The Impact of Extreme Climate Events on Financial Performance: Evidence from Manufacturing Firms in Europe

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Dissertation written under the supervision of Jose David Garcia Revelo and Claudia Imperatore

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Title: The Impact of Extreme Climate Events on Financial Performance: Evidence from Manufacturing Firms in Europe

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Keywords: Climate Change, Extreme weather events, Risk management, financial performances, Private European manufacturing company, ROA, ROE, Cashflow, Gearing, EBIT, EBITDA, regression analysis.

Abstract:

Climate change is one of the most significant challenges of our time, with profound implications for global economies, societies, and ecosystems worldwide. The scientific community is clear: human activities, particularly the burning of fossil fuels, deforestation, and industrial processes, have drastically increased greenhouse gas (GHG) emissions, driving global temperatures higher and altering climate patterns. The Intergovernmental Panel on Climate Change (IPCC) warns that without urgent and coordinated action, that global warming is expected to surpass 1.5°C over pre-industrial levels by 2030, resulting in disastrous consequences for natural and human systems. The impacts of climate change are already evident worldwide, materializing as increasingly frequent and severe extreme weather phenomena such as heatwaves, floods, and storms. The impacts of climate change are already being felt, manifesting in more frequent and intense extreme weather events such as heatwaves, floods, and storms. These events pose substantial risks to various industries, particularly the manufacturing sector in Europe, which faces vulnerabilities in supply chains, energy availability, and production stability.

This paper examines the impact of extreme climate events on the financial performance of private manufacturing firms in Europe. Using a regression model, it analyzes how different climate variables have affected the financial health and performance of European companies over the past decade (2013–2023), offering insights into the challenges posed by climate-related disruptions.

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Abstract Portuguese:

A mudança climática é um dos desafios mais significativos do nosso tempo, com implicações profundas para as economias globais, sociedades e ecossistemas em todo o mundo. A comunidade científica é clara: as atividades humanas, particularmente a queima de combustíveis fósseis, o desmatamento e os processos industriais, aumentaram drasticamente as emissões de gases de efeito estufa (GEE), elevando as temperaturas globais e alterando os padrões climáticos. O Painel Intergovernamental sobre Mudanças Climáticas (IPCC) alerta que, sem uma ação urgente e coordenada, o aquecimento global deve ultrapassar 1,5°C em relação aos níveis pré-industriais até 2030, resultando em consequências desastrosas para os sistemas naturais e humanos. Os impactos da mudança climática já são evidentes em todo o mundo, manifestando-se em fenômenos climáticos extremos cada vez mais frequentes e severos, como ondas de calor, inundações e tempestades. Esses eventos representam riscos substanciais para várias indústrias, particularmente o setor de manufatura na Europa, que enfrenta vulnerabilidades nas cadeias de suprimento, disponibilidade de energia e estabilidade de produção.

Este artigo examina o impacto de eventos climáticos extremos no desempenho financeiro de empresas privadas de manufatura na Europa. Usando um modelo de regressão, analisa como diferentes variáveis climáticas afetaram a saúde financeira e o desempenho de empresas europeias na última década (2013–2023), oferecendo insights sobre os desafios impostos por interrupções relacionadas ao clima.

Table of Contents

INTRODUCTION

Climate change is one of the most urgent worldwide issues of the 21st century, with economic, social, and ecological implications. The scientific community is unequivocal: human activities, particularly the burning of fossil fuels and deforestation, have led to an unprecedented increase in greenhouse gas (GHG) concentrations, intensifying global temperatures and modifying climate patterns. As highlighted and emphasized by the Intergovernmental Panel on Climate Change report of 2023 (IPCC Climate Change 2023 Report), if prompt and comprehensive measures are not taken, global warming is expected to surpass 1.5°C above pre-industrial levels in the next ten years, leading to disastrous consequences for both natural and human systems.

The implications of climate change are particularly pressing for the manufacturing industry in Europe, which represents the backbone of the region's economy. The sector is highly dependent on reliable supply networks, uninterrupted energy provision, and foreseeable climatic circumstances, all of which are put under pressure by climate-related occurrences such as floods, heatwaves, and intense storms. The increase in natural disasters in recent years has strained the strategies and financial health under discussion. Indeed, the European industrial sector, renowned for its significant energy usage and vast infrastructure, is now confronted with a dual task: mitigating the physical hazards brought about by climate change and managing the legal and market changes linked to the global shift towards a low-carbon economy.

The significance of these concerns is underscored by recent reports. The yearly Global Risks Report 2024 by the World Economic Forum highlighted that climate change and climate action failure are seen globally as the most critical risks projected for the next ten years. This underscores the pressing necessity for companies to include climate risk in their strategic decision-making processes. For the manufacturing sector, this integration is not only a precautionary measure but also a crucial determinant in guaranteeing sustained financial stability and competitiveness.

Although the threat of climate change to the manufacturing sector is evident and increasing, the precise financial consequences of this phenomenon on the operational and financial health have not been thoroughly investigated, especially within the European setting. Although there has been significant study on the environmental and operational dimensions of climate change, there is a distinctive absence in the literature about its impact on the financial performance of corporations.

Current research frequently concentrates on the wider economic consequences at the national or regional scale, neglecting the specific ways in which climate-related events directly affect the financial health of particular companies in the manufacturing industrial sector. Understanding the financial consequences of climate change for the manufacturing industry is essential for several reasons. First, as climate risks become more pronounced, they are likely to lead to increased volatility in revenue streams, higher operational costs, and greater uncertainty in supply chains. Second, the transition to a low-carbon economy will require significant investment in new technologies, processes, and infrastructure, posing both risks and opportunities for manufacturers.

This thesis seeks to address these gaps by analyzing the impact of climate change-related events on the financial performance of the manufacturing industry in Europe. Specifically, it will examine how extreme weather events' frequency affects key financial indicators such as profitability, cash flow, and leverage.

1. Chapter 1: Climate Change literature review

1.1 Understanding Climate Change: Its Causes, Consequences, and Future Scenarios

"The planet is changing faster than we have expected. We are, despite years of raising the alarm, now seeing that the planet is actually in a situation where we underestimated risks."

This remarkable statement from a leading climate scientist Johan Rockström at TED Countdown Bloomberg Green Festival July 2024, underscores the pressing need to tackle the climate change. Before diving into the core investigation of this research, it is essential to comprehend the complex relationship of elements that have contributed to the present condition of the Earth, the risks associated with future warming, and the possible scenarios that may occur.

Defining Climate Change

Climate change refers to significant and lasting changes in the Earth's climate system, manifested primarily through alterations in temperature, precipitation, and weather patterns. Unlike the natural climate variability that has occurred over millions of years the changes we observe today are largely driven by human activities. The consensus among scientists is unequivocal: the primary driver of recent climate change is the increase in greenhouse gases (GHGs) in the atmosphere due to human activities as burning fossil fuels, deforestation, and growth of industrial processes.

To fully grasp the significance of current changes, it is important to contextualize them within the Earth's long climate history. Over the past 60 million years, the Earth has experienced significant climatic shifts, however all influenced by natural factors as: like volcanic eruptions, solar variations, and changes in the Earth's orbit.

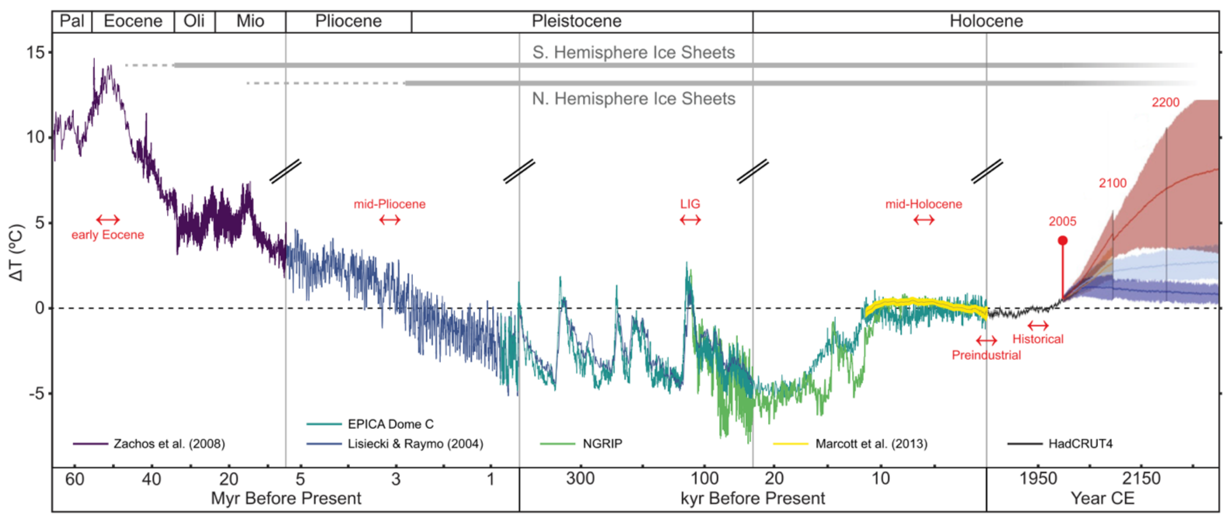


Figure 1 : Pliocene and Eocene provide best analogs for near- future climates Edited by Noah S. Diffenbaugh, Stanford University, Stanford, CA, and accepted by Editorial Board Member Robert E. Dickinson November 6, 2018 (received for review June 29, 2018)

Figure 1 illustrates the temperature variations throughout the period, illustrating the early Eocene, a time when the Earth temperature was much higher than it is today. During this period, elevated levels of CO2, mainly emitted by volcanic activity, led to temperatures 5 to 15 time warmer than the Holocene. Once again, the pace of change was far slower than what we are observing today. In addition to the Eocene Figure 1 illustrate in depth the entire historical evolution of the temperature of our planet until today.

As visible the, the current warming is unprecedented in its speed and scale. Since the late 19th century, human activities have dramatically altered the composition of the atmosphere and it equilibrium. The concentration of CO2, the most significant and impacting greenhouse gas, has increased from approximately 280 parts per million (ppm) before the Industrial Revolution to over

415 ppm today a level not seen for millions of years. In addition to CO_2 also Methane (CH_4) and nitrous oxide (N_2O), present in smaller quantities, possess significantly greater strength. Methane, for example, is about 28-34 times more effective at retaining heat than CO_2 . The enormous introduction of GHGs in the atmosphere has enhanced the natural greenhouse effect, leading to a rise in global temperatures.

This increase in global temperatures, currently at 1.2°C above pre-industrial levels, is already having profound impacts. The warming has not been uniform, some regions, as the Arctic, have warmed at more than twice the global average. This phenomena, referred to as Arctic amplification, is resulting in fast ice melting, which in turn is causing a reduction in reflective ice surfaces and intensifying warming in a positive feedback loop. The impacts of temperature rise are having an impact at 360° on our planet, affecting everything from sea levels to weather patterns and biodiversity.

After this excursus on the temperature history of our home, is important to distinguish between weather and climate. While weather refers to short-term atmospheric conditions and changes, climate represents long terms patterns over decades or even centuries. This distinction is crucial because climate change is not about individual weather events but rather about the long-term picture of our planet and its change in averages and extremes. For instance, the increasing frequency and intensity of heatwaves, hurricanes, and heavy rainfall events are clearly correlated to a changing in climate averages and extremes. These events are becoming more common every years as the climate system absorbs more energy due to increased GHG concentrations. How will the planet look in 50 years?

The Historical Causes of Climate Change

Before analyzing the current situation, it is interesting to take note of how we arrived at this point. The origins of modern climate change causes can be traced back to the Industrial Revolution, around 18th century, a period marked by the beginning of the transition from agrarian economies to industrialized ones. Increasing production capacity and energy consumption burning: coal, oil, and natural gas to power machinery, transportation, and industry. This fossil fuels served as the foundation and booster of economic progress, driving remarkable expansion in wealth, infrastructure, and technology. However, the massive combustion of these fuels also marked the beginning of a dramatic increase in GHG emissions.

Since the 18th century, the global economy has steadily grown. Following World War II, however, a period known as the "Great Acceleration" triggered rapid industrialization, urban expansion, and population booms. This surge in human activity came with a sharp rise in greenhouse gas emissions, driving significant environmental consequences. The increased demand for energy and mass production during this time played a pivotal role in accelerating climate change, leaving us to confront its long-term impacts today.

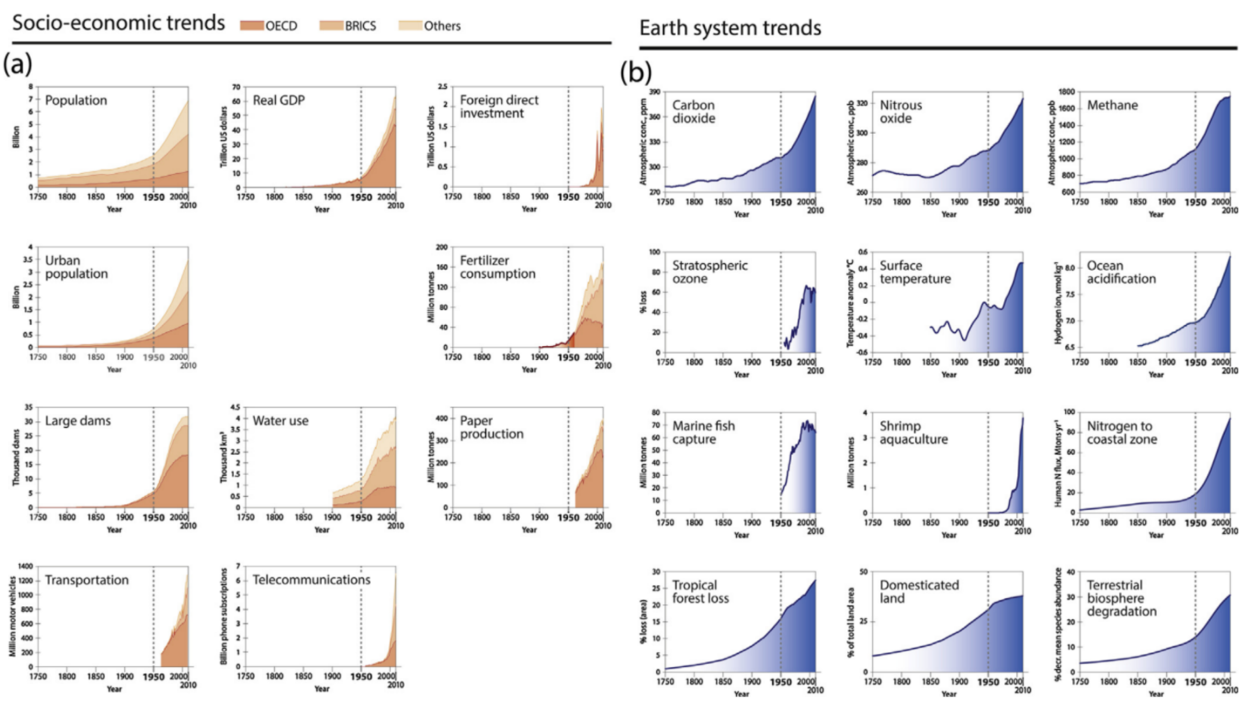


Figure 2 : Bai, X., van der Leeuw, S., O'Brien, K., Berkhout, F., et al. (2016). Plausible and desirable futures in the Anthropocene: A new research agenda. Global Environmental Change, 39, 351–362. Earth system and socio-economic trends.

Figure 2 illustrates these socio-economic trends and Earth system trends, clearly showing the rapid rise in industrial activities and the corresponding environmental degradation. This era is characterized by a dramatic increase in CO_2 emissions, driven by the global demand for energy, transportation, and manufacturing.

The consequences of these activities are now painfully evident. The rise in global temperatures has already led to significant environmental changes including melting polar ice caps, warming oceans, and altering precipitation patterns as previously stated .

Polar ice caps are melting at alarming rates, raising sea levels. Since 1992, Greenland alone has lost about 3.8 trillion tons of ice, increasing global sea levels by over 10 millimeters. If the entire ice sheet melts, sea levels could rise by 7 meters, flooding coastal cities and displacing millions of people (Bai, X., van der Leeuw, S., O'Brien, K., Berkhout, F., et al. (2016). Plausible and desirable futures in the Anthropocene: A new research agenda. *Global Environmental Change, 39*, 351–362).

Warming oceans, which absorb 90% of the excess heat from human activity, are another major issue. This causes coral bleaching, disrupts marine ecosystems, and fuels stronger hurricanes and typhoons, as warmer waters give these storms more energy.

Climate change is also shifting precipitation patterns. Some areas experience heavier rains and flooding, while others face prolonged droughts. These changes are already harming agriculture, water supplies, and ecosystems. Droughts in places like the American West and parts of Africa are leading to crop failures and water shortages, while regions with more rainfall suffer from floods, landslides, and soil erosion, threatening food security and infrastructure.

Biodiversity is also at risk, as many species struggle to adapt. Some are migrating to cooler areas, while others face extinction as their habitats vanish. Coral reefs, particularly vulnerable to rising sea temperatures and ocean acidification, are suffering from widespread bleaching, endangering the marine life that depends on them.

The Tipping Points of our Climate System

As global temperatures continue to rise, the risk of crossing critical tipping points in the Earth's climate system becomes increasingly likely. Tipping points are thresholds beyond which small changes can lead to dramatic and often irreversible shifts in the state of the system. These changes can occur rapidly and unpredictably, with profound consequences for the global climate, ecosystems, and human societies. The concept of tipping was developed by the climate scientist Johan Rockström around 2009. The aim of this framework is to represent graphically the "points of no return" after which the Earth's climate could shift into a new and potentially much less hospitable state.

Professor Johan Rockström with other scientific bodies in the renewed paper Planetary Boundaries: Exploring the Safe Operating Space for Humanity of 2009 and the revised version fo 2023 Earth beyond six of nine planetary boundaries**,** have identified several key tipping points that could be crossed if global temperatures continue to rise.

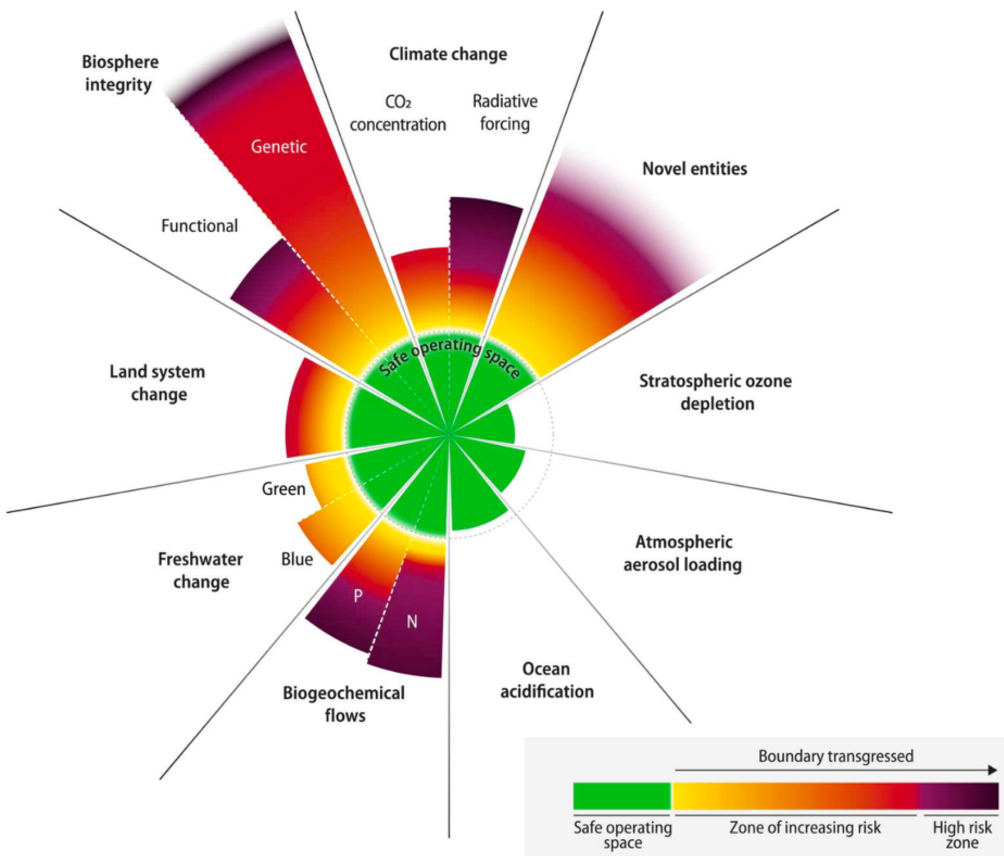


Figure 3: Richardson, K., Steffen, W., Lucht, W., et al. (2023). Earth beyond six of nine planetary boundaries. Science Advances, 9, eadh2458.

The one shown in picture is the current state of the tipping point. This provides an overview of the tipping elements, illustrating their interconnected nature and the potential for cascading effects.

Among the most critical are:

- Greenland and West Antarctic Ice Sheets: The potential collapse of these ice sheets is one of the most alarming tipping points. If the Greenland ice sheet were to melt completely, it could contribute to a global sea level rise of up to 7 meters. Similarly, the West Antarctic ice sheet holds enough ice to raise sea levels by several meters.
- Amazon Rainforest Dieback: The Amazon rainforest is one of the planet's most important carbon sinks, absorbing vast amounts of CO_2 from the atmosphere. However, deforestation, coupled with rising temperatures and changing precipitation patterns, is pushing the Amazon towards a tipping point where it could transition from a rainforest to a savanna. This shift would result in the release of enormous amounts of stored carbon, further accelerating global warming.
- Atlantic Meridional Overturning Circulation (AMOC): The AMOC is a critical component of the Earth's climate system, responsible for transporting warm water from the tropics to the North Atlantic. A disruption in this circulation could lead to significant cooling in Europe, changes in rainfall patterns across the tropics, and more intense storms in the North Atlantic. Recent studies suggest that the AMOC is already weakening, and continued warming could push it past a tipping point.

The crossing of one tipping point could trigger others, leading to a domino effect of climate system changes. For example, the collapse of the Greenland ice sheet could lead to the disruption of the AMOC, which in turn could affect weather patterns across the globe.

The possibility of crossing these tipping points is not just a distant concern; it is a near-term risk. The IPCC's reports 2023 indicate that some tipping points, such as the collapse of the Greenland ice sheet, could be triggered at around 1.5°C to 2°C of warming a threshold we are rapidly approaching. If these tipping points are crossed, the resulting changes could be irreversible, leading to long-term shifts in climate patterns that would be catastrophic for human societies and natural ecosystems alike.

One of the most critical aspects of tipping points is their unpredictability. While scientists can estimate the temperature thresholds at which tipping points might be crossed, the exact timing and sequence of events remain uncertain. This uncertainty complicates efforts to develop effective climate policies, as it is difficult to predict when and where the most severe impacts will occur. However, the consensus is clear: the risk of crossing tipping points increases dramatically as global temperatures rise, underscoring the urgency of reducing GHG emissions.

Possible Future Scenarios of our planet

As it possible to understand form the previous paragrapher, the current situation is dramatic and far from safe. The future of our planet depends on the actions we take today. The IPCC in the IPCC reports or climate scenario studies 2023 outlines several emissions pathways, ranging from stringent mitigation efforts to business-as-usual scenarios. These scenarios, often referred to as Representative Concentration Pathways (RCPs) or Shared Socioeconomic Pathways (SSPs), represent different levels of GHG emissions and their associated impacts on global temperatures.

- RCP2.6/SSP1-1.9: This scenario assumes significant and immediate reductions in GHG emissions, leading to a peak in global temperatures around 1.5°C above pre-industrial levels before gradually declining. Achieving this scenario would require unprecedented global cooperation, rapid transitions to renewable energy, large-scale reforestation, and other mitigation strategies. This pathway represents our best chance of avoiding the most severe impacts of climate change, including the crossing of key tipping points.
- RCP4.5/SSP2-4.5: This scenario represents a more moderate effort to reduce emissions, with global temperatures stabilizing around 2.4°C above pre-industrial levels by the end of the century. While this pathway is less extreme than higher-emission scenarios, it still carries significant risks, including the potential crossing of critical tipping points. The impacts of this scenario would include more frequent and severe heatwaves, changes in precipitation patterns, and continued sea-level rise.
- RCP8.5/SSP5-8.5: This is the "business as usual" scenario, where no significant efforts are made to reduce emissions. In this scenario, global temperatures could rise by over 4°C by 2100, leading to catastrophic impacts on ecosystems, human health, and economies. This pathway would likely result in the crossing of multiple tipping points, leading to a cascade of irreversible changes in the Earth's climate system.

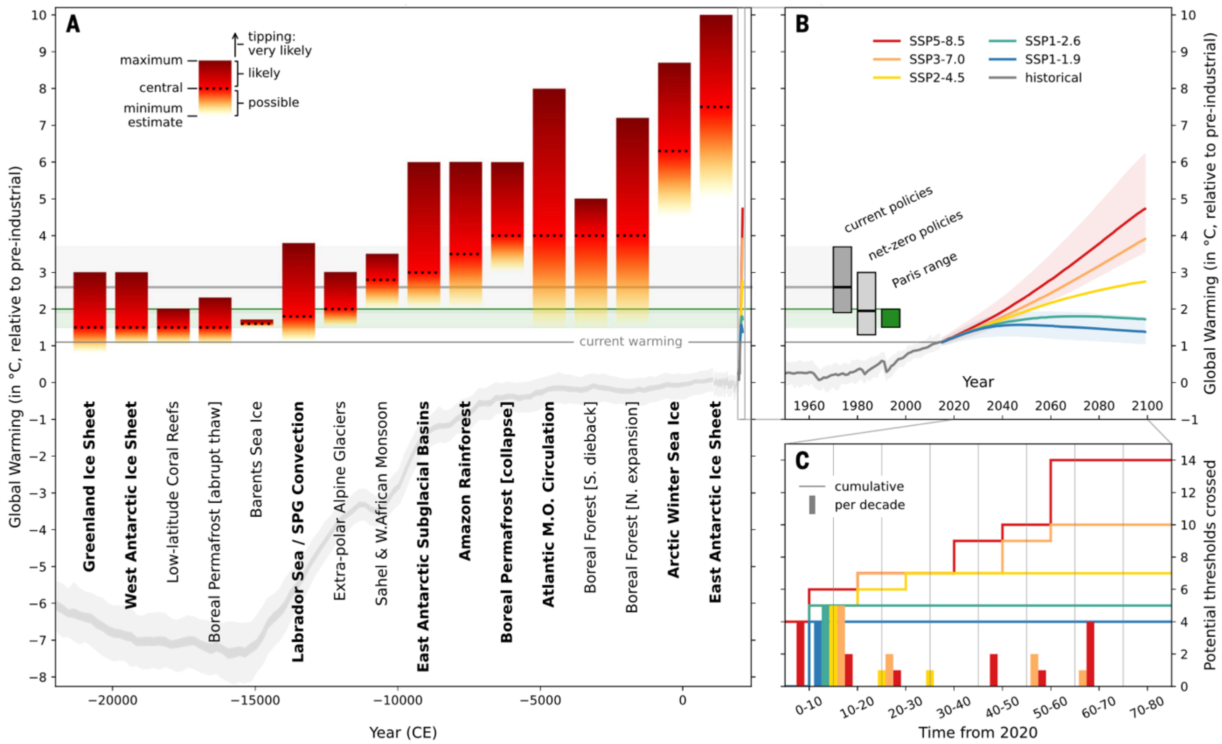


Figure 4 : Armstrong McKay, D. I., Staal, A., Abrams, J. F., Winkelmann, R., Sakschewski, B., Loriani, S., Fetzer, I., Cornell, S. E., Rockström, J., & Lenton, T. M. (2022). Exceeding 1.5°C global warming could trigger multiple climate tipping points. Science, 377(6611), eabn7950.

These scenarios are depicted in Figure 4, which shows the projected temperature increases under different emissions pathways and the associated risks of crossing tipping points. The future of the planet hinges on which path we choose. While the most severe scenarios would lead to increasingly dire consequences, even the more optimistic pathways require significant and sustained efforts to mitigate the impacts of climate change.

The implications of these scenarios are profound. Even under the most optimistic scenario, we are likely to experience some degree of "overshoot," where temperatures temporarily exceed critical thresholds before eventually stabilizing. During this period, we can expect more frequent and intense extreme weather events, rising sea levels, and significant disruptions to ecosystems and human societies. The economic costs of climate change, already substantial, are projected to grow exponentially if current trends continue. For instance, according to a study published in 2023, the global economy could lose up to 18% of GDP by 2050 if we fail to take action (sources: Exceeding

1.5°C global warming could trigger multiple climate tipping points) (sources: The economic commitment of climate change).

Furthermore, the social impacts of climate change are expected to exacerbate existing inequalities. Vulnerable populations, particularly in low-lying coastal areas and developing countries, are at the greatest risk of displacement, food insecurity, and economic loss. Climate change is not just an environmental issue; it is a humanitarian crisis that threatens to undermine decades of development progress (source: Exceeding 1.5°C global warming could trigger multiple climate tipping points) (sources The economic commitment of climate change**)**.

The Importance of Science and Policy in Addressing Climate Change

As we move forward, the role of science in informing policy and societal action cannot be overstated. The IPCC provides a robust scientific foundation for understanding climate risks and guiding mitigation and adaptation strategies. However, the window for action is closing rapidly. To avoid the most catastrophic outcomes, we must halve global emissions by 2030 and achieve net-zero emissions by mid-century. This will require unprecedented transformations in energy, industry, land use, and urban systems, as well as the protection and restoration of natural ecosystems.

The challenge is daunting, but not insurmountable. We have the knowledge, the technology, and the solutions to mitigate climate change and build a sustainable future. However, success will require coordinated global action, political will, and a shift in societal values towards long-term thinking and stewardship of our planet. The concept of societal goals within the context of planetary boundaries is illustrated in

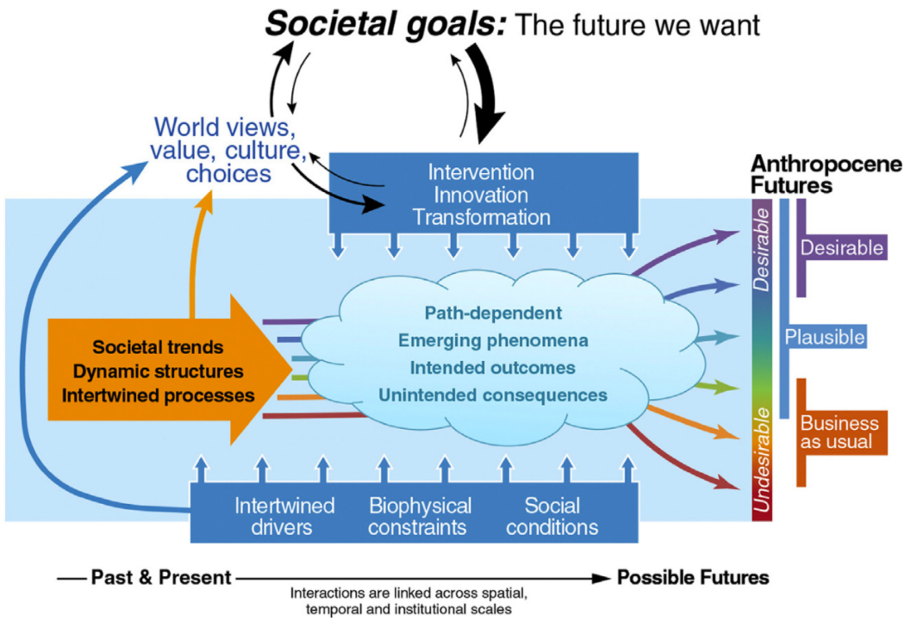


Figure 5 : Bai, X., van der Leeuw, S., O'Brien, K., Berkhout, F., et al. (2016). Plausible and desirable futures in the Anthropocene: A new research agenda. Global Environmental Change, 39, 351–362. A new research Agenda, Conceptualization of the inter-linkages between factors and dynamic processes shaping the Anthropocene futures.

Figure 5, emphasizing the need for immediate intervention, innovation, and transformation to steer away from the most undesirable outcomes.

The pathway forward is clear: immediate and sustained reductions in GHG emissions, combined with efforts to restore and protect natural ecosystems, are essential to prevent the worst impacts of climate change. However, even with the most ambitious mitigation efforts, we are likely to experience some degree of overshoot, where temperatures temporarily exceed critical thresholds before eventually stabilizing. (sources : Plausible and desirable futures in the Anthropocene: A new research agenda 2016) (IPCC's reports 2023)

1.2 Extreme Weather Events Related to Climate Change

Defining Extreme Weather Events

Definition by EM-Data (the international center for disaster) of Disaster:

” A situation or event which overwhelms local capacity, necessitating a request to the national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction, and human suffering”.

As previously state the worsening of climate condition and the deviation from it equilibrium have resulted in the increase of Extreme weather events (EWE). EWE are significant deviations from typical climate conditions, often resulting in severe natural disasters. These include events like floods, droughts, storms, extreme temperatures, and wildfires.

Global overview

Over the past two decades, climate-related disasters have intensified in both frequency and severity, posing unprecedented challenges to ecosystems, communities, and infrastructure worldwide. Despite global efforts to reduce carbon emissions and mitigate climate change, the carbon already accumulated in the atmosphere continues to drive extreme weather events, leading to widespread socio-economic and environmental impacts. Even if net-zero emissions were achieved today, the legacy of past emissions will continue to influence climate systems and exacerbate the severity of these disasters. Between 2000 and 2020, the world experienced over 4,600 documented climate-related disasters, directly affecting more than 3.3 billion people, with substantial loss of life and economic damages. Droughts, riverine floods, and tropical cyclones emerged as the most devastating types of disasters, impacting over 1.4 billion, 1.2 billion, and 501 million people, respectively. The disproportionate impact of these events is evident, as regions such as Central America, the Caribbean, Eastern Africa, Southern and Eastern China, and Southeast Asia have consistently faced the highest concentrations of affected populations, which highlights the global hotspots of these disasters (sources: Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction 2024).

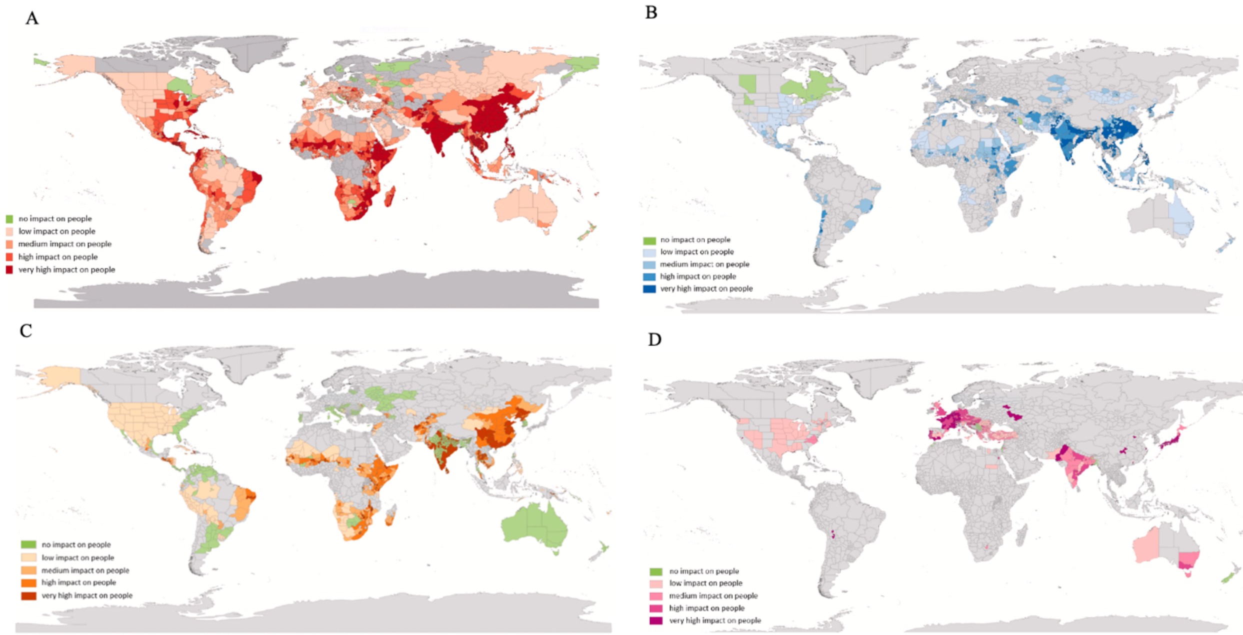


Figure 6: Global Map of Climate-Related Disaster Hotspots: A all impact combined, B Flash flood, C Droughts, D Hit waves. Donatti, C. I., Nicholas, K., Fedele, G., Delforge, D., Speybroeck, N., Moraga, P., Blatter, J., Below, R., & Zvoleff, A. (2024). Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction, 108, 104488.

Countries with lower levels of human development have been particularly vulnerable to the cascading effects of climate-related disasters. The Human Development Index (HDI) has proven to be a significant determinant in a country's ability to cope with such events. A negative correlation between HDI and the percentage of population impacted by climate disasters suggests that countries with higher levels of development experience fewer human casualties and social disruptions, even if the number of events remains comparable to those in less developed regions. For example, highly developed nations such as those in Europe have implemented robust climate adaptation strategies, including early warning systems, disaster preparedness, and resilience-building infrastructure, which have mitigated the human toll of climate disasters. Conversely, African nations, despite experiencing a relative decline in the number of climate-related disasters, have witnessed an increase in the number of people affected. This indicates that the severity of impacts may be growing in these regions, possibly due to insufficient adaptation measures, inadequate resources for resilience, and escalating socio-economic vulnerabilities (Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction 2024). A visual breakdown of disaster types further emphasizes the massive scale of droughts and floods as the leading causes of climate-related disruptions globally.

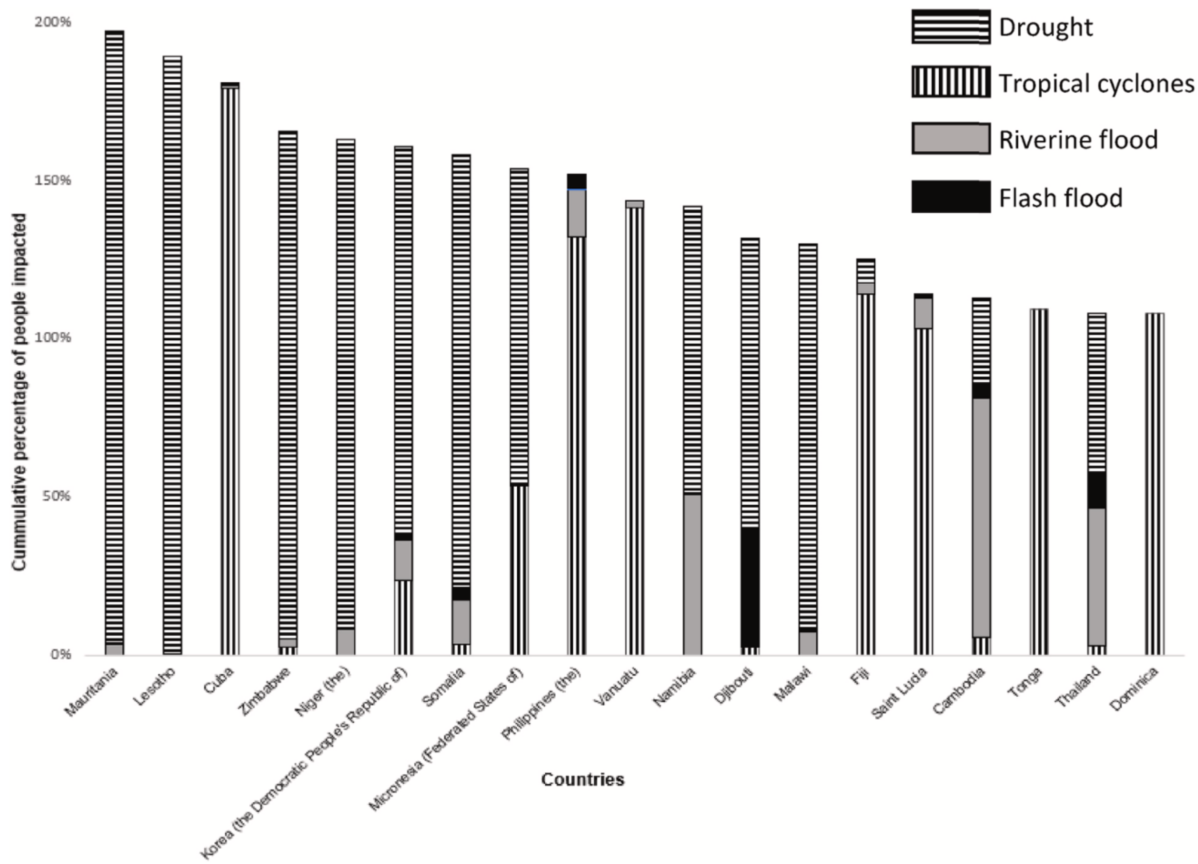


Figure 7: Bar Chart of Disaster Types and Impact. Global Map of Climate-Related Disaster Hotspots: A all impact combined, B Flash flood, C Droughts, D Hit waves. Donatti, C. I., Nicholas, K., Fedele, G., Delforge, D., Speybroeck, N., Moraga, P., Blatter, J., Below, R., & Zvoleff, A. (2024). Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction, 108, 104488.

As climate-related disasters continue to unfold, it is imperative that adaptation strategies be scaled up, particularly in regions with low human development where populations remain most at risk. Figure 8 illustrates the trend in the number of people affected by climate-related disasters globally, which shows a steady increase in population impact, especially in countries with lower HDI scores. This trend highlights the urgency of accelerating adaptation measures to safeguard vulnerable populations.

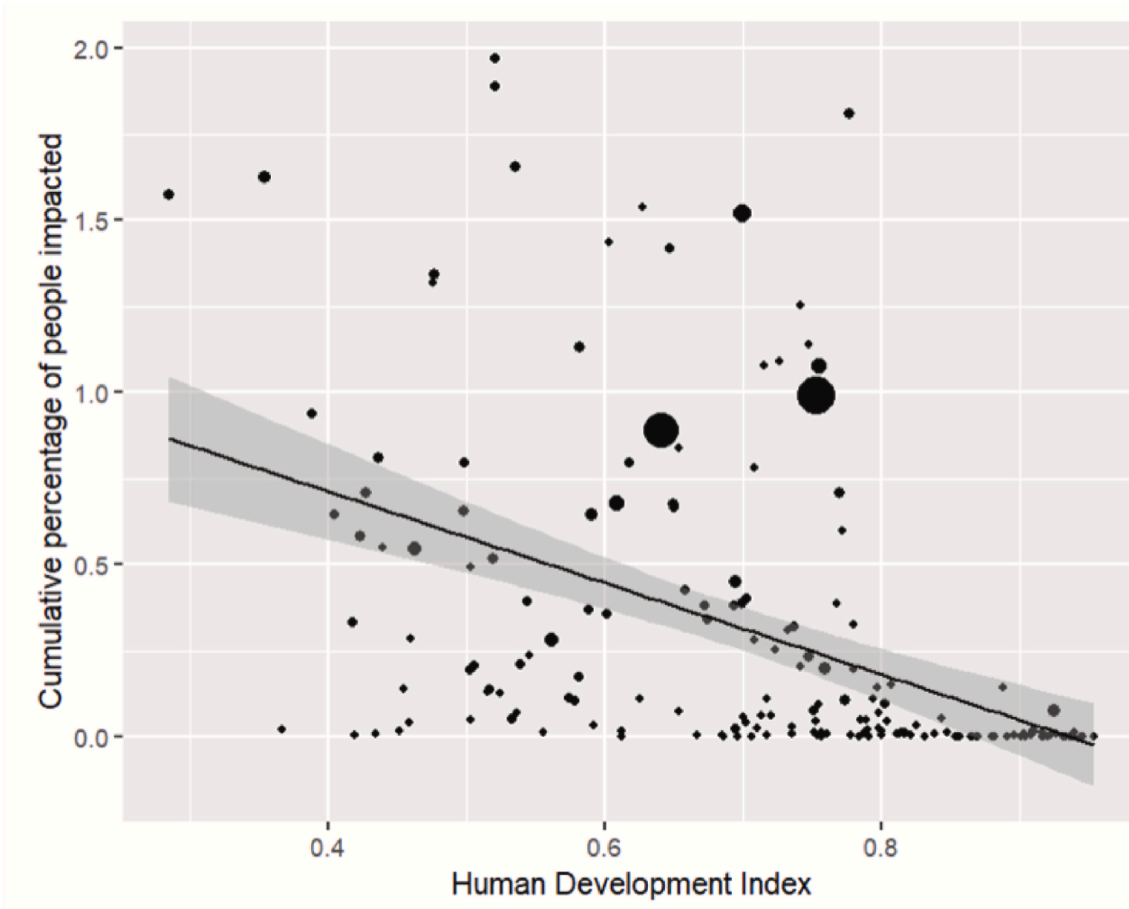


Figure 8: Line Graph of Population Impact Trends. Global Map of Climate-Related Disaster Hotspots: A all impact combined, B Flash flood, C Droughts, D Hit waves. Donatti, C. I., Nicholas, K., Fedele, G., Delforge, D., Speybroeck, N., Moraga, P., Blatter, J., Below, R., & Zvoleff, A. (2024). Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction, 108, 104488.

A key factor in understanding the disparity of disaster impacts across countries is the Human Development Index (HDI). The scatterplot in Figure 9 demonstrates the strong negative correlation between HDI and the percentage of the population affected by climate-related disasters. Countries with higher HDI tend to experience fewer impacts due to their increased capacity to implement adaptive measures such as disaster early warning systems, infrastructure resilience, and effective governance. On the other hand, countries with lower HDI, particularly in Africa and Southeast Asia, are more severely affected as they lack the resources and institutional capacity to effectively cope with such disasters (Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction 2024).

Climate-related disaster	N. of people impacted	N. of deaths	Number of events	N. of people impacted*/event	N. of deaths/event
Drought	1,441,038,477	21,291	341	4,225,919	62.43
Riverine flood	1,265,219,766	69,667	1,964	644,205	35.47
Tropical cyclone	501,227,733	188,812	1,020	491,399	185.1
Flash flood	178,721,860	19,795	583	306,555	33.95
Landslide and Mudslide	4,910,747	15,910	334	14,702	47.63
Wildfire	2,316,409	170	238	9,732	0.71
Heat wave	476,975	157,320	143	3,335	1,100.13
Total	**3,393,911,967**	**472,965**	**4,623**	**734,136**	**102.31**

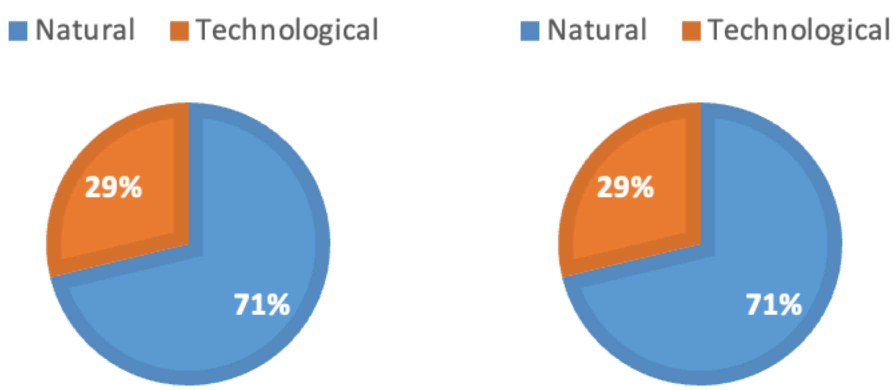
Figure 9: Scatterplot of HDI vs. Climate Disaster Impact. Global Map of Climate-Related Disaster Hotspots: A all impact combined, B Flash flood, C Droughts, D Hit waves. Donatti, C. I., Nicholas, K., Fedele, G., Delforge, D., Speybroeck, N., Moraga, P., Blatter, J., Below, R., & Zvoleff, A. (2024). Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction, 108, 104488.

As the severity and frequency of climate-related disasters continue to escalate, it is essential that global efforts focus on supporting vulnerable nations. Nature-based solutions, which leverage ecosystems' natural resilience to mitigate the effects of climate change, have shown promise in several regions. For instance, the restoration and management of mangrove forests in the Philippines have significantly reduced the impacts of coastal flooding, while also delivering ecological and social benefits. Similarly, the protection of grasslands in drought-prone areas of Ethiopia has helped communities withstand extreme weather events by providing alternative sources of food and income. These solutions offer cost-effective and sustainable methods of adaptation, particularly in regions where resources are scarce. The disparity between the resources available for adaptation in high- and low-HDI countries highlights the need for international support mechanisms, such as the recently established "Climate Impact and Response Fund," to prioritize vulnerable countries that bear the brunt of climate change but contribute the least to its causes (Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction 2024)

Europe overview

The Center for Research on the Epidemiology of Disasters (CRED) maintains the EM-DAT database, which compiles data on the occurrence and effects of over 26,000 mass disasters worldwide, including those caused by natural and technological factors. This extensive dataset provides insight into the growing trend of extreme weather events and their impacts across different regions.

The database can provide and extensive and better overview of the European whether extreme event situation. In Figure 10 & 11 is possible to see the number of technological and Natural disaster in Europe over the period 2013-2023. (https://doc.emdat.be/docs/data-structure-and-content/core-structure-of-the-database/)



Count of Disaster Group	Grand Total
Natural	1302
Technological	526
Grand Total	**1828**

Figure 10 & 11: Aggregation of Natural and Technological disaster form 2013 to 2023 in Europe from EM-Data

Breakdown of Disaster Groups

The images shows a table that categorizes disasters into two main groups: Natural and Technological disasters. According to the data:

- Natural disasters accounted for 71% of the total incidents (1302 events), including floods, storms, droughts, wildfires, and extreme temperatures.

- Technological disasters made up 29% of the incidents (526 events), encompassing industrial accidents and infrastructural failures.

This distribution highlights the significant impact of natural calamities on human life and property, especially in the context of climate change-driven events.

Detailed Breakdown by Natural Disasters in Europe

Events	Total Deaths	No. Affected	No. Injured	Homeless	Total Affected	Total Damage, Adjusted	Total Damage	Insured Damage, Adjusted	Insured Damage	Reconstruction Costs, Adjusted	Reconstruction Costs	AID Contribution
Drought	2	1304769	0	0	1304769	$ 17,755,117	$ 13,317,709	$ 300,000	$ 300,000	$ -	$ -	$ -
Earthquake	783	599640	4414	147520	751574	$ 53,497,500	$ 41,492,532	$ 4,126,854	$ 3,088,000	$ 11,125,605	$ 9,450,000	$ 549
Epidemic	19	17170	0	0	17170	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Extreme temperature	213829	688787	23237	0	712024	$ 29,876,995	$ 20,011,051	$ 344,214	$ 220,000	$ -	$ -	$ -
Flood	2178	8763848	9097	160009	8932954	$ 212,589,288	$ 157,285,805	$ 46,891,235	$ 34,562,366	$ 3,253,636	$ 2,235,751	$ 37,948
Glacial lake outburst flood	11	0	0	0	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Impact	0	300000	1491	0	301491	$ 43,163	$ 33,000	$ -	$ -	$ -	$ -	$ -
Infestation	0	0	0	0	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass movement (dry)	8	200	0	0	200	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mass movement (wet)	264	7391	38	3	7432	$ 1,041,887	$ 640,000	$ 342,781	$ 195,000	$ -	$ -	$ -
Storm	961	4099612	4358	520923	4624893	$ 82,441,112	$ 58,914,404	$ 36,641,164	$ 25,490,134	$ -	$ -	$ 3,247
Volcanic activity	0	300	28	0	328	$ 144,880	$ 118,100	$ -	$ -	$ -	$ -	$ -
Wildfire	601	1381735	4765	12311	1398811	$ 17,723,004	$ 12,123,187	$ 581,737	$ 437,000	$ 702,336	$ 565,000	$ 1,535
Grand Total	**218656**	**17163452**	**47428**	**840766**	**18051646**	**$ 415,112,946.00**	**$ 303,935,788.00**	**$ 89,227,985.00**	**$ 64,292,500.00**	**$ 15,081,577.00**	**$ 12,250,751.00**	**$ 43,279.00**

Figure 12: Detailed Breakdown by Natural Disasters in Europe 2013 to 2023 from EM-Data. All amount in dollar are provided in ('000 US$), the adjustment is here better explained.

Thanks to further usage of EM-DAT is possible to analyze a detailed table showcasing various natural disasters and their impacts in Europe. This table, quantifies the human and economic costs associated with each type of disaster. Key metrics include the number of deaths, people affected, injuries, total economic damage, insured losses, and reconstruction costs. Here's a closer look at the most significant types of extreme weather events affecting Europe:

- Floods: Flooding stands out as the most damaging extreme weather event, both in terms of human casualties and economic loss. In July 2021, devastating floods hit Germany, Belgium, and nearby countries, causing over €40 billion in economic losses and €13 billion in insured damages (*Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers*. Milliman Report.) These floods were the most expensive natural disaster in Europe since 1970, driven by increasingly erratic weather patterns due to climate change.
- Heatwaves (Extreme Temperatures): The data highlights that heatwaves are one of the deadliest extreme weather events, with 213,829 deaths recorded due to extreme temperatures. Such events are becoming more frequent across Europe, leading to severe

public health crises, particularly for vulnerable populations like the elderly (*Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers*. Milliman Report.).

- Wildfires: Wildfires in Southern Europe, including countries like Italy, Spain, and Greece, have caused widespread destruction. In 2021 alone, wildfires affected over 1.3 million people and led to €17.7 billion in damages (*Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers*. Milliman Report.). Climate change is making summers drier, which increases the frequency and intensity of wildfires across the Mediterranean region.
- Storms: Storms, including severe thunderstorms and tornadoes, caused €82 billion in damage across Europe in recent years (*Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers*. Milliman Report.). These events are not only destructive to infrastructure but also result in costly insurance payouts.

Detailed Breakdown by countries in Europe

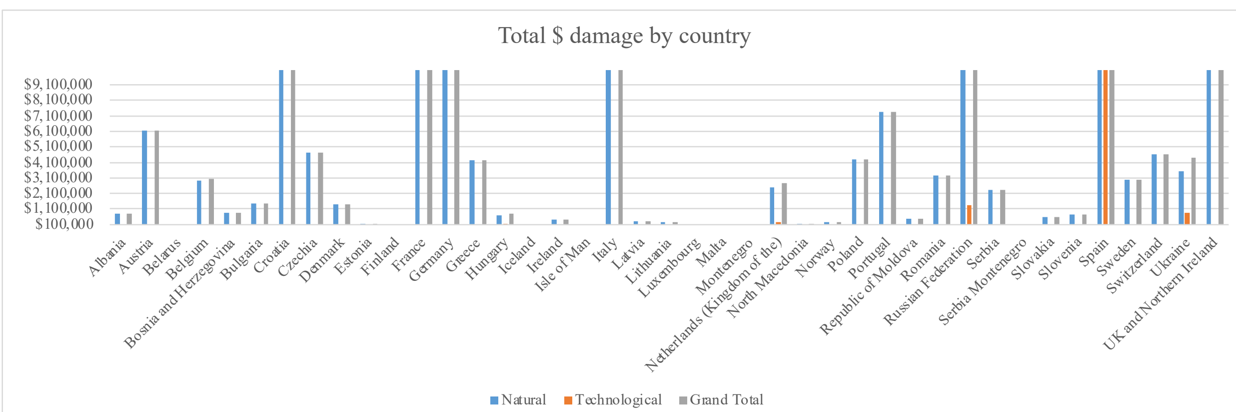


Figure 13 &14 : Detailed Breakdown by countries in Europe 2013 to 2023 for Natural and Tech disaster from EM-Data. All amount in dollar are provided in ('000 US$).

Country	Natural		Technological		Grand Total	
Albania	$	771,573	$	-	$	771,573
Austria	$	6,123,000	$	-	$	6,123,000
Belarus	$	40,300	$	-	$	40,300
Belgium	$	2,952,146	$	100,000	$	3,052,146
Bosnia and Herzegovina	$	847,580	$	-	$	847,580
Bulgaria	$	1,467,304	$	-	$	1,467,304
Croatia	$	13,872,150	$	-	$	13,872,150
Czechia	$	4,730,012	$	-	$	4,730,012
Denmark	$	1,400,000	$	-	$	1,400,000
Estonia	$	130,000	$	-	$	130,000
Finland	$	-	$	-	$	-
France	$	31,622,400	$	-	$	31,622,400
Germany	$	88,712,631	$	-	$	88,712,631
Greece	$	4,232,659	$	-	$	4,232,659
Hungary	$	688,000	$	103,000	$	791,000
Iceland	$	99,000			$	99,000
Ireland	$	425,000			$	425,000
Isle of Man	$	-			$	-
Italy	$	59,930,553	$	-	$	59,930,553
Latvia	$	325,000	$	-	$	325,000
Lithuania	$	255,573	$	-	$	255,573
Luxembourg	$	31,000	$	-	$	31,000
Malta	$	-	$	-	$	-
Montenegro	$	-	$	-	$	-
Netherlands (Kingdom of the)	$	2,510,431	$	256,000	$	2,766,431
North Macedonia	$	164,163	$	-	$	164,163
Norway	$	260,000	$	-	$	260,000
Poland	$	4,311,050	$	-	$	4,311,050
Portugal	$	7,342,636	$	-	$	7,342,636
Republic of Moldova	$	446,184	$	-	$	446,184
Romania	$	3,263,518	$	-	$	3,263,518
Russian Federation	$	10,351,160	$	1,320,000	$	11,671,160
Serbia	$	2,308,522			$	2,308,522
Serbia Montenegro	$	-	$	-	$	-
Slovakia	$	567,300	$	-	$	567,300
Slovenia	$	752,000	$	-	$	752,000
Spain	$	14,961,285	$	10,098,407	$	25,059,692
Sweden	$	2,972,000			$	2,972,000
Switzerland	$	4,609,000	$	-	$	4,609,000
Ukraine	$	3,542,616	$	867,000	$	4,409,616
UK and Northern Ireland	$	26,918,042	$	-	$	26,918,042
Grand Total	**$**	**303,935,788**	**$**	**12,744,407**	**$**	**316,680,195**

After the analysis based on different types of disasters, it is interesting to examine where natural disasters had the greatest impact. Germany experienced the highest economic losses from natural disasters between 2013 and 2023, with total damages amounting to $88.7 million. This is followed by Italy with $59.9 million and France with $31.6 million, underscoring the significant vulnerability of large European economies to natural events like floods, storms, and earthquakes. Other countries, such as Spain, Austria, and Croatia, also faced substantial impacts, indicating the widespread and unpredictable nature of natural disasters across Europe. Smaller nations like Luxembourg, Lithuania, and Latvia reported minimal losses, likely due to their lower exposure to extreme natural events.

In contrast, technological disasters contributed far less to the overall economic damage. Spain reported the highest technological disaster-related losses at $10 million, followed by the Russian Federation at $1.32 million. For most European countries, however, the financial impact of technological disasters was negligible compared to the extensive damages caused by natural events.

The total economic damage across Europe over this period reached $316.68 million, with $303.94 million attributed to natural disasters. This disparity underscores the overwhelming impact of natural disasters and highlights the need for stronger disaster risk management and mitigation efforts, especially in countries with high exposure to environmental risks.

The Rising Impact of Climate Change on Europe

According to the Milliman Report on extreme weather events in Europe for 2021, climate change is a critical factor driving the increased frequency and intensity of these disasters (*Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers*. Milliman Report). For instance, the report notes that average temperatures in Europe have consistently risen, contributing to more frequent and severe heatwaves, storms, and floods. It also highlights that winters are getting wetter and summers drier, leading to an increase in storm damage and agricultural losses due to drought.

Europe's insurance industry has been significantly impacted by these events, with insurers paying out record sums for climate-related damages. For example, the July 2021 floods resulted in €13 billion in insured losses, highlighting the gap between total economic loss and insured damage(*Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers*. Milliman Report). This "protection gap" underscores the need for better climate risk management strategies and insurance coverage across the continent.

Germany: A Case Study of Devastating Floods

In Germany, the July 2021 floods were particularly devastating. The slow-moving storm "Bernd" dumped unprecedented levels of rainfall, leading to catastrophic flooding in regions like Rhineland-Palatinate and North Rhine-Westphalia. The German Insurance Association (GDV) estimated that the floods caused €33 billion in total economic losses, with €7 billion in insured losses *(Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers.* Milliman Report).

The flood disaster caused over 700 injuries and nearly 200 deaths, making it one of the deadliest natural disasters in modern German history. Months after the floods, many affected areas were still struggling to recover, with highways and rail lines remaining closed, leaving some communities isolated. The aftermath of these floods highlighted the vulnerabilities in Germany's infrastructure and the need for greater resilience to climate change.

Europe’s Outlook and Future Risks

Looking ahead, Europe faces increasing risks from extreme weather events, driven by a warming climate. A report from the Intergovernmental Panel on Climate Change (IPCC), released in February 2022, confirms that many of the impacts of climate change are now unavoidable. The future is likely to see more frequent and severe events, including:

- Increased flooding due to more moisture-rich and slower-moving storms.
- Longer fire seasons and more intense wildfires, particularly in Southern Europe.

- More frequent heatwaves that threaten public health and agriculture (*Extreme weather events in Europe for 2021 and beyond: Insurance industry impact and actionable steps for insurers*. Milliman Report).

Governments and insurers across Europe are calling for higher risk awareness and investment in protective infrastructure. Economists estimate that every €1 invested in climate change protection saves €15 in damages from future extreme weather events This reinforces the urgency of climate action, including more aggressive greenhouse gas emission cuts and better adaptation strategies.

1.3 Climate Change Risk & Taxonomy

Introduction: The Concept of Double Materiality

After analyzing the historical progression of climate change, its potential future impacts and the current statistics it is crucial to shift focus toward understanding how these shifts translate into risks, particularly for businesses and their financial performance. Climate change is no longer a distant threat; it is a present and escalating challenge that directly impacts businesses across all sectors. The financial consequences of extreme weather events, shifting regulatory landscapes, and evolving market demands are shaping a new reality for corporate risk management. To tackle these risks comprehensively, companies must adopt the double materiality approach a concept that emphasizes the need to assess both the financial impact of climate change on businesses and the environmental consequences of corporate activities.

The European Union has embedded double materiality at the core of its sustainability framework through initiatives such as the Corporate Sustainability Reporting Directive (CSRD), which requires companies to assess and disclose how climate change affects their financial performance and how their operations contribute to environmental degradation (Working Paper Series The double materiality of climate physical and transition risks in the euro area). This dual focus is crucial as businesses navigate the complexities of the global transition toward a low-carbon economy.

This chapter explores the taxonomy of climate risks transition risks and physical risks and their financial and operational implications. Additionally, we will examine the opportunities that arise from proactive climate action, including resource efficiency, innovation, and market growth.

Double materiality distinguishes between two perspectives:

1. Financial materiality: How climate change risks affect a company's financial performance, through factors like compliance costs, technological investments, and physical asset damage.
2. Environmental materiality: How a company's operations impact the environment, influencing regulatory risks and reputational consequences.

The EU's Green Deal and Sustainable Finance Disclosure Regulation (SFDR) underscore the importance of this dual approach. The EU is leading global efforts to ensure that companies account for their environmental and financial risks in equal measure.

1.3 Taxonomy of Climate-Related Risks

Figure 15: Climate-Related Risks, Opportunities, and Financial Impacts. Task Force on Climate-related Financial Disclosures (TCFD). (2017). Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures.

Climate risks for businesses can be categorized into transition risks and physical risks, each with its own set of challenges. These risks are interconnected, influencing corporate strategy, risk management, and financial stability.

Transition Risks:

Transition Risks arise from the societal, regulatory, and market shifts required to move toward a low-carbon economy. As shown in the diagram from the Task Force on Climate-related Financial Disclosures (2017), these risks can affect companies in various ways, from policy changes to reputational concerns.

a) Policy and Legal Risks: Governments worldwide are enacting stringent regulations to curb carbon emissions, including carbon taxes, emissions trading systems, and enhanced environmental reporting requirements. Non-compliance with these policies can lead to legal penalties, fines, and operational restrictions, significantly increasing costs for businesses (Task Force on Climate-related Financial Disclosures) (2017).

    - Example: The EU Emissions Trading System (ETS) caps the amount of greenhouse gases certain sectors can emit. Companies that exceed their allowance must purchase additional carbon credits, leading to increased operational costs.

b) Technology Risks: Transitioning to low-carbon technologies is essential for reducing emissions, but it also presents risks. Companies that fail to invest in cleaner technologies could face stranded assets investments that become obsolete as regulatory standards and market preferences shift. Conversely, early adoption of new technologies requires significant R&D investment, which carries its own financial risks (Task Force on Climate-related Financial Disclosures) (2017).

c)

    - Example: In the automotive industry, firms slow to transition to electric vehicles (EVs) risk losing market share to competitors that have embraced this technology.

d) Market and Preference Change Risks: Consumer and investor preferences are shifting toward sustainable products and services. Companies that do not align with these preferences may face declining demand, lower revenues, and decreased market share. Investors are increasingly factoring environmental, social, and governance (ESG) criteria into their decision-making processes, which can impact stock prices and investment flows (Task Force on Climate-related Financial Disclosures) (2017).

- Example: Fast-moving consumer goods (FMCG) companies are increasingly adopting sustainable packaging and supply chain practices to meet consumer demand for environmentally friendly products.

e) Reputational Risks: A company's reputation is often tied to its environmental performance. Businesses that lag in addressing climate risks face reputational damage, which can lead to customer loss, investor withdrawal, and diminished market value. Stakeholders increasingly prioritize transparency and sustainability in corporate practices (Task Force on Climate-related Financial Disclosures) (2017).

- Example: Fossil fuel companies have been working to rebrand themselves as energy providers, investing in renewable energy to mitigate the reputational risks associated with their historical reliance on oil and gas.

Physical Risks

Physical Risks it stem from the direct impact of climate change, such as extreme weather events and gradual shifts in climate patterns. These risks can be categorized into acute risks (sudden, severe weather events) and chronic risks (long-term changes like temperature increases and rising sea levels). Figure 2 illustrates how these risks affect different business operations.

a) Acute Physical Risks: Acute physical risks involve sudden, extreme weather events, including floods, hurricanes, and wildfires. These events can damage physical infrastructure, disrupt supply chains, and impair business continuity (Task Force on Climate-related Financial

Disclosures) (2017). Companies with facilities in vulnerable regions must invest in protective measures to mitigate potential losses.

- Example: The 2021 flooding in Germany and Belgium caused billions in damages, disrupting critical infrastructure and supply chains, especially for industries dependent on logistics.

b) Chronic Physical Risks: these risks refer to longer-term changes in climate, such as rising temperatures, altered precipitation patterns, and rising sea levels. These risks can gradually erode business models, particularly in sectors that rely heavily on stable environmental conditions.

- Example: Rising sea levels pose a long-term threat to coastal industries, requiring substantial investments in infrastructure adaptation or relocation to avoid operational disruptions.

Financial and Economic Implications of Climate Risks

Climate risks have significant financial implications that impact various aspects of corporate performance, from income statements to balance sheets. Both transition risks, as businesses shift to a low-carbon economy, and physical risks from climate events, carry substantial financial consequences, both directly and indirectly.

Transition risks may lead to reduced demand for carbon-intensive products and services, while physical risks can disrupt company operations, causing lost sales. In addition, complying with new environmental regulations often increases costs, which can erode profit margins.

On the expenditure side, businesses are likely to encounter rising operating costs due to the need for compliance with environmental laws, adoption of new technologies, and physical adjustments to climate change impacts. This can lead to increased capital expenditures, ultimately affecting overall profitability.

When it comes to capital and financing, as investors increasingly integrate environmental, social, and governance (ESG) factors into their investment strategies, companies with poor environmental performance may face challenges in accessing financing or may encounter higher borrowing costs. Additionally, firms might need to raise capital to finance projects aimed at mitigating or adapting to climate-related risks, further impacting their financial structure.

At a larger scale, climate risks can have and impact at macroeconomic level. Indeed it can result in disrupt labor markets, increase insurance premiums, and cause shifts in productivity. The most severe climate scenarios suggest significant economic contractions due to widespread infrastructure damage and resource scarcity. A 2.6°C rise in global temperatures is projected to cause a 13.9% reduction in global GDP, with Europe facing an 8% contraction (Task Force on Climate-related Financial Disclosures) (2017).

Climate change transition opportunity

Climate change, while presenting significant risks, also brings substantial opportunities for companies that proactively embrace sustainability. One of the key areas where businesses can benefit is through resource efficiency. By investing in energy conservation, reducing waste, and adopting circular economy practices like recycling, companies can lower operational costs while enhancing their environmental credentials. This is exemplified by companies such as Unilever and Patagonia, which have successfully integrated sustainability into their operations, achieving both cost savings and reduced environmental impact

In addition to resource efficiency, climate action offers the potential to build resilience. Companies that invest in adaptive infrastructure, diversify supply chains, and secure renewable energy sources are better equipped to withstand climate-related disruptions, ensuring long-term operational stability. Firms like Google and Amazon have made significant investments in renewable energy, not only to reduce their carbon footprints but also to ensure energy security and mitigate exposure to volatile energy prices (ECB Working Paper No. 2665) These actions illustrate how addressing climate risks can strengthen a company’s competitive advantage and position it for future growth.

Europe is playing a key role in fostering this shift, with regulatory frameworks like the EU Green Deal and Sustainable Finance Action Plan leading global efforts. These initiatives promote transparency in corporate reporting, push for innovation in green technologies, and ensure that companies integrate climate risks and opportunities into their strategic planning

1. Chapter 2: Literature Review: The Impact of Extreme Climate Events on Financial Performance of Manufacturing Firms

Currently, many are the papers and researchers that are exploring and examining the relationship between climate change and financial performance. In the recent year, the research has evolved and improved significantly, yet many are still gaps in the literature that can be filled, particularly when it comes to specific regions, sectors, and types of firms. Most of the past literature has focused on analyzing developing economies and industries such as agriculture, energy, and mining. These sectors are especially exposed and vulnerable to climate disruptions, which has made them the subject of extensive empirical analysis. However, there are still few papers that explore the effect of climate change on the economic performance of companies in developed economies such as Europe and that especially focus on private companies, which are affected by different challenges compared to public entities.

2.1 Existing Research and Findings

One of the key studies of this research area, Sun et al. (2020) the paper analyzed the mining industry in China and proved that the climate change as a direct and statistical effect financial impact of the industry . The authors highlighted how different types of climate events ranging from floods to droughts have varying consequences for a firm's financial performance. For instance, floods can directly interrupt mining activities, resulting in immediate financial losses, whereas droughts may have the effect of raising operational expenses due to water scarcity. However, they can also provide prospects for companies that exercise more effective resource management. The findings of Sun et al. demonstrated the intricate nature of climate risk effects, revealing that these risks do not consistently result in adverse financial consequences. Instead, they are influenced by the specific circumstances, such as the geographical location, industry, and capacity of the firm to adjust (The impacts of climate change risks on financial performance of mining industry: Evidence from listed companies in China 2020).

Similarly, Giang et al. (2021) conducted research on the sector of listed manufacturing company in Vietnam and found again that specific extreme climate variables, such as temperature fluctuations and high humidity, led to significant reductions in profitability (The Impacts of Climate Change Risks on Financial Performance: Evidence from Listed Manufacturing Firms in Vietnam 2021). As in the previous paper the findings of this study demonstrate the direct impact of environmental conditions on operational expenses, product quality, and worker productivity, negatively affecting financial performance of the vientamees industries . The asian county, is characterized by a relatively lax regulatory framework and dependence on labor-intensive manufacturing, emphasized the low elasticity and preparation of companies that lack the necessary resources to cope with the impacts of climate variation. However, like many studies in this field, Giang et al.'s research focused on public firms and developing economies, leaving a critical gap in understanding how these dynamics play out in more regulated, developed markets.

In the European context, Angelini (2022) explored the financial impacts of climate-related regulations, particularly focusing on the European Union's Green Deal and its stringent sustainability targets (The financial risks posed by climate change: information gaps and transition plans). Angelini's research revealed that European firms are increasingly facing transition risks as they are required to comply with new environmental regulations, which mandate substantial investments in low-carbon technologies, shifts in operational models, and the restructuring of supply chains to meet emissions targets. According to Angelini's (2022) the regulatory pressures introduce by green new deal has significantly impacted financial results, especially for firms that are less prepared or financially capable of adapting to these changes. The emphasis in this research was largely on public firms, given the availability of data and the higher levels of regulatory scrutiny they face compared to private companies.

While Angelini's study provided valuable insights into the regulatory risks faced by European firms, it primarily concentrated on the financial resilience of large, publicly traded companies. This leaves out a substantial portion of the European economy, namely private firms that may not have the same access to capital or the internal resources to adapt to regulatory changes as efficiently. Furthermore, the current body of research frequently regards the manufacturing industry as a single and homogeneous entity, disregarding the substantial differences in how various sub-sectors encounter climate hazards. For instance, car manufacturers are particularly susceptible to supply chain interruptions resulting from severe weather events, but companies in the heavy machinery industry may have more challenges with increasing energy costs because of their dependence on energy-intensive manufacturing facilities. The present study often fails to examine these sector-specific issues, as it seeks to consolidate data from whole industries without considering these crucial distinctions.

Furthermore, apart from the emphasis on publicly traded companies and general industry classifications, another constraint of current research is their dependence on macro-level data, which sometimes overlooks the intricacies of vulnerabilities specific to individual organizations. Most studies use publicly available financial data from listed companies, which skews the findings toward larger firms with more resources and greater access to capital. As a result, smaller, private firms many of which are critical to the European economy are underrepresented in the literature. These firms often lack the financial strength and the institutional support that larger firms enjoy, making them less reactive and more susceptible to both physical climate risks and the financial strain of regulatory compliance.

2.2 Contribution to the Literature

As previously stated, the existing literature review has discovered and demonstrated gaps that the paper is eager to address and investigate. An important contribution of this research is its targeted examination of private European manufacturing companies, a group that has been mostly neglected in research on climate risk and financial performance. Although the majority of the current literature is on major, publicly traded companies because of a large amount of data, this study offers a more detailed, individual firm-level examination of the impact of climate risks on private firms. This is especially pertinent in the European setting, where private enterprises have a vital social and economic function as the central component of the economic and production systems. However, their adaptability, scale, and financial capabilities render them more susceptible to climate related hazards.

Utilizing firm-level data from private companies, this research provides novel insights into the management of physical and transition risks by these firms. The emphasis on private enterprises is crucial due to their distinct obstacles in obtaining funding for climate adaptation and adhering to regulatory reforms, which differ from those faced by state enterprises. Public companies, with their enhanced access to stock markets, typically have a more advantageous position to allocate resources towards sustainability projects and effectively handle the expenses associated with regulatory compliance. However, commercial enterprises may face difficulties in funding the required modifications, resulting in increased financial strain and possibly long-term susceptibility. The present study aims to fill this research gaps by offering a comprehensive examination of the effects of climate hazards on several categories of enterprises operating in the manufacturing industry.

This study not only analyses the variations within different sectors but also investigates the immediate and enduring financial consequences of climate risks.

In brief, this study provides a substantial addition to the current body of knowledge by directing attention towards a hitherto neglected sector of the economy: privately-owned manufacturing enterprises in Europe. This paper contributes to our knowledge of how climate threats, physically financial performance in a mature, highly regulated environment by offering a more comprehensive analysis at the business level.

2. Chapter 3: Methodology, data and Research Design

3.1 Description of Database: deep dive on financial data and E3CI

The third chapter provides a detailed overview of the core datasets used in this research, which form the foundation of the analysis. As previously state the following research paper explore how climate change impacts the financial performance of manufacturing firms in Europe, using two key sources of data: financial data from Orbis and climate data from the European Extreme Events Climate Index (E3CI). These datasets are crucial as they provide the basis for understanding the link between climate risks and financial outcomes, making it possible to explore how firms in the manufacturing sector are affected by extreme weather events.

The Orbis database supplies detailed financial information on a large number of European manufacturing firms, while the E3CI dataset tracks the frequency and intensity of extreme weather events across Europe. These datasets toughener produce a comprehensive analysis of how climate-related risks impact the financial health and performance of companies.

The following sections, will explain how these datasets were selected, processed, and integrated to ensure a robust analysis. This includes an overview of how the data was treated and prepared for the regression models that form the core of the empirical investigation. By carefully managing and combining the financial and climate data, the study aims to provide clear insights into the financial vulnerabilities and resilience of manufacturing firms in response to climate change.

Introduction to Financial Data on European Manufacturing Companies

The financial dataset used in this analysis originally comprised data from 11,316 private manufacturing companies across Europe, sourced from Orbis, a global database that holds financial and corporate information for over 300 million companies. Orbis provides an extensive range of financial metrics, firm-specific details, and industry classifications, making it an invaluable resource for studying firm-level performance across different regions and time periods.

Following a refinement process to ensure data quality and relevance, the number of companies in the dataset was reduced to approximately 10,000. This adjustment involved filtering out incomplete records and focusing on firms that best matched the study's criteria. The final dataset provide a snapshot of European manufacturing company over the period 2013 - 2023, providing insights on financial health and operational status of these firms and during the last decade.

The key financial indicators selected for the research are here listed:

Table 1: Key Financial Variables from Orbis

Variable	**Description**
Cash Flow / Operating Revenue	Measures a firm's liquidity and its ability to generate cash through its core operations.
Current Ratio	Liquidity ratio comparing current assets to current liabilities, indicating short-term financial health.
EBIT Margin	Earnings Before Interest and Taxes (EBIT) as a percentage of revenue, representing operating profitability.
EBITDA Margin	Similar to EBIT margin, but excluding depreciation and amortization, giving a clearer view of cash flow.
Gearing	Leverage ratio comparing company debt to equity, indicating financial risk associated with debt.
Gross Margin	Production efficiency, the result of the difference between revenue and the cost of goods sold (COGS).
Liquidity Ratio	Broader liquidity measure that assesses a firm's ability to meet short-term obligations.
Net Assets Turnover	Efficiency metric showing how effectively a company utilizes its assets to generate revenue.
Number of Employees	Reflects company size and operational capacity.
Profit Margin	The percentage of revenue that results in profit after all expenses have been deducted.

Return on Assets (ROA)	Profitability measure showing how effectively a company uses its assets to generate income.
Return on Equity (ROE)	Measure of financial performance that calculates how efficiently a firm uses shareholders' equity.
Solvency Ratios	Asset- and liability-based measures that reflect a company's long-term ability to meet financial obligations.

In addition to these financial metrics, the dataset includes several key classifications:

- Company Name
- Inactive/Quoted Status: Indicates whether the company is currently operational or publicly listed.
- Country of Operation (ISO Code)
- NACE Rev. 2 Core Code: A 4-digit classification used to define the firm's economic activities.

Introduction to Extreme Weather Event Data

On the other hand, to quantify the exposure of companies to climate risks, this study uses data from the European Extreme Events Climate Index (E3CI). Index developed by the International Foundation Big Data and Artificial Intelligence for Human Development (IFAB) in collaboration with the Euro-Mediterranean Climate Change Centre (CMCC), the E3CI provides a cutting-edge tool for evaluating the frequency and intensity of extreme weather events across Europe.
The E3CI Index has been instrumental to assess the influence of climate variability on firms. It captures a wide range of meteorological events, including floods, storms, heatwaves, and other significant phenomena. The period selected for the analysis was the same as the financial data, from 2013 to 2023.

The key features of the E3CI Dataset and reason for its selection are:

- Geographical Scope: Comprehensive coverage of extreme weather events across Europe, with specific geographic subdivision for country, region, and GPS coordinates.
- Temporal Resolution: Data is provided annually from 2013 to 2023, with detailed monthly snapshots of event occurrences and severities.
- Identification and division of seven dynamics of Extreme Events: These include a wide range of meteorological variables, such as precipitation, temperature anomalies, wind speeds, and more. The dataset calculates and captures deviations from historical averages (data before 2010), enabling the identification of regions under climate stress.

The data are sourced from ERA5 atmospheric re-analysis, maintained by the Copernicus Climate Change Service (C3S). ERA5 provides a high-resolution dataset, dating back to 1950, which is widely recognized for its accuracy in estimating atmospheric conditions.

The E3CI dataset was identified used for the sake of the research for three main reason. First and foremost, the database focuses only on the European area enabling an extensive assessment of severe weather patterns on the region, therefore offering a holistic perspective on the evolution of climate trends throughout time. Secondly, it assesses the severity of each extreme weather event by comparing it to prevailing historical standards, providing a precise, understandable and practical numerical indication of the magnitude of these incidents. In conclusion, it offers crucial risk management insights by pinpointing the areas and its industries that are mostly threaten by climate change. This collection of data are not only essential for carrying out this empirical research but also valuable for providing important direction to companies and policymakers in comprehending and reducing the hazards presented by severe weather phenomena.

Data Selection for the Financial Data

The process of selecting the financial dataset for this study followed a methodical, multi-step approach to meet the research objective. The aim is to explore the impact of extreme weather events on the financial performance of private manufacturing companies across Europe. To that end, Orbis database was filtered to focus on companies operating in the manufacturing sector in both Western and Eastern Europe.

The selection of financial data was guided by four key steps: geographic appetences, industry classification, company type, and financial metric selection.

Geographic Scope: The dataset was restricted to companies located in countries across Western and Eastern Europe. This regional focus was designed to capture a broad spectrum of economic conditions, ranging from the highly industrialized nations in Western Europe to the more developing economies in Eastern Europe.
Western Europe includes industrial powerhouses such as Germany, France, and Italy, while Eastern Europe captures nations like Poland, Hungary, and the Czech Republic, which are experiencing rapid economic transformation.

Industry Classification: To respect the research objective, to identify manufacturing company the NACE Rev. 2 industry classification system was applied to filter out all other entities in the region. The NACE Rev. 2 system is the European Union's standard industrial classification system, and it helps to maintain consistency across industries by assigning codes that represent specific sectors.

In this study, the focus is on manufacturing firms, and the selection was narrowed to include the following divisions under NACE Rev. 2 selecting form Division 10 to 33 that are, according to the system, the 23 different manufacturing subdivision in Europe :

Division 10: Manufacture of food products

Division 11: Manufacture of beverages

Division 12: Manufacture of tobacco products

Division 13: Manufacture of textiles

Division 14: Manufacture of wearing apparel

Division 15: Manufacture of leather and related products

Division 16: Manufacture of wood and of products of wood and cork, except furniture
Division 17: Manufacture of paper and paper products
Division 18: Printing and reproduction of recorded media
Division 19: Manufacture of coke and refined petroleum products
Division 20: Manufacture of chemicals and chemical products
Division 21: Manufacture of basic pharmaceutical products and pharmaceutical preparations
Division 22: Manufacture of rubber and plastic products
Division 23: Manufacture of other non-metallic mineral products
Division 24: Manufacture of basic metals
Division 25: Manufacture of fabricated metal products, except machinery and equipment
Division 26: Manufacture of computer, electronic and optical products
Division 27: Manufacture of electrical equipment
Division 28: Manufacture of machinery and equipment n.e.c.
Division 29: Manufacture of motor vehicles, trailers, and semi-trailers
Division 30: Manufacture of other transport equipment
Division 31: Manufacture of furniture
Division 32: Other manufacturing
Division 33: Repair and installation of machinery and equipment

These divisions encompass a wide variety of manufacturing activities, ensuring that the dataset is representative of different manufacturing subsectors, each with unique exposure to supply chain disruptions, operational risks, and financial vulnerabilities brought on by extreme weather events. For example, companies involved in textiles (Division 13) may face different risks compared to firms producing motor vehicles (Division 29), highlighting the importance of industry-specific analysis in understanding the impact of climate-related disruptions.

To narrow down the selection a Company Type filter was applied. The analysis focuses on non-quoted (privately held) companies, meaning firms that are not publicly listed on stock exchanges. This decision was made for several reasons. First, privately held firms are more likely to have limited access to financial resources when compared to publicly traded companies, which can typically raise funds through capital markets. As a result, these companies may be more directly exposed to financial pressures resulting from extreme weather events. Secondly, public companies often diversify their operations across different regions and industries, potentially insulating them from localized climate risks. Focusing on non-quoted firms allows the study to capture a clearer picture of how smaller, independent companies cope with climate risks. In addition, focusing on private company this research is able to fulfill a gap in the Literature review, where other research mainly focus on public entities.

The last selection on Orbis was the identification of the best Financial Metric need to perform the regressions. The financial metrics used in the study were selected based on their relevance to understanding the performance and health of manufacturing firms under varying economic and environmental conditions. These metrics include indicators of liquidity, profitability, solvency, and operational efficiency. The full list of financial metrics is presented in Table 1: Key Financial Variables from Orbis, in the previous paragrapher (Introduction to Financial Data on European Manufacturing Companies). These financial metrics were chosen to provide a comprehensive analysis of firm performance, enabling the study to evaluate both short-term liquidity and long-term profitability. The combination of these indicators ensures that the dataset cover the overall financial health fact of a firm and its ability to respond to external shocks, such as climate-induced disruptions.

Descriptive Statistics of Financial Data

Summary Statistics - Firm Data

Variable	Obs	Mean	Std. Dev.	Min	Max
Cash flow / Operating revenue	73941	7.093	6.38	-22.326	34.895
Current ratio	85144	1.958	1.521	0	13.996
EBIT margin	84589	5.526	6.536	-24.074	35.328
EBITDA margin	79600	8.566	7.133	-21.529	36.893
Gearing	80256	76.565	91.49	0	489.603
Gross margin	61140	33.773	19.418	-46.189	97.355
Liquidity ratio	84907	1.352	1.206	0	12.752
Net assets turnover	84579	3.79	5.021	0	69.61
Number of employees	76648	811.616	1277.952	0	13999
Profit margin	85017	5.264	6.974	-26.848	37.651
ROA using Net income	83252	5.547	7.299	-25.61	36.192
ROA using Profit (Loss) before t	85656	7.269	8.837	-28.477	43.091
ROE using Net income	81804	13.036	22.387	-150.524	174.252
ROE using Profit (Loss) before t	84110	17.757	27.68	-174.889	212.237
Solvency ratio (Asset based)	86186	43.666	21.793	-33.437	100
Solvency ratio (Liability based)	51632	48.281	25.269	0	100

To get a better understanding of the financial data used a comprehensive descriptive analysis was performed to summarize the key financial metrics of the firms in the dataset. The table presents the summary statistics for these financial variables, including the number of observations, means, standard deviations, and minimum/maximum values for each metric.

The key result of this analysis are:

- The mean of Cash Flow/Operating Revenue was 7.09, with a standard deviation of 6.38, indicating moderate variability across firms.
- The EBIT Margin and EBITDA Margin also displayed considerable variability, with mean values of 5.52% and 8.57%, respectively.
- Liquidity Ratios and Solvency Ratios suggest that most firms are financially stable, though some exhibit extremely high debt levels, as reflected in the large standard deviations.
- The number of employees ranged widely, from smaller firms with only a few employees to larger firms employing over 130,000 people. This wide variation in firm size indicates that the dataset captures a diverse range of companies, from small to large manufacturers.

These descriptive statistics offer important insights into the financial health and dimension of the firms in the dataset providing a solid foundation for assessing how climate-related weather events may impact their performance.

Extreme Weather Event Data: Description, Statistics, and Data Treatment

As previously introduced to carry out the analysis of the impact of extreme climate even the European Extreme Events Climate Index (E3CI) data were selected. The E3CI is a climate index used to assess the frequency and severity of extreme weather events across Europe. In the following paragraph is possible to find a detailed description of the index, perform descriptive analysis of the extreme weather data, and explain how the raw data was processed to create a final dataset for empirical analysis.

The E3CI Index is an ensemble of seven indices designed to track and quantify the occurrence and intensity of weather-induced hazards across Europe. It is built upon atmospheric reanalysis data from ERA5, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), and covers several decades of climate data since 1950 onward. The ERA5 data is available in high spatial (0.25° x 0.25° latitude-longitude) and temporal resolution, allowing precise tracking of extreme meteorological conditions.

The E3CI focuses on the following seven components, each corresponding to a specific type of weather hazard:

1. Extreme Max Temperature: Represents anomalies of extreme daily maximum temperatures compared to a historical baseline (1981-2010).
2. Extreme Min Temperature: Represents anomalies of extreme daily minimum temperatures.
3. Drought: Quantifies rainfall deficits using the Standardized Precipitation Index (SPI).
4. Extreme Precipitation: Measures extreme precipitation events relative to historical norms.
5. Hailstorms: Assesses the probability of hailstorm occurrences using the Significant Hail Parameter (SHIP).
6. Extreme Winds: Represents anomalies in daily maximum wind speeds.

7. Fire: Uses the Fire Weather Index (FWI) to estimate forest fire risk due to weather conditions.
8. E3CI: The E3CI is the eight variable and it represent the mean value of the all seven components into a single index.

Each of these components is measured monthly and returns a standardized score based on how the current values deviate from the historical reference (Z-score relative to 1981-2010). The E3CI data is updated regularly, ensuring that it reflects recent extreme weather events.

Understanding E3CI data and its treatment:

In order to understand how E3CI were treated to perform the final dataset that merged the financial and extreme event data is important first to understand how the index is calculated and when this is considered to be extreme.

The E3CI index is based on seven variables, previously illustrated, developed by the International Foundation Big Data and Artificial Intelligence for Human Development (IFAB) in collaboration with the Euro-Mediterranean Climate Change Centre (CMCC). The variable are the result of the manipulation of ERA5 data and are calculated in the following way to provide insights on the extreme event in Europe. All components are treated similarly in the index except for drought. For each variable, a historical baseline (e.g., 1981–2010) is established to set a reference, and exceedances are calculated by comparing the observed values with the 95th percentile threshold.

The exceedances are calculated as follows:

$$S_{j,k} = \sum_{i=1}^{n_j} \max\left(0, X_{i,j,k} - X_{\text{threshold},j}\right)$$

Where:

- Sj,k represents the cumulative exceedance for month j and year k,
- Xi, j, k is the observed value on day i,
- X threshold, j is the predefined threshold for each variable.

The exceedances for each month are summed and standardized using the following formula:

$$Z = \frac{S_{j,k} - \mu(S_j)}{\sigma(S_j)}$$

Where:

- $\mu(Sj)$ is the mean exceedance for month j during the baseline period,
- $\sigma(Sj)$is the standard deviation of exceedances for month j.

For drought, the Standard Precipitation Index (SPI) is used as a reference, with a three-month accumulation period (SPI-3). The values are fitted to a gamma distribution and then normalized. Positive SPI values represent greater than median precipitation, while negative values indicate les than median precipitation. To maintain consistency with other variables, the opposite of the SPI-3 value is used for drought in the E3CI.

Finaly The E3CI for each month is calculated by averaging the standardized components from all variables.

Thanks to the support of Hypermeteo, the company that manages and controls the usage of E3CI data, under request, it was possible to obtain data from 2013 to 2023 on a monthly basis, per region, and for all seven different climate variables. To finalize the dataset and merge the financial and climate data, it was necessary to calculate the frequency of extreme events, identifying how many times a specific region was impacted by each event annually. An extreme event so is considered to have occurred when the monthly standardized anomaly exceeds 1, a threshold that marks significant deviations from historical norms and indicates the presence of an extreme event. This approach enables the systematic tracking of extreme events, allowing for an analysis of their frequency and potential impacts across various regions and sectors.

Descriptive Statistics

Summary Statistics - Climate Data Extreme Events Frequency

Variable	Obs	Mean	Std. Dev.	Min	Max
Drought	87239	2.093	1.967	0	9
Max Temp	87239	4.495	1.775	0	9
Min Temp	87239	.787	.779	0	3
Precipitation	87239	1.245	1.075	0	5
Wind	87239	1.356	1.032	0	5
Fire	87239	1.527	1.703	0	7
Hail	87239	1.109	1.181	0	6
E3CI Index	87239	.981	1.123	0	5

To get a better understanding of the data from E3Ci a Summary statics table was created, developing a summary statistic for each climate variable. These figures provide valuable insights into the overall frequency and severity of extreme events over the studied period:

- Drought: The mean score of 2.09 reflects a moderate frequency of rainfall deficits. Extreme drought events reached a value of 9, indicating significant water shortages during certain years. The standard deviation captures variability, highlighting the inconsistency in rainfall patterns.
- Max Temperature: With a mean score of 4.49 and a high standard deviation of 1.77, this variable indicates frequent and severe heatwaves. The high variability points to years with particularly extreme temperatures, reflecting the increasing prevalence of heat-related risks for industries reliant on outdoor operations and stable climate conditions.
- Precipitation: The mean score of 1.24 suggests that extreme precipitation events, while less frequent than drought or extreme heat, occurred regularly over the decade. Sudden heavy

rainfall, which can lead to flooding, poses serious risks to infrastructure, supply chains, and industries like transportation and agriculture.

- Hail: The mean score of 1.10 reveals that hailstorms, though less common, reached extreme levels in some cases, with scores as high as 6. These events can cause significant damage to crops, vehicles, and buildings, particularly in sectors like agriculture and construction.
- E3CI Index: The combined index averaging 0.98 offers a summary measure of climate stress. This index captures the aggregate impact of all extreme weather variables, serving as a useful indicator of overall environmental challenges faced by companies across multiple industries.

Mean Extreme Event Frequency by Year

Mean Extreme Event Frequency

	Drought	Max Temp	Min Temp	Precipitation	Wind	Fire	Hail	E3CI Index
2013	.44	2.53	1.76	.96	1.12	.52	1.3	.1
2014	1.01	3.3	0.53	1.3	.86	.14	1	.03
2015	1.65	5	0.56	1.1	1.7	1.13	1.53	1.42
2016	1.65	3.18	0.72	1.44	.71	.81	.68	.49
2017	1.68	4.03	0.60	.97	1.42	.82	.82	.61
2018	2.49	4.88	1.29	.94	1.02	2.47	.66	1.46
2019	.81	5.36	0.64	1.24	1.54	1.8	1.55	1.17
2020	4.28	5.08	1.03	1.39	2.07	2.93	1.01	2
2021	1.38	3.75	0.90	1.64	1.34	.35	2.54	.33
2022	5.21	6.63	0.34	1.01	1.5	3.71	0	1.64
2023	.48	5.29	0.25	2.29	1.73	1.42	1.16	1.35
Total	2.09	4.49	0.79	1.25	1.36	1.53	1.11	.98

After also a study to understand the years frequency of each extreme event was developed. This Table focuses on the annual mean frequency of extreme weather events, offering a year-by-year comparison of the variability in climate conditions from 2013 to 2023. This table highlights how the occurrence of extreme events fluctuated over time, revealing critical patterns that affect long-term risk assessments for industries.

Years like 2020 and 2021 recorded a notable increase in extreme temperature and drought conditions. These years were marked by intense heatwaves and significant rainfall deficits, which compounded risks for businesses. The frequent extreme heat events during these years might have put under pressure infrastructure, elevated energy consumption, and disrupted production schedules.

In contrast, 2022 presented a rise in fire-related risks, largely due to the combined effects of prolonged drought and extreme heat. This uptick in fire hazards during 2022 illustrates the cascading effects of multiple extreme weather events, particularly in regions vulnerable to wildfires. These conditions not only pose risks to human health and safety but also threaten business operations.

The data in the Mean Extreme Event Frequency by Year table demonstrates the significant interannual variability in extreme event frequency, underlining the importance of adaptive risk management practices. Some years, like 2016 and 2019, experienced relatively moderate levels of extreme weather events, while others, such as 2020 and 2022, presented more severe challenges. Understanding this variability is essential for developing flexible strategies to mitigate the effects of climate change on business operations and financial performance

Final Data Integration

The next stage involved integrating the climate data with firm-level financial data to create a comprehensive dataset covering the period from 2013 to 2023. This dataset forms the backbone of the empirical analysis, allowing for an investigation into how extreme weather events influence financial performance metrics, such as profit margins, return on assets (ROA), and liquidity ratios. The integration and merging followed these key steps:

1. Geographical matching: Firm locations, provided in the financial data, were matched, based on their national location, with the region of occurrence of the extreme event reported in the E3CI database. This matching ensured that the firm's climate exposure was accurately represented.
2. Year matching: to create a final database after matching for geographical location, the year of occurrence of the extreme climate event and the financial data were matched, in order to have a matching of the two and develop a final database, used as a foundation to run the regressions.

The final integrated dataset combines firm-level financial data from Orbis with region-specific climate event frequencies, providing a robust framework for analyzing the impact of extreme weather on the financial performance of Europe's manufacturing firms.

3.2 Empirical Methodology: Hypothesis and model

This study employs multiple regression analysis to evaluate the impact of climate change-related events on the financial performance of manufacturing firms in Europe. The regression framework allows for the estimation of how climate risks (e.g., drought, extreme temperatures) influence financial metrics such as Return on Assets (ROA), Return on Equity (ROE), and Profit Margins and leverage while controlling for firm-specific factors like size, liquidity. This approach isolates the direct effects of climate risks from other variables, providing precise insights into how these events affect firm performance.

Why use Regression Analysis?

The decision to use multiple regression analysis is based on the following advantages:

1. Quantifying Relationships: Regression models quantify the relationship between climate risks (independent variables) and financial performance metrics (dependent variables). The model estimates the strength and direction of these effects, making it clear how each climate variable, such as extreme temperature or drought, impacts firm performance.
2. Isolating Effects: By including control variables such as firm size and leverage, the regression analysis ensures that the effects of climate risks are isolated from other potential influences. This approach allows us to focus on the direct impact of climate events on financial outcomes.
3. Testing Hypotheses: Regression models allow for hypothesis testing by evaluating the significance of the coefficients. This enables the study to test whether the effects of climate risks on financial performance are statistically significant or could be attributed to chance.
4. Clarity and Interpretability: The results from regression models are easy to interpret. For example, a negative coefficient on drought for ROA would indicate that increased drought conditions lead to reduced asset efficiency, providing clear, actionable insights.
5. Adaptability: Regression analysis is flexible enough to handle different types of data (continuous, categorical), making it suitable for analyzing various financial metrics and accounting for the heterogeneity of firm characteristics.

In summary, multiple regression analysis offers a rigorous framework to identify and quantify how climate risks affect the financial performance of manufacturing firms, providing a solid empirical foundation for this research.

Regression Model Structure

The general structure of the regression models used to test the hypotheses is as follows:

$$
\begin{aligned}
Yit = \alpha + \beta 1 \cdot Droughtit + \beta 2 \cdot MaxTempit + \beta 3 \cdot MinTempit + \beta 4 \cdot Precipitationit \\
+ \beta 5 \cdot Windit + \beta 6 \cdot Fireit + \beta 7 \cdot Hailit + \beta 8 \cdot E3CIIndexit + \delta Zit + \epsilon it
\end{aligned}
$$

Where:

- Yit is the dependent variable representing the financial performance of firm i at time t.
- Drought it, MaxTemp it, MinTemp it, Precipitation it, Wind it, Fire it, Hail it are the independent variables capturing climate risks for firm i.
- E3CIIndexit is the Environmental Climate Impact Index measuring overall climate risk exposure.
- Zit represents a vector of control variables (e.g., firm size).
- ϵit is the error term, capturing unexplained variation.

This model structure will be adapted to each specific financial performance metric, as described in the following sections.

Hypothesis H1: Climate Events Impact Return on Assets (ROA)

Return on Assets (ROA) measures how efficiently a company uses its assets to generate profit. ROA is highly relevant for assessing the operational impact of climate risks. Extreme weather events, such as droughts, high temperatures, and heavy precipitation, could reduce asset efficiency by disrupting production processes, damaging infrastructure, or leading to underutilization of assets. ROA helps explain how external shocks like climate events affect the core profitability of the firm, particularly from an operational perspective.

Regression Model:

$$ROAit = \alpha + \beta 1 \cdot Droughtit + \beta 2 \cdot MaxTempit + \beta 3 \cdot MinTempit + \beta 4 \cdot Precipitationit + \beta 5 \cdot Windit + \beta 6 \cdot Fireit + \beta 7 \cdot Hailit + \beta 8 \cdot E3CIIndexit + \delta Zit + \epsilon it$$

Hypothesis H2: Climate Events Impact Return on Equity (ROE)

Return on Equity (ROE) measures how effectively a company generates profits from its shareholders' equity. ROE is important because it provides insights into how climate risks affect the firm’s ability to deliver value to shareholders. Severe climate events can increase operational costs or reduce revenues, ultimately lowering profitability. ROE captures the firm's overall financial health from a shareholder perspective and shows how well equity is being used in adverse conditions.

Regression Model:

$$ROEit = \alpha + \beta 1 \cdot Droughtit + \beta 2 \cdot MaxTempit + \beta 3 \cdot MinTempit + \beta 4 \cdot Precipitationit + \beta 5 \cdot Windit + \beta 6 \cdot Fireit + \beta 7 \cdot Hailit + \beta 8 \cdot E3CIIndexit + \delta Zit + \epsilon it$$

Hypothesis H3: Climate Events Impact Cash Flow to Operating Revenue

Cash Flow to Operating Revenue is a critical measure of a firm's liquidity and its ability to generate cash from its core operations. In times of climate-related disruptions, cash flow is directly impacted due to increased costs or operational halts. It is important to analyze how well a firm can maintain liquidity in the face of extreme events, as cash flow is crucial for meeting short-term obligations and funding operations. Cash flow is also a vital indicator of a firm's short-term financial health and resilience. Lower cash flow during climate risks could signal operational stress, difficulties in covering operating expenses, or delays in payments, which can affect the firm's overall liquidity and solvency.

Regression Model:

$$CashFlowit = \alpha + \beta 1 \cdot Droughtit + \beta 2 \cdot MaxTempit + \beta 3 \cdot MinTempit + \beta 4 \cdot Precipitationit + \beta 5 \cdot Windit + \beta 6 \cdot Fireit + \beta 7 \cdot Hailit + \beta 8 \cdot E3CIIndexit + \delta Zit + \epsilon it$$

Hypothesis H4: Climate Events Impact Gearing Ratio

The Gearing Ratio measures the proportion of a firm's debt relative to its equity. This is a key indicator of financial leverage and risk. Climate events may force firms to borrow more to cover damages, fund repairs, or make up for lost revenues, thus increasing their debt levels. Monitoring changes in the gearing ratio provides insight into how climate risks affect firms' financial structure and long-term risk profile.

Regression Model:

$$Gearingit = \alpha + \beta 1 \cdot Droughtit + \beta 2 \cdot MaxTempit + \beta 3 \cdot MinTempit + \beta 4 \cdot Precipitationit + \beta 5 \cdot Windit + \beta 6 \cdot Fireit + \beta 7 \cdot Hailit + \beta 8 \cdot E3CIIndexit + \delta Zit + \epsilon it$$

Hypothesis H5: Climate Events Impact Profit Margins (EBIT and EBITDA)

EBIT (Earnings Before Interest and Taxes) and EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization) are widely used indicators of profitability. Profit margins provide insight into how well a company can maintain profitability in the face of increased costs or reduced revenues caused by climate risks. These measures help explain how efficiently a firm manages its costs relative to its revenue generation, which is critical during disruptive events.

EBIT Regression Model:

$$EBITMargini = \alpha + \beta 1 \cdot Droughtit + \beta 2 \cdot MaxTempit + \beta 3 \cdot MinTempit + \beta 4 \cdot Precipitationit + \beta 5 \cdot Windit + \beta 6 \cdot Fireit + \beta 7 \cdot Hailit + \beta 8 \cdot E3CIIndexit + \delta Zit + \epsilon it$$

EBITDA Regression Model:

$$EBITDAMargin = \alpha + \beta 1 \cdot Droughtit + \beta 2 \cdot MaxTempit + \beta 3 \cdot MinTempit + \beta 4 \cdot Precipitationit + \beta 5 \cdot Windit + \beta 6 \cdot Fireit + \beta 7 \cdot Hailit + \beta 8 \cdot E3CIIndexit + \delta Zit + \epsilon it$$

Control Variables in the Regression Models

To ensure the models accurately capture the effects of climate risks on financial performance, several control variables are included:

1. Firm Size: Larger firms may be more resilient to climate risks due to greater resources, so firm size is expected to have a positive impact on financial performance metrics like ROA and ROE.
2. Liquidity Ratio: Firms with higher liquidity ratios may have more flexibility to absorb short term financial shocks, so liquidity is expected to have a positive impact on financial outcomes.

3. Solvency Ratios: Higher solvency ratios suggest greater long-term financial stability, likely mitigating the financial impacts of climate risks. These are expected to have a positive relationship with financial performance.

4. Chapter 4: Regression Results and Discussion

4.1. Correlation Analysis

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
(1) CashflowOperat~e	1.000																					
(2) Currentratio	0.210	1.000																				
	(0.000)																					
(3) EBITmargin	0.776	0.249	1.000																			
	(0.000)	(0.000)																				
(4) EBITDAmargin	0.885	0.222	0.907	1.000																		
	(0.000)	(0.000)	(0.000)																			
(5) Gearing	-0.217	-0.175	-0.185	-0.172	1.000																	
	(0.000)	(0.000)	(0.000)	(0.000)																		
(6) Grossmargin	0.414	0.154	0.328	0.472	-0.054	1.000																
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)																	
(7) Liquidityratio	0.227	0.921	0.256	0.234	-0.181	0.151	1.000															
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)																
(8) Netassetsturno~r	-0.309	-0.227	-0.218	-0.314	0.058	-0.297	-0.202	1.000														
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)															
(9) Numberofemploy~s	0.039	-0.026	-0.014	0.033	0.036	0.097	-0.027	-0.067	1.000													
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)														
(10) Profitmargin	0.825	0.263	0.919	0.830	-0.255	0.307	0.278	-0.207	-0.022	1.000												
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)													
(11) ROAusingNetin~e	0.653	0.204	0.729	0.598	-0.276	0.122	0.202	-0.057	-0.051	0.780	1.000											
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)												
(12) ROEusingNetin~e	0.436	0.009	0.511	0.391	-0.081	0.047	0.021	0.125	-0.038	0.550	0.765	1.000										
	(0.000)	(0.012)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)											
(13) Solvencyratio~d	0.432	0.514	0.347	0.379	-0.652	0.143	0.486	-0.388	-0.034	0.405	0.342	-0.021	1.000									
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)										
(14) Solvencyratio~d	0.244	0.186	0.197	0.213	-0.550	0.076	0.155	-0.307	-0.019	0.231	0.248	0.023	0.984	1.000								
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)									
(15) drought_extre~u	-0.023	0.045	-0.013	-0.021	-0.030	-0.026	0.023	0.007	0.026	-0.009	0.009	-0.004	0.017	0.006	1.000							
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.042)	(0.000)	(0.007)	(0.010)	(0.199)	(0.000)	(0.183)								
(16) extrememaxT_e~f	-0.018	0.003	-0.021	-0.021	-0.012	0.051	-0.011	-0.013	-0.002	-0.012	-0.024	-0.026	-0.001	0.001	0.434	1.000						
	(0.000)	(0.322)	(0.000)	(0.000)	(0.001)	(0.000)	(0.002)	(0.000)	(0.598)	(0.000)	(0.000)	(0.000)	(0.674)	(0.777)	(0.000)							
(17) extrememinT_e~f	-0.026	0.034	-0.031	-0.032	-0.007	-0.056	0.040	0.021	0.021	-0.020	-0.003	0.002	0.004	0.005	0.068	-0.136	1.000					
	(0.000)	(0.000)	(0.000)	(0.000)	(0.039)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.453)	(0.542)	(0.210)	(0.222)	(0.000)	(0.000)						
(18) extremeprec_e~f	0.023	-0.012	0.020	0.020	-0.007	-0.056	-0.013	0.004	-0.010	0.013	0.025	0.010	0.029	-0.001	-0.181	-0.093	-0.181	1.000				
	(0.000)	(0.000)	(0.000)	(0.000)	(0.049)	(0.000)	(0.000)	(0.210)	(0.005)	(0.000)	(0.000)	(0.003)	(0.000)	(0.851)	(0.000)	(0.000)	(0.000)					
(19) extremewind_e~f	0.002	0.026	0.007	0.002	0.012	-0.029	0.024	-0.007	-0.006	0.001	-0.002	-0.006	0.010	0.004	0.066	0.119	-0.013	0.122	1.000			
	(0.682)	(0.000)	(0.043)	(0.554)	(0.000)	(0.000)	(0.000)	(0.054)	(0.102)	(0.866)	(0.511)	(0.064)	(0.004)	(0.316)	(0.000)	(0.000)	(0.000)	(0.000)				
(20) fire_extreme_~c	-0.046	0.034	-0.042	-0.042	-0.021	0.041	0.010	0.008	0.028	-0.036	-0.036	-0.033	-0.007	-0.001	0.658	0.595	0.069	-0.291	0.038	1.000		
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.019)	(0.000)	(0.000)	(0.000)	(0.000)	(0.050)	(0.833)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
(21) hail_extreme_~c	0.021	-0.025	-0.002	0.013	-0.020	0.040	-0.023	-0.019	-0.025	0.000	-0.005	-0.007	0.011	0.006	-0.291	-0.152	0.071	-0.002	0.034	-0.194	1.000	
	(0.000)	(0.000)	(0.623)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.948)	(0.145)	(0.061)	(0.001)	(0.149)	(0.000)	(0.000)	(0.000)	(0.476)	(0.000)	(0.000)		
(22) E3CIIndex_ext~e	-0.039	0.033	-0.031	-0.038	-0.024	0.002	0.018	0.014	0.030	-0.026	-0.017	-0.017	0.001	-0.005	0.499	0.519	0.156	-0.131	0.181	0.697	-0.061	1.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.657)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.665)	(0.251)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	

To understand possible multicollinearity and the relationship between variable correlation matrix was developed. This analysis allows for a basic understanding of how these variables interact, shedding light on potential associations that can inform the subsequent regression analysis.

First, as expected, the financial performance metrics demonstrate strong internal correlations. Cash Flow to Operating Revenue exhibits a highly positive correlation with Profit Margin (0.825, $p < 0.01$), indicating that firms generating higher profit margins are also more likely to generate stronger cash flows. Similarly, EBIT Margin and EBITDA Margin are highly correlated (0.776, $p < 0.01$), which is expected given that EBITDA is derived from EBIT by excluding non-cash expenses such as depreciation and amortization. This strong association suggests that both variables effectively measure operational profitability, though EBITDA may be a slightly better indicator of cash-generating capacity.

Another notable finding from the matrix is the positive correlation between Liquidity Ratio and profitability metrics like ROA (0.227, $p < 0.01$) and ROE (0.255, $p < 0.01$). This suggests that firms with better liquidity are generally more capable of generating returns on assets and equity.

Liquidity, as an indicator of a firm's ability to meet short-term obligations, appears to play a crucial role in maintaining profitability, especially in environments where operational disruptions may occur due to climate risks. The correlation with both profitability measures further emphasizes the importance of liquidity in firm resilience.

Similarly, the Solvency Ratio (Asset-based) demonstrates strong positive correlations with key financial metrics like Cash Flow (0.432, $p < 0.01$), ROA (0.653, $p < 0.01$), and ROE (0.504, $p < 0.01$). This reinforces the notion that firms with stronger balance sheets, particularly those with a higher proportion of assets relative to liabilities, are better positioned to sustain profitability and operational efficiency. Conversely, the Solvency Ratio (Liability-based) has a weaker, yet still significant, positive relationship with ROA (0.144, $p < 0.01$), suggesting that firms with lower liabilities relative to equity also tend to perform better financially.

In terms of the climate variables, the results from the correlation matrix reveal weaker associations with financial performance metrics. Max Temperature shows weak negative correlations with ROA (-0.018, $p > 0.05$), ROE (-0.051, $p > 0.05$), and Cash Flow (-0.034, $p > 0.05$). Though the signs suggest a potential adverse effect of extreme temperatures on firm performance, these relationships are not statistically significant at conventional levels. Similarly, Drought, Precipitation, and Wind exhibit weak and statistically insignificant correlations with financial metrics. These findings suggest that the direct linear relationships between individual climate variables and financial outcomes may not be strong, indicating that the effect of climate risks on firm performance is likely more complex and might require a more nuanced analysis, such as regression modeling, to capture these dynamics.

One notable exception in the climate data is the E3CI Index, which captures the frequency of extreme climate events. It shows a positive and significant correlation with EBIT Margin (0.143, $p < 0.01$) and EBITDA Margin (0.149, $p < 0.01$), suggesting that firms exposed to more frequent extreme events may still maintain or even improve profitability margins. This may reflect the ability of these firms to adapt to climate risks through operational resilience or investment in risk management strategies.

In summary, while the correlation matrix provides valuable initial insights, particularly regarding the importance of liquidity and solvency for maintaining financial performance, it suggests that climate variables such as extreme temperatures, drought, and precipitation do not exhibit strong linear relationships with firm profitability. The overall positive correlation of the E3CI Index with profitability metrics points to the potential for certain firms to develop resilience in the face of climate-related risks, though more in-depth regression analysis is necessary to confirm these findings and explore the interactions between financial health and climate exposures.

4.2 Regression and results

VARIABLES	(1) ROA using Net income	(2) ROE using Net income	(4) Cash flow/Operating revenue	(5) Gearing	(6) EBIT Margin	(7) EBITDA Margin
Drought - Extreme Event Frequency	0.032	0.140	0.016	-0.057	0.008	0.030
	(0.043)	(0.157)	(0.032)	(0.259)	(0.038)	(0.030)
Max Temp - Extreme Event Frequency	-0.049	-0.096	-0.034	0.161	-0.015	-0.038
	(0.038)	(0.139)	(0.028)	(0.207)	(0.032)	(0.026)
Min Temp - Extreme Event Frequency	0.027	-0.033	0.092*	-0.168	0.015	0.051
	(0.076)	(0.275)	(0.053)	(0.591)	(0.058)	(0.046)
Precipitation - Extreme Event Frequency	-0.041	-0.296	-0.004	0.151	-0.059	-0.014
	(0.051)	(0.181)	(0.042)	(0.398)	(0.043)	(0.035)
Wind - Extreme Event Frequency	0.003	0.003	0.024	-0.433	-0.043	0.022
	(0.046)	(0.174)	(0.038)	(0.324)	(0.042)	(0.030)
Fire - Extreme Event Frequency	-0.066	-0.246	-0.003	-0.042	-0.079**	-0.026
	(0.047)	(0.173)	(0.037)	(0.327)	(0.037)	(0.030)
Hail - Extreme Event Frequency	-0.014	0.010	-0.022	0.396	-0.062	-0.036
	(0.049)	(0.163)	(0.043)	(0.311)	(0.039)	(0.037)
E3CI Index - Extreme Event Frequency	0.105*	0.327	0.078*	-0.529	0.143***	0.107***
	(0.060)	(0.215)	(0.046)	(0.447)	(0.052)	(0.035)
Current ratio	-0.555***	-0.637**	-0.394***	37.198***	-0.229***	-0.344***
	(0.076)	(0.280)	(0.075)	(1.369)	(0.069)	(0.070)
Liquidity ratio	1.195***	4.000***	0.582***	-16.415***	0.893***	0.686***
	(0.125)	(0.491)	(0.099)	(1.380)	(0.102)	(0.088)
Solvency ratio (Asset based)	0.227***	0.096	0.149***	-9.330***	0.151***	0.165***
	(0.012)	(0.111)	(0.014)	(0.370)	(0.011)	(0.013)
Solvency ratio (Liability based)	-0.043***	-0.152***	-0.020***	1.700***	-0.031***	-0.030***
	(0.006)	(0.041)	(0.007)	(0.143)	(0.006)	(0.007)
Constant	-8.188**	3.867	-3.456	280.897***	-5.118	-1.095
	(3.592)	(8.489)	(3.256)	(8.839)	(3.639)	(3.358)
Observations	48,780	46,489	43,742	48,402	50,159	46,971
R-squared	0.144	0.091	0.195	0.478	0.172	0.200

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The results are presented across six models, previously illustrated, each corresponding to a different dependent variable, allowing to analyze the effects of climate risk factors in a comprehensive manner. Overall, the findings highlight the multifaceted relationship between climate risks and firm performance, underscoring the importance of proactive climate risk management in maintaining financial health.

1. Impact on ROA and ROE

- Drought Frequency: The results suggest that the frequency of drought events has a positive but statistically insignificant effect on both ROA (0.032, $p > 0.1$) and ROE (0.140, $p > 0.1$). This indicates that droughts, although disruptive, may not severely impact asset efficiency or equity returns for manufacturing firms, possibly due to adaptations measure in their operational processes.
- Max Temperature Frequency: Higher temperatures are associated with a negative impact on both ROA (-0.049, $p > 0.1$) and ROE (-0.096, $p > 0.1$), though these effects are not statistically significant. These findings imply that extreme temperatures could slightly reduce asset efficiency and equity returns, possibly through increased cooling costs or disruptions in the supply chain.
- Min Temperature Frequency: Interestingly, the frequency of minimum temperature extremes shows mixed results, with a positive but insignificant impact on ROA (0.027, $p > 0.1$) and a positive significant impact on cash flow (0.092, $p < 0.1$). This suggests that milder weather conditions might slightly benefit operational cash flow but have a limited effect on overall returns.
- E3CI Index: The E3CI index, which aggregates various climate risks, shows a significant positive impact on ROA (0.105, $p < 0.1$), implying that firms exposed to higher environmental risks may benefit from improved asset efficiency, possibly through enhanced resource optimization or sustainable practices. The effect on ROE (0.327, $p > 0.1$) follows a similar positive trend but lacks statistical significance.

2. Impact on Cash Flow and Gearing

- Cash Flow to Operating Revenue: Cash flow results show some noteworthy patterns, particularly the positive and significant impact of minimum temperature frequency (0.092, $p < 0.1$) and the E3CI index (0.078, $p < 0.1$). These results suggest that firms may generate stronger cash flows during periods of milder temperatures and when they adopt strategies to address climate risks. Other extreme events, such as maximum temperature and precipitation, exhibit negative but statistically insignificant impacts on cash flow.
- Gearing Ratio: The E3CI index has a strong negative effect on the gearing ratio (-0.529, $p < 0.1$), indicating that firms exposed to climate risks prefer to reduce their reliance on debt. This could reflect a risk-averse financial strategy in response to environmental uncertainties. Other extreme weather variables, such as wind, drought, and precipitation, show no significant effect on gearing, indicating that these events do not drastically influence firms' leverage decisions.

3. Impact on Profit Margins (EBIT and EBITDA)

- EBIT and EBITDA Margins: The analysis reveals that extreme temperatures and fire events negatively impact profitability. For example, maximum temperature frequency exhibits a negative but insignificant impact on EBIT (-0.015, $p > 0.1$) and EBITDA (-0.038, $p > 0.1$). Fire events, however, have a statistically significant negative effect on EBIT margin (-0.079, $p < 0.05$), highlighting the operational challenges associated with fire-related disruptions. These results point to increased costs, such as production downtime or damage repair, affecting profitability.
- E3CI Index: In contrast, the E3CI index consistently shows a significant positive effect on both EBIT (0.143, $p < 0.01$) and EBITDA margins (0.107, $p < 0.01$). This suggests that firms facing higher climate risks are more capable of maintaining profitability, possibly through resilient operational strategies and climate adaptation measures.

4. Control Variables

- Current Ratio: The current ratio has a significant negative effect on cash flow (-2.047, $p < 0.01$) and gearing (-0.394, $p < 0.01$), indicating that firms with higher liquidity ratios tend to have lower reliance on debt but may face challenges in efficiently managing cash flow. This finding suggests that while liquidity helps reduce leverage, it may come at the cost of less effective cash flow management.

- Liquidity Ratio: The liquidity ratio, however, has a positive and statistically significant effect on several performance indicators, particularly ROA (1.195, $p < 0.01$), ROE (4.000, $p < 0.01$), and EBIT margin (0.893, $p < 0.01$). This implies that firms with stronger liquidity are more resilient to financial shocks, including those caused by climate-related risks, and can maintain stronger performance in terms of both returns and profitability.
- Solvency Ratios: The asset-based solvency ratio has a positive effect on ROA (0.227, $p < 0.1$) and cash flow (0.149, $p < 0.1$), suggesting that firms with a solid balance sheet perform better in terms of asset utilization and liquidity. Conversely, the liability-based solvency ratio has a negative and significant impact on ROA (-0.043, $p < 0.01$) and ROE (-0.152, $p < 0.01$), indicating that higher financial leverage negatively affects asset efficiency and shareholder returns, particularly in the face of climate risks.

4.3 Summary of Findings

To summarize the regression results, the following table provides an overview of the effects of climate variables on each financial performance indicator. The signs indicate the direction of the relationship, while statistical significance is marked where applicable.

	ROA	ROE	Cash Flow	Gearing	EBIT Margin	EBITDA Margin
Drought	0	0	0	0	0	0
Max Temperature	-	-	0	+	0	0
Min Temperature	+	0	+	-	0	0
Precipitation	0	0	0	0	0	0
Wind	0	0	0	-	0	0
Fire	-	-	0	0	-* **	0
Hail	0	0	0	0	0	0
E3CI Index	+* **	+	+* **	-* **	+* **	+* **
Current Ratio	-	-	-	+	-	-* **
Liquidity Ratio	+	+	+	-	+	+
Solvency Ratio (Assets)	+* **	+* **	+* **	0	+* **	+* **
Solvency Ratio (Liabilities)	-* **	-* **	-* **	+* **	-* **	-* **

Notes:

- "0" indicates no statistically significant effect.
- "-" and "+" indicate the direction of the relationship (negative or positive, respectively).
- *** indicates significance at the 1% level.
- ** indicates significance at the 5% level.
- indicates significance at the 10% level.

Key Insights:

The analysis uncovered several key insights into how climate variables impact financial performance. The E3CI Index consistently showed a positive effect on ROA, Cash Flow, EBIT, and EBITDA Margins, suggesting that firms are generally resilient to climate risks and, in some cases, may even benefit from exposure to extreme events.

Wind events had a negative impact on Gearing, indicating firms reduce their debt reliance when facing wind-related disruptions. Fire, however, negatively affected EBIT Margins, highlighting the damaging effect of fires on profitability.

Liquidity Ratio was a strong positive contributor across most metrics, reinforcing the importance of liquidity in navigating climate disruptions. In contrast, the Current Ratio negatively impacted ROA, Cash Flow, and EBIT, suggesting inefficiencies from excess short-term assets.
Lastly, firms with higher Solvency Ratios performed better, demonstrating that strong solvency positions are crucial for maintaining profitability and efficiency under climate risks.

5. Chapter 5 Research Limitation and future research

In light of the results obtained, it is important to outline the potential limitations of this research, which may have influenced the findings. One key limitation is the geographical scope used in the analysis. The extreme weather events were measured at the national level rather than being localized to specific location. This approach may have averaged the effects of extreme events, reducing the observed impact on financial performance and weakening the significance of negative outcomes. The averaging effect likely diminished the granularity of the data, thus obscuring the true variation in how different regions within a country are affected by extreme weather. In future research, it would be beneficial to adopt a more detailed geographical approach, analyzing events at a local or regional level with a maximum distance of 100 km. This would allow for a more accurate comparison of extreme weather events and their financial impacts, providing clearer insights into the relationship between proximity to events and financial performance.

Another limitation arises from the potential issue of endogeneity, which could be present in this analysis. Endogeneity occurs when independent variables are correlated with the error term, possibly due to omitted variables that influence both climate events and financial performance. Such missing variables may have skewed the results, leading to biased conclusions. Addressing this concern in future studies by using more robust econometric models or introducing instrumental variables would help mitigate the risk of endogeneity, improving the accuracy of the findings.

Furthermore, the fact that this research was conducted in Europe may limit the generalizability of the results. Europe, as an advanced economy, has a strong focus on climate change adaptation and mitigation measures. This could mean that European firms are better equipped to manage the financial impacts of extreme weather events compared to firms in other regions. The presence of comprehensive regulations, infrastructure, and adaptation strategies in Europe may have reduced the significance of the climate-related financial effects observed in this study. For future research, it would be interesting to explore the impacts of extreme climate events in regions with varying levels of economic development, particularly in areas where mitigation measures are less advanced. This would allow for a deeper understanding of how climate risks affect financial performance across different contexts.

In addition, future research could focus on regional deep-dive analyses to identify the specific geographic areas and industries most vulnerable to extreme weather events. This would help to highlight the region’s most at risk, providing valuable information for both policymakers and businesses on how to better prepare for and mitigate the financial impacts of climate change. By focusing on the most vulnerable regions and sectors, future studies could also offer more targeted insights into how firms can build resilience in the face of increasing climate risks.

In conclusion, while this research offers valuable insights, its limitations highlight the need for further exploration. More localized analysis, addressing potential endogeneity, and expanding the study to different regions will enrich our understanding of the complex relationship between extreme climate events and financial performance.

6. Chapter 6: Conclusion

This thesis has explored a pressing and current theam that is impacting our life on a daily basis, climate change. In particular its impact on the financial performance of Europe’s manufacturing sector, revealing both challenges and opportunities for resilience. Through empirical analysis, it has been demonstrated that extreme climate events can cause substantial disruptions to operations, profitability, and overall financial stability. Yet, firms with strong liquidity and solvency structures are often better equipped to withstand these disruptions, highlighting the importance of financial health in mitigating the adverse effects of climate risks.

The authenticity and relevance of this research cannot be overstated, particularly given the ever-increasing urgency of the climate crisis. Climate change is a global challenge, affecting not just the natural environment but the economic foundations upon which societies are built. The threat it poses to financial performance in key industries underscores the magnitude of the crisis and the need for immediate and sustained action. Even if the findings of this research do not completely align with the broader consensus that climate change represents an existential threat, not only to ecosystems but to global economies and the future of industries. The frequency and severity of extreme climate events are expected to continue rising, and the financial impacts of these events will likely grow in the near future unless immediate and radical change are made. For this reason, businesses, governments, and policymakers must collaborate to develop strategies that enhance resilience and sustainability.

However, while the research has provided valuable insights, it is essential to acknowledge the limitations of this study and the potential for further exploration. One limitation of this research lies in its geographic scope. The analysis focused on Europe, a region that is relatively advanced in terms of climate change mitigation and adaptation strategies. European firms benefit from strong regulatory frameworks, access to technological innovations, and government support for sustainability initiatives. As a result, the findings may not fully capture the experiences of firms in other regions, particularly in developing economies where climate risks are more pronounced, and mitigation efforts are less advanced. Future research could expand beyond Europe to examine the impact of extreme climate events on financial performance in other parts of the world, such as regions with higher climate vulnerability or weaker regulatory frameworks.

Additionally, this research did not fully explore the potential issue of endogeneity, which may have influenced the results. Endogeneity occurs when independent variables, such as climate risk exposure, are correlated with the error term, potentially biasing the findings. Addressing this issue in future studies through more robust econometric models, such as instrumental variables or two-stage least squares, would strengthen the validity of the conclusions. This would ensure that the relationships identified between climate risks and financial performance are more accurately measured and better understood.

The potential for future research in this area is vast and essential. As climate change continues to accelerate, the need for in-depth, data-driven studies on its impact on financial performance will become increasingly critical. Future studies could delve into specific industries, examining how different sectors are affected by various climate risks. For example, the manufacturing sector, which was the focus of this thesis, is highly sensitive to supply chain disruptions caused by extreme weather events.

Moreover, future research could explore the role of technological innovation in enhancing resilience to climate risks. As the world transitions toward a low-carbon economy, the adoption of new technologies, such as renewable energy, carbon capture, and smart grid systems, will play a critical role in mitigating the effects of climate change. Understanding how these technologies impact financial performance, both in terms of reducing costs and creating new revenue streams, would provide valuable insights for firms seeking to enhance their resilience.

The importance of decarbonization as a pathway to future economic growth cannot be overstated. In his recent speech, Mario Draghi emphasized the pivotal role that Europe must play in leading the global charge toward decarbonization. As Draghi pointed out, in its report on Europe's future competitiveness (2024), the union need to foster its ability to innovate in clean technologies and to reduce its reliance on fossil fuels. The transition to a low-carbon economy is not only necessary to meet climate targets but also represents an unparalleled opportunity for economic growth. The green economy is poised to be a major driver of job creation, technological innovation, and industrial competitiveness. Europe, with its strong regulatory frameworks, technological expertise, and commitment to sustainability, is uniquely positioned to lead this global transition.

Draghi's call to action is particularly relevant in the context of this research. Decarbonization is not only the key to mitigating the risks associated with climate change but also the path to unlocking new opportunities for growth. As noted in *The Future of European Competitiveness* report, the joint focus on decarbonization and innovation is essential for maintaining Europe's global leadership (The future of European competitiveness). The shift toward clean technologies, renewable energy, and circular economies will allow Europe to mitigate the effects of climate change while driving economic growth and industrial transformation.

In the context of global climate policy, Europe must continue to strengthen its leadership in decarbonization. Draghi's emphasis on the importance of decarbonization resonates with the broader goals of European competitiveness and sustainability. Europe has the opportunity to become a global leader in clean technologies, from renewable energy to electric vehicles, while also ensuring that its industries remain competitive in a rapidly changing global economy. However, achieving this goal will require bold and coordinated action from governments, businesses, and civil society. Policymakers must implement policies that support the transition to a low-carbon economy, while businesses must invest in the technologies and strategies that will allow them to thrive in a climate-conscious world.

Looking ahead, the path forward is clear. Decarbonization, innovation, and resilience are the pillars upon which Europe's future economic success will be built. By embracing these principles, Europe can not only mitigate the risks associated with climate change but also secure long-term economic growth and global leadership. The findings of this research reinforce the idea that firms that prioritize sustainability and climate resilience are better positioned to succeed in the face of growing climate risks. The manufacturing sector, a key contributor to Europe's economy, must continue to lead the charge in adopting clean technologies, enhancing sustainability, and building resilience to climate disruptions.

In conclusion, this thesis has highlighted the critical need for continued research, innovation, and action to address the growing threats posed by climate change. The findings underscore the importance of decarbonization as the only viable path to future economic growth and sustainability. Mario Draghi's call for Europe to lead the global transition to a low-carbon economy is not only timely but necessary. Decarbonization is not just a strategy for mitigating climate risks; it is essential for ensuring the survival of our industries, economies, and societies in the face of an increasingly uncertain climate future. Only by aligning economic growth with environmental sustainability can Europe secure its place as a global leader, ensuring the well-being of its industries, economy, and society for generations to come.

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Picture index

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- Figure 9: Scatterplot of HDI vs. Climate Disaster Impact. *Global Map of Climate-Related Disaster Hotspots: A all impact combined, B Flash flood, C Droughts, D Hit waves. Donatti, C. I., Nicholas, K., Fedele, G., Delforge, D., Speybroeck, N., Moraga, P., Blatter, J., Below, R., & Zvoleff, A. (2024). Global hotspots of climate-related disasters. International Journal of Disaster Risk Reduction, 108, 104488.*
- Figure 10 & 11: Aggregation of natural and tech disaster form 2013 to 2023 from EM-Data
- Figure 12: Detailed Breakdown by Natural Disasters in Europe 2013 to 2023 from EM-Data. All amount in dollar are provided in ('000 US$), the adjustment is here better explained.
- Figure 13 &14 : Detailed Breakdown by countries in Europe 2013 to 2023 for Natural and Tech disaster from EM-Data. All amount in dollar are provided in ('000 US$).
- Figure 15: Climate-Related Risks, Opportunities, and Financial Impacts. Task Force on Climate-related Financial Disclosures (TCFD). (2017). *Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures*.

Appendix:

To assess the regression model assumptions, the following three diagnostic tests were performed:

1. Q-Q Plot: This test evaluates the normality of the residuals by comparing their distribution to a theoretical normal distribution. Deviations from the diagonal line indicate that the residuals are not normally distributed, which may affect the accuracy of statistical inferences.
2. Histogram of Residuals: A bell-shaped histogram centered around zero would confirm normality of residuals. However, skewness or heavy tails suggest non-normality, potentially impacting the reliability of the model's results.
3. Residuals vs. Fitted Values Plot: This plot examines the homoscedasticity assumption by checking whether the residuals are randomly scattered around zero. Patterns or clustering in this plot suggest heteroscedasticity, which can lead to inefficient estimates and biased standard errors.

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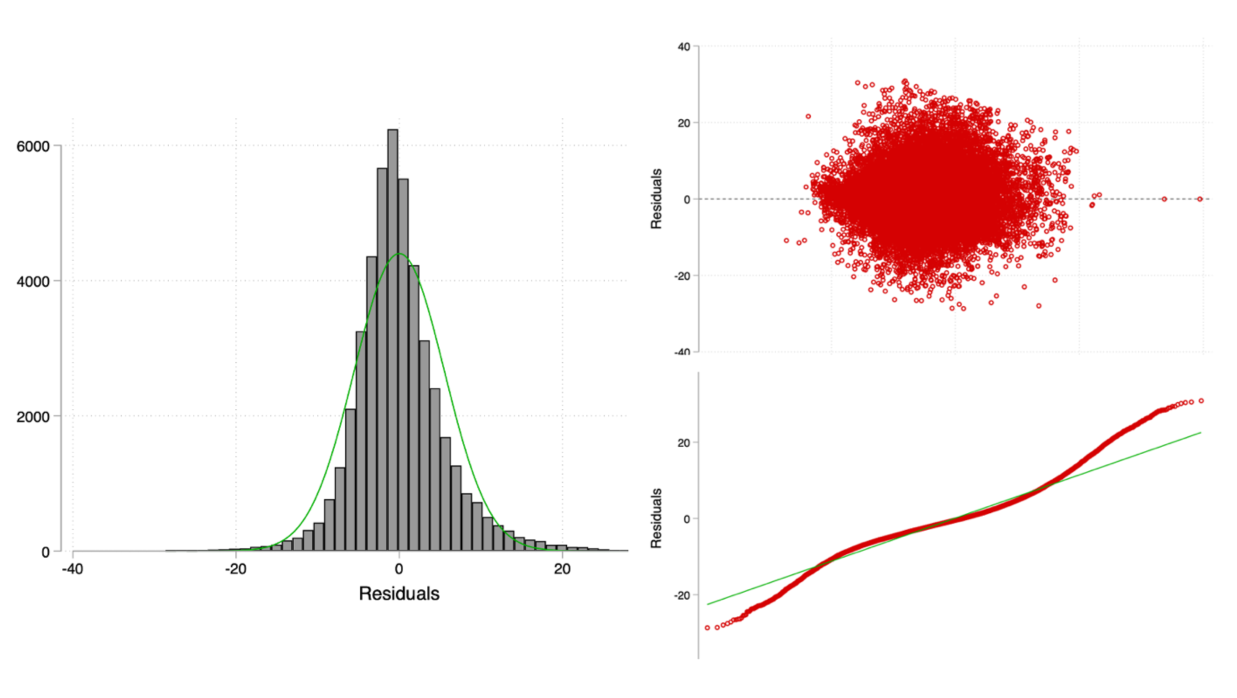

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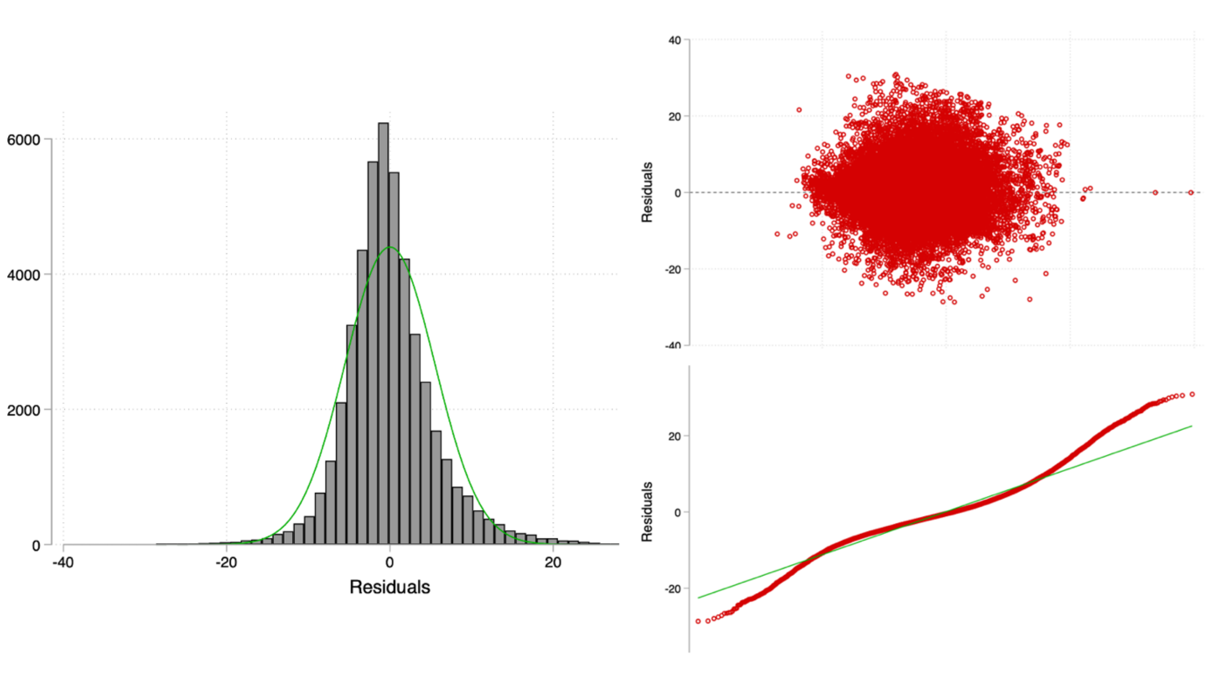
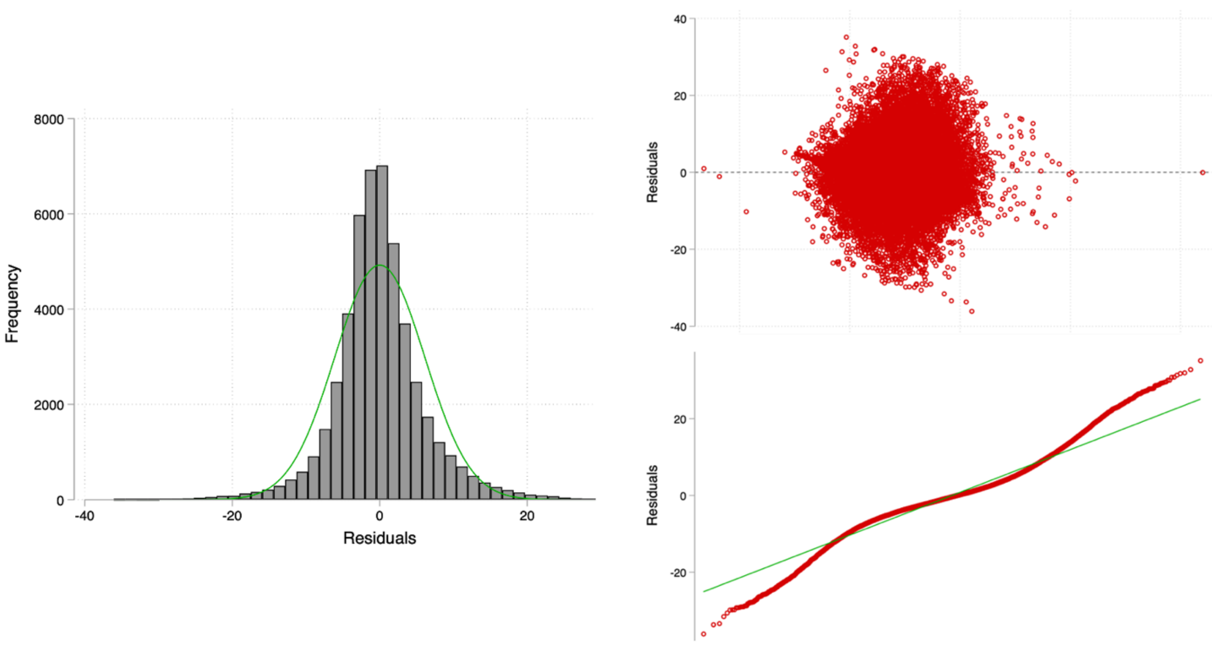
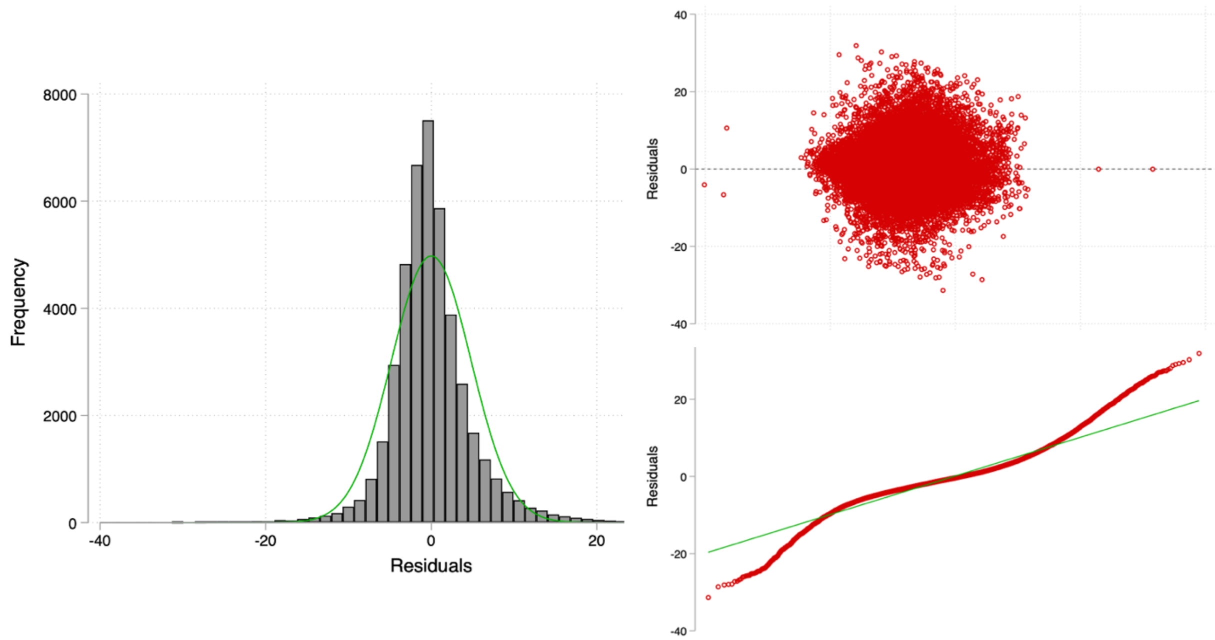


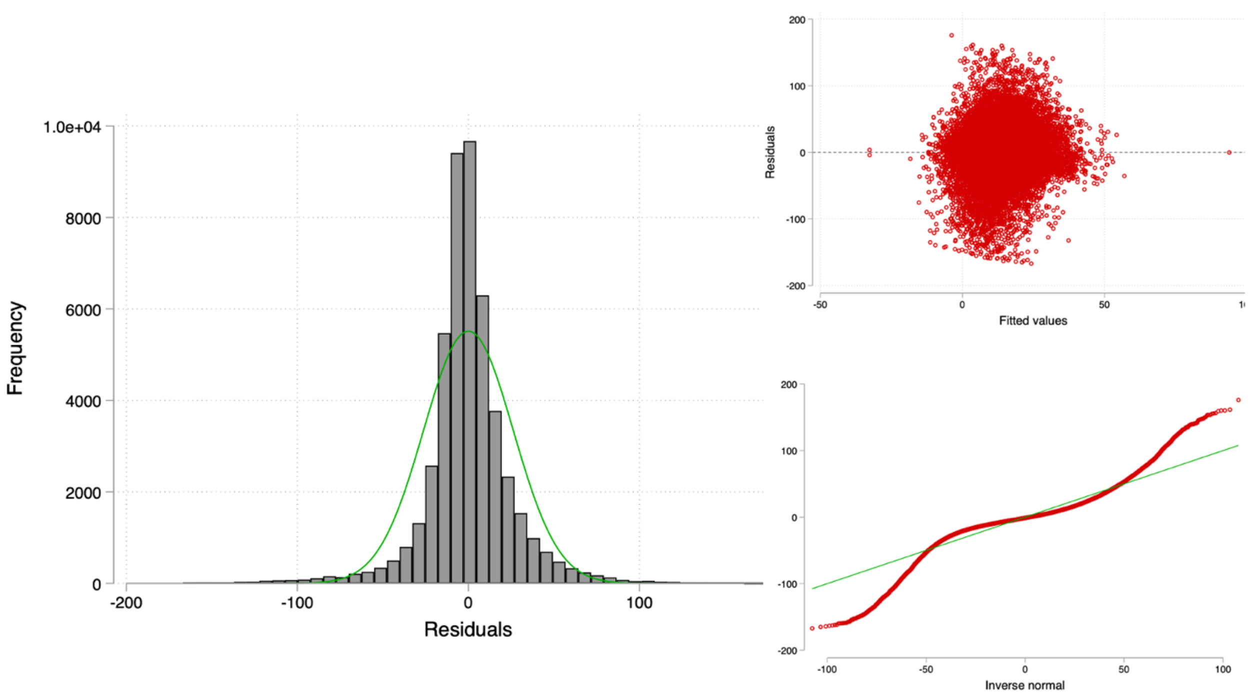
Cash Flow



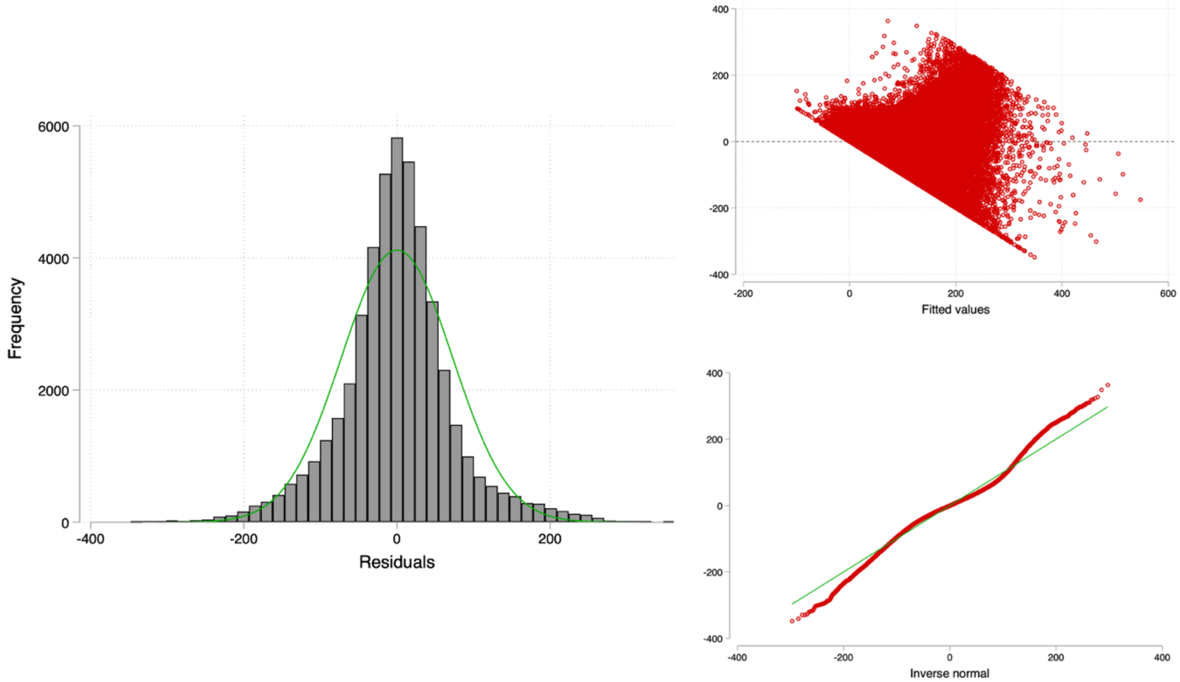
ROA


Frequency
Residuals
Residuals
Residuals

ROE


Frequency
Residuals
Residuals
Fitted values
Inverse normal

Gearing



Frequency
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-400
-200
0
200
Residuals
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200
0
-200
-400
-200
0
200
400
600
Fitted values
400
200
0
-200
-400
-400
-200
0
200
400
Inverse normal