should involve examining the macroeconomic implications of adopting sustainable treasury management strategies, with a focus on the effects of regulatory frameworks and public policies on the integration of climate risk measurement and management practices. Furthermore, the influence of technological advancements on managing climate instability risks warrants attention, particularly through the evaluation of artificial intelligence, data analytics, and predictive modelling in forecasting and mitigating the impacts of climatic volatility.

Based on the research findings, policymakers could consider recommending tax incentives for companies adopting strategies to measure and manage climate instability risks, such as offering tax credits for those implementing climate derivatives or other protective mechanisms. There is potential for policymakers to establish regulations that encourage businesses to at least self-reporting their exposure to climate risks internally, similar to the way ESG reporting fosters transparency and prompts companies to incorporate climate instability risk into their CTM frameworks. Policymakers should also prioritise promoting public-private partnerships aimed at developing climate derivatives markets, with the goal of fostering financial mechanisms to mitigate the effects of climate volatility, particularly in sectors vital to the economy. Furthermore, policymakers can leverage the findings of this article to align climate risk management strategies with national climate policies by incorporating the measurement and management of climate instability risks into broader climate change adaptation plans and establishing funds to assist companies in implementing these solutions. The adoption of such measures would enhance the resilience of businesses against extreme climatic events, ultimately contributing to long-term financial stability and improving the competitiveness of the economy in which these measures are successfully introduced.

Implementing a policy of sustainable Treasury Management alongside ecological sustainability will enable market participants to achieve superior economic outcomes in the future. This article addresses only a subset of related issues, and highlights that a consistently applied strategy of sustainable business practices and environmentally conscious development will mitigate the risks posed by climate impacts on the company. This, in turn, will reduce investments in prudential assets, such as inventories and precautionary cash reserves. The diminished climate instability risk will further decrease the need for hedging through the acquisition of climate-related financial instruments, as well as lower overall risk management expenditures, as discussed in Section 5. However, it is challenging to envision individual companies proactively adopting sustainability practices (with a few notable exceptions). Therefore, macroeconomic policies, governmental regulations, and/or cultural shifts that affect all market participants are necessary to incentivise businesses toward such actions. Using climate instability risk as a case study, the author demonstrated that conducting sustainable business not only corresponds with the primary economic objectives but also, by reducing the impact of climate instability, actively contributes to achieving those goals. This article outlines the interplay between executing sustainable business, environmental sustainability policies, climate instability risk, and the associated depreciation in company value. If companies currently operating adopt sustainable Corporate Treasury Management (CTM) practices, along with sustainable development policies, future organizations will benefit from a more robust performance in maximising the business owners' treasury.

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Ograniczenie ryzyka pogodowego kluczem do wyników biznesowych – ramy zrównoważonego zarządzania finansami przedsiębiorstw (CTM)

Streszczenie

Cel: Celem niniejszego artykułu jest analiza wpływu ryzyka pogodowego na korporacyjne zarządzanie finansami (CTM) i pokazanie, w jaki sposób zrównoważone strategie zarządzania mogą zmniejszyć to ryzyko, jednocześnie poprawiając wyniki finansowe przedsiębiorstw.

Metodyka: W artykule zastosowano podejście ekonometryczne i analizę teoretyczną. Wykorzystano przegląd literatury na temat ryzyka pogodowego i jego wpływu na działalność przedsiębiorstw, analizę instrumentów finansowych wykorzystywanych do zarządzania tym ryzykiem (np. pogodowych instrumentów pochodnych) oraz modele ekonometryczne w celu zbadania związku między zmiennością pogody a kluczowymi wskaźnikami finansowymi przedsiębiorstw.

Wyniki: Przeprowadzone badania wskazują, że wdrożenie strategii uwzględniających ryzyko pogodowe przyczynia się do poprawy płynności finansowej przedsiębiorstw i zmniejszenia niepewności przepływów pieniężnych. Brak strategii zarządzania tym ryzykiem prowadzi do wzrostu kosztów zabezpieczeń gotówkowych i większej zmienności kapitału obrotowego netto. Firmy posiadające odpowiednie strategie hedgingowe są bardziej skuteczne w minimalizowaniu negatywnego wpływu zmiennej pogody na ich działalność.

Implikacje i rekomendacje: Artykuł sugeruje potrzebę włączenia zarządzania ryzykiem pogodowym do strategii skarbowych firm, a także wprowadzenia regulacji makroekonomicznych i zachęt podatkowych dla firm wdrażających takie strategie. Wskazuje również na potrzebę dalszych badań nad optymalizacją zarządzania ryzykiem pogodowym i zastosowania modeli uczenia maszynowego do przewidywania jego wpływu na finanse przedsiębiorstw.

Oryginalność/wartość: Artykuł wnosi wkład do literatury na temat zarządzania finansami przedsiębiorstw poprzez zastosowanie podejścia ekonometrycznego do analizy wpływu ryzyka pogodowego. Zawiera praktyczne zalecenia dla menedżerów skarbu i decydentów politycznych dotyczące włączenia zarządzania ryzykiem pogodowym do długoterminowej strategii finansowej przedsiębiorstw.

Słowa kluczowe: ryzyko pogodowe, zrównoważone zarządzanie finansami, wyniki finansowe przedsiębiorstw