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The Impact of Climate Variability on Major European Economies

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FOREWORD

The Urgent Call for the Design of Actionable Climate Risk Indicators

Since the last 2008 financial crisis, the management of Non-Financial Risks (NFR) has gained in sophistication and is attracting an ever-increasing allocation of resources. This observation applies not only to financial institutions but to all companies operating in a growingly complex world that requires all risks to be clearly identified, quantified, managed and controlled to ensure stable growth in profitability and value. Non-financial risks are often defined as any risk other than traditional financial risks, i.e., foreign exchange, interest rate, commodity or credit risks, as if there were risks with non-financial consequences on the one hand and those with financial consequences on the other. To academics, risk is about uncertainty of outcome and probability distribution. Business managers refer to loss and probability. The Institute of Risk Management defines risk as the combination of the probability of an event and its consequence. Ultimately, what it says is that all risks have financial consequences.

Non-financial risks typically include operational, compliance, ethics and conduct, information technology and cyber, business continuity, fraud, money laundering, third party, and legal risks. They tend to cover qualitative strategic risks that involve many internal and external stakeholders in the value creation chain. Firms generally lack data on these risks and managing them can be challenging.

Climate risks meet all of the above eligibility criteria. Yet one can browse through the content of the reports published by the major audit and advisory firms on non-financial risks, or even the annual surveys of the Centre for the Financial Professions, climate risks are hardly mentioned and do not appear as a clearly identified stand-alone risk category.

At best, climate risk is buried in the concept of strategic risks among other factors resulting from the adoption by firms and institutions of a more climate-friendly approach in their business model, such as the Environment, Society and Governance (ESG), changing societal expectations and socio-political challenges.

One aspect of climate risk, that of the company's potential impact on the climate and more specifically on climate change, is generally embedded in different categories of non-financial risks such as legal risks, or ethical and conduct risks.

Another aspect of climate risk relates to the impact of the climate on the firm. What exactly is it about? In part, this aspect of risk includes the consequences of extreme events such as hurricanes, storms or floods, which can damage or destroy productive assets, which is partly dealt with under the category of non-financial business continuity. In the ESG universe, these aspects are beginning to be addressed under a general heading of physical risk.

The first initiatives to measure physical risk or climate risk mostly have a qualitative approach, providing a vulnerability rating for a given sector or company, the use of which by an analyst or portfolio manager is not straightforward, due to the opacity of the methods, and the qualitative, not to say a perceived arbitrary, side of the ratings in question.

In addition, none of these methods consider another aspect of climate risk that is climate variability, i.e., the impact of abnormally hot, cold or wet periods, which spread throughout the value creation chain of each company, from the supply chain to the final consumer and increasingly affect cash flows and earnings.

The purpose of this research is to lay the groundwork of a quantitative method to measure the impact of climate variability on business activity.

Executive Summary

Every day, climate conditions influence consumption, supply and production decisions in a wide range of sectors. Academic literature has shown that climate can be an important factor influencing the level of demand and sales of many products and services, from energy to tourism, agriculture, construction and retail to name a few, although research to quantify and connect the contribution of climate variability to financial performance is still scarce.

Most climate-related economic impact studies seek to establish the long-term cost of climate change applicable to different sectors, making assumptions about the price of carbon, and long-term scenarios of greenhouse gas emissions converted into climate change. The resulting estimates struggle to provide reliable quantitative data and indicators that are easily usable today.

The time horizon of a company or policy maker is not that of a climatologist. One is measured in quarters or years while the other is measured in decades or centuries, a difference in perspective known as the "tragedy of the horizons", a term coined by Marc Carney, Governor of the Bank of England, to refer to the inability of governments and businesses to take action today when indicators measure long-term risk. In order to engage firms and investors in taking climate change into account today, these time horizons need to be reconciled.

The relationship between climate change and the private sector is not a one-way traffic. A body of the literature focuses on estimating the cost of complying with environmental guidelines and regulations, in other words the cost of *mitigating* the influence of the private sector on climate change. Another stream of the literature to which this research belongs measures the impact of climate change on the private sector, i.e., the cost of *adapting*.

And adapting to climate change is not just a long-term issue. Climate change is inextricably linked to *climate variability*. Climate change is the trend, variability is the standard deviation. Climate variability is the link that reconciles the time horizons of the economic agents and climatologists.

WMO reports and IPCC experts note that as a result of climate change, the number, duration and intensity of climate risks have increased significantly in recent decades, and this trend is expected to continue. The climate risk to which the private sector is exposed is a matter of unseasonal weather patterns. Climate conditions that are too

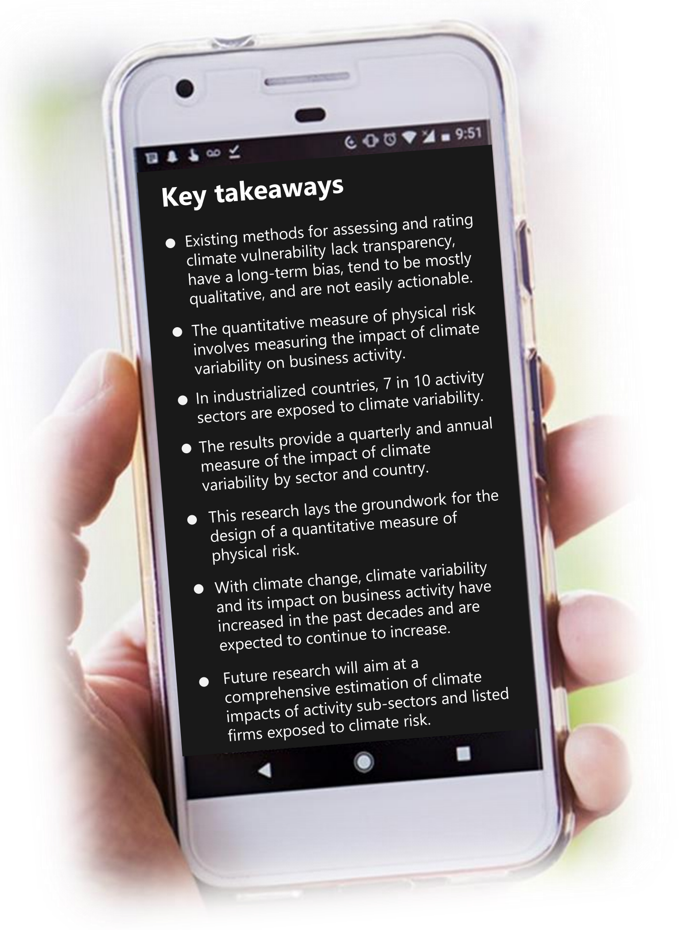
hot, too cold, too dry or too wet are anomalies that accumulate over the course of days, months and quarters and have a lasting and definitive impact on the sales and margins of many companies.

Measuring the potential impact of climate variability on the private sector means showing that climate change is already having an impact and providing actionable measures to encourage investors and business decision-makers to put an immediate price tag on climate change adaptation.

We analyze the influence of climate variability on the GDP of the top 5 major European economies. We develop a methodology to evaluate if and how temperature and precipitation anomalies specifically affect the Gross Value Added (GVA) of each Eurostat category of activity.

Despite the highly aggregated nature of GVA, and the inevitable offsetting phenomena within each sector of activity masking the specific impacts of climate variability, our methodology provides the quarterly and cumulative annual contribution of climate variability by sector, by country, and allows deriving the maximum potential impact of adverse climate variability using historical climate observations.

These results are a step in the right direction and call for further investigation on each activity sub-sector and ultimately on each listed firm, so as to provide each analyst and portfolio manager with a specific *quantitative* and *actionable* measure of climate risk.



BACKGROUND

Climate risks and business sectors

Retailers have long known that climate conditions influence sales and profits and can disrupt the best business plan. They affect consumers' decisions as to what products they buy, in what quantity, where, and when these purchases are made (Maunder, 1973; Agnew and Palutikof, 2006), and triggers purchases that would not have taken place otherwise.

Academic research on the influence of climate conditions on retail sales dates back to 1951, when Steele simply observed consumers in one department store in Iowa during several weeks and found that some climate conditions could discourage consumers from going to the store, notably in the case of unusually cold, warm, rainy, or windy conditions. He noted that other climate conditions could keep consumers home in the event of snow drifts over roads or have psychological effects that change consumers' shopping habits. He was the first to define in modern terms the ways by which climate conditions can affect sales, although at the time he did not quantify these impacts. Linden (1962) continued this work and showed that sales of women's winter coats in New York department stores were influenced by average monthly temperatures in September and October. The following year, Shor (1963), provided a first national estimate of the effects of climate variability on 13 retail sectors. It was not until 2000 that Starr-McCluer from the Federal Reserve provided an assessment of the impact of climate conditions on US retail sales.

Climate conditions are regularly mentioned to explain why sales volumes are lower than expected. The unusually warm winter temperatures across Europe in 2015–2016 were cited as the reason why consumer spending and sales were lower than expected. Individual firms are no exception. For instance, Superdry shares fell 21% after the company warned hot weather in Europe and the U.S. had hit demand for its jackets and sweats, and fashion giant Esprit's sales were down 16.3% in September 2018 with warm summer and early autumn to blame. The largest sporting goods retailer Sports Direct issued a profit warning in the run-up to Christmas blaming abnormal warm conditions. In July 2017, the UK DIY chain B&Q attributed a 10% drop in quarterly sales of barbecues, gardening equipment and outdoor furniture to adverse climate conditions in spring. The UK-based Restaurant Group, which operates more than 500 restaurants and pubs, claimed to have suffered sales decline partly due to wintry weather followed by a heatwave.

In the US, large groups such as Target, J.C. Penney, Lowe's and Home Depot all blamed poor spring weather in the US to explain disappointing first-quarter earnings. The casual-dining chain The Cheesecake Factory issued a profit warning because of lousy 2017 spring climate conditions that caused the share price to fall almost 11% in a day. At the same time, sales of Harley-Davidson were expected to fall, with weather in April and May to blame. In each case, however, the exact contribution of climate to the decline in performance was not assessed or reported, either by analysts or companies themselves.

Retail sales continue to be published and used by analysts and traders without being adjusted for the impact of climate variability

The fact that climate variability has an influence on the consumption of many consumer products, such as beverage, clothing, footwear, or cosmetics, is well accepted. Temperature and precipitation are the two most influential variables. Yet, retail sales continue to be published and used by analysts and traders without being adjusted for the impact of climate variability.

Retail is not the only sector involved. In recent years, a number of academic studies have shown that climate influences other sectors through the analysis of specific products in restricted geographical areas such as cities (Parikh 1979; Arbel and Ravid 1985; Parsons 2001; Murray et al. 2010; Ramanathan and Muyldermans 2010; Bahng and Kincade 2012).

Other studies have focused on understanding how severe events such as heat waves, cold winters, windstorms or heavy rains affect certain sectors of the economy (Bansal and Ochoa 2011; Schmidlin 1993; Changnon 2012; Niemel et al. 2002; Seppnen and Lei 2006; Connolly 2008; Cachon et al., 2012; Nordhaus 2010; Hsiang and Narita 2012; Golob and Recker 2003).

The researchers were thus able to demonstrate that, in addition to retail activities, a wide range of sectors such as energy, agriculture, agri-food, tourism, industry, transport, construction to name but a few, were exposed to the consequences of climate variability both upstream and downstream, i.e., demand and production (Deschênes and Greenstone, 2007; Mirasgedis et al., 2014; Changnon, 2012; Subak et al., 2000; Day et al., 2013; Fergus, 1999).

Even consumer behavior when shopping on-line is subject to the influence of weather (Steinker and Hoberg, 2017).

The accumulation of adverse climate conditions over several weeks or months can cause significant shortfalls in cash-flows

The climate risk to which businesses is exposed is due to the accumulation of adverse deviations of observed climate conditions from expected normal climate conditions (Dischel, 2002).

Risk does not exist in isolation, but against a business plan, a budget. In all sectors exposed to climate variability, business managers make assumptions about exchange rates, interest rates and commodity prices, evaluate potential losses if these parameters deviate from the chosen assumptions, and implement hedging strategies, either operational or financial, to limit the consequences of adverse market movements against plan.

When it comes to climate variability and its potential effects on sales and margins, the assumption made whether consciously or not by finance executives, analysts and investors is that climate conditions are *normal*. It is the unexpected deviation from normal conditions, called *anomalies*, that cause a problem. The accumulation of adverse climate conditions over several weeks or months can cause significant shortfalls in cash-flows.

For climatologists, normal conditions are defined as a 30-year average of daily observations (World Meteorological Organization). The 30-year period is updated every 10 years, to best reflect climate as experienced by consumers, and take into account the effects of climate change.

To compute normal temperatures on a given day, in a given place, the normal temperature is the average of the temperatures observed that day between 1981 and 2010. This year, the period for calculating normal climate conditions will change to 1991-2020 from 1981-2010.

This change of reference period is likely to have an impact on earnings forecasts especially in the energy sector for which temperature alone explains up to 85% of demand (Bertrand and Chabot, 2020).

Indeed, earnings forecast are used usually based on the total number of Heating Degree Days, a temperature index which measures the quantity of energy as a proxy to demand, by difference between the outside temperature and the comfort temperature of 18°C. Due to climate change and rising temperatures, the quantity of energy when the average temperature was calculated over 1991-2020 will be lower than the one resulting from the 1981-2010 average temperature. This inevitably will translate into sales and earnings.

Climate variability and economics

Research to quantify the contribution of climate variability to each component of the economy is scarce. Climate has in fact long been ignored by the economic theories. Geographers and climatologists such as Bruckner, Tooke, Huntington, Beveridge and Heckschner were the first to carry out scientific studies on the impact of climate variability on the economy. They analyzed the role of climate on crops and crop prices to understand its effect on rural employment, urban incomes and ultimately economic growth (Bertrand and Sinclair-Desgagné, 2011) .

It was not until 1875 that the economist Jevons, a pioneer in the use of mathematics and statistics in economics, modelled the relationship between climate variability and business cycles. Later, Moore (1914) linked precipitation cycles to business cycles in the United States.

In the early 2000s, Dutton (2002), using a subjective, non-empirical unsophisticated approach, aggregated marginal contributions to GDP of sectors he considered exposed to climate variability, namely agriculture, energy, construction, transportation, tourism and leisure and retail, and divided the aggregate amount by the total GDP to conclude that about 30 per cent of the US economy was exposed. Larsen (2006) used sensitivity factors and found that 7 in 10 activity sectors were affected by either temperature or precipitation levels.

Given the historical variability of weather close to 10%, their analysis leads to a contribution of climate each year of 3.5% of GDP (Figure 1). This means each year €87 billion in France, £75 billion in the UK, €601 billion in Europe and $750 billion in the United States. By way of comparison, the global economic impact of catastrophic weather events and natural disasters in 2018 is estimated at $160 billion, of which $80 billion was insured.

The only other study by Lazo et al. (2011) examined the sensitivity of the US private sector output to climate variability and estimated the annual economic output for 11 sectors as a function of economic inputs and climate. The authors used both temperature and precipitation. Contrary to Larsen and Dutton, they found a more modest level of exposure of the US economy but recognized that their methodology did not avoid possible wash-out effects between months or seasons. These wash-out effects arise when the same temperature or precipitation anomaly has a positive effect in a given month or season and an opposite negative effect in another season.

As a result, it is not detected with an annual analysis approach. In addition, the level of aggregation of the categories under consideration is such the potential effects of weather on sales within the same category may offset each other. The sensitivity of the European private sector to climate variability has not yet been investigated, which is the purpose of this research.

Climate change, climate variability, and business activity

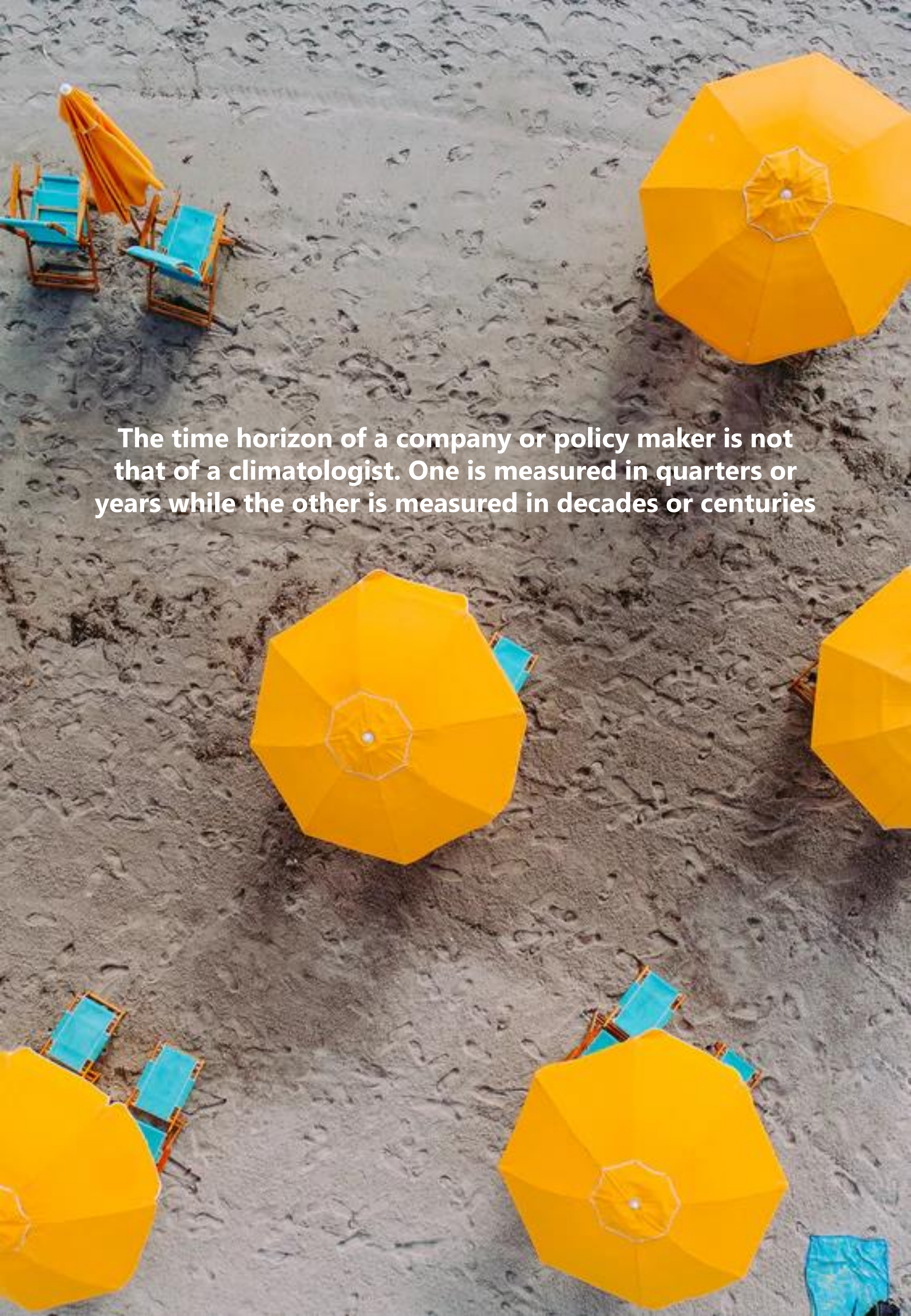
In the last few decades, climate variability and its potential influence on the economy have turned into a serious concern as climate change is exacerbating naturally occurring variability (WMO 2013; IPCC 2014). At the end of 2016, the audit firm EY stated that the number of profit warnings issued by UK listed companies citing the weather had outpaced those mentioning the impact of the EU referendum (Hudson et al. 2016). In the US, 60 companies of the S&P 500, including PepsiCo, Walmart, Starwood hotels, The Home Depot, or Johnson Controls stated that they were already battling the consequences of abnormal weather (CDP 2014).

Smaller businesses are even more exposed to weather risks. They are usually less diversified than large companies, do not have the same financial strength and resilience, and devote fewer resources to risk management than larger companies (Judge, 2006; Hiemstra et al., 2006; Davlasheridze and Geylani, 2017).

A report produced by the U.K. Federation of Small Businesses in 2015 confirmed the vulnerability of small businesses, with two-thirds of them reporting that they had been negatively affected by climate conditions in the previous three years. Furthermore, 93% of small business owners believed severe climate poses a threat to their survival, but half of them did not know how to assess and reduce their exposure to the consequences of adverse weather conditions.

In 2018, S&P Global ratings issued a report to confirm that all eyes are now on climate risks. Lenders and institutional investors are increasingly becoming more interested in how abnormal climate events are hitting the bottom lines of listed companies around the world. S&P examined public corporate annual reports and earnings calls to identify a disclosure or comment on climate conditions related to a *material* impact on earnings. 708 large listed companies in a wide range of business sectors, announced a material impact of climate conditions on their results and suffered the reaction of the market. Their report showed that climate and weather were the most frequently discussed topics between analysts and executives in earnings calls, even more common than "Trump", "the dollar", and "oil". By and large, the value of the contribution of climate to earnings or sales was unquantified: 89% of the time, management attributed to climate conditions an effect on earnings without putting a monetary value on this effect. In financial year 2017, the majority (87%) of mentions of climate risk factors came from quarterly earnings call transcripts as opposed to more formal methods of reporting such as annual reports.

This is however changing as pressure to report information on climate-related risks is building. In April 2015, the G20 Finance Ministers and Central Bank Governors asked the Financial Stability Board to convene public- and private-sector participants and review how the financial sector can take account of climate-related issues. To help identify the information needed by investors, lenders, and insurance underwriters and appropriately assess and price climate-related risks and opportunities, the Financial Stability Board established an industry-led task force: the Task Force on Climate-related Financial Disclosures (TCFD).



The time horizon of a company or policy maker is not that of a climatologist. One is measured in quarters or years while the other is measured in decades or centuries

The main purpose of TCFD’s framework is to allow financial markets to price climate risks and make informed capital allocation decisions

The TCFD was mandated to create a voluntary framework for companies to report climate-related risks in a way that would be useful to all stakeholders such as investors, lenders and insurance underwriters.

The Task Force has a broad mandate and is accountable to the G20. It draws on the expertise of 31 members covering all stakeholders, from investment funds to asset managers, accounting and consulting firms, pension funds, banks, insurers and rating agencies.

By September 2018, the TCFD issued a status report that confirming that 513 companies had already adopted the reporting framework, including 287 financial firms, managing assets of nearly $100 trillion. In September last year, the adoption rate had made further progress, reaching over 1,500 organizations globally, including over 1,340 companies with a market capitalization of $12.6 trillion and financial institutions responsible for assets of $150 trillion.

The main purpose of TCFD’s framework is to allow financial markets to price climate risks and make informed capital allocation decisions. Recommendations are designed to fit all organizations, to encourage forward-looking, decision-useful information on financial impacts, bridge the gap between long-term and short-term horizons, and emphasize information on risks and opportunities related to the transition to a lower-carbon economy. But TCFD remains *voluntary* and patchy.

Given the growing and urgent demand, it is likely that a *mandatory* framework will follow shortly, possibly under the leadership of the IFRS. A proposal, including a roadmap with timeline, is expected by the end of September 2021. Understanding the potential magnitude of the effects of climate events on earnings is expected to become more critical as climate variability and its influence on credit quality increase.

Reconciling the “Tragedy of Horizons”

Most studies that attempt to estimate the impact of climate change, be it on economic sectors or companies, focus on long-term potential impacts. Researchers usually make assumptions on the evolution of the price of carbon, the price of energy, economic growth, discount rates, and so on, assumptions to which should be added uncertainties related to long-term climate projections. Each study comes up with its own set of indicators and measures, that are tested in long-term climate scenarios based on integrated assessment models (IAMs) to project what the impact of climate change might be, and therefore what the climate-related risk premium might be in a distant future. Some methods are quantitative, others are qualitative, but very few provide actionable measures for both investors and risk managers.

The uncertainty surrounding long-term impact measures combined with the fact that this impact concerns a future that is outside the usual investment time horizon is a clear impediment to decision making and committing financial resources to address adaptation strategies.

Under these conditions, it is both difficult for decision makers to choose the relevant adaptation strategy and to convince stakeholders to commit financial resources today when the perceived potential benefit is far in the future.

The time horizon of a company or policy maker is not that of a climatologist. One is measured in quarters or years while the other is measured in decades or centuries, a difference in perspective known as the "tragedy of the horizons", a term coined by Marc Carney, Governor of the Bank of England, to refer to the inability of governments and businesses to act today when indicators measure long-term risk. For companies and investors to integrate climate change into their strategy today, they need indicators that measure the impact of climate change today, which is why we measure their vulnerability to climate variability.

For many years, the limited fluctuations of the weather around stable normal values had little impact on business activity. Over the past few decades, the global average temperature has risen and so has climate variability. Not everywhere, not every quarter, and not at the same pace. But overall, climate variability is rising. In Western Europe for instance, variability of Q2 temperature anomalies measured as the absolute value of the deviation from the mean has gone up 67% in France, 130% in Germany, 25% in the UK, and 43% in Spain between the last decade and the previous decade.

With climate change, climate variability has increased, making the need to measure its impact on business activity more pressing.

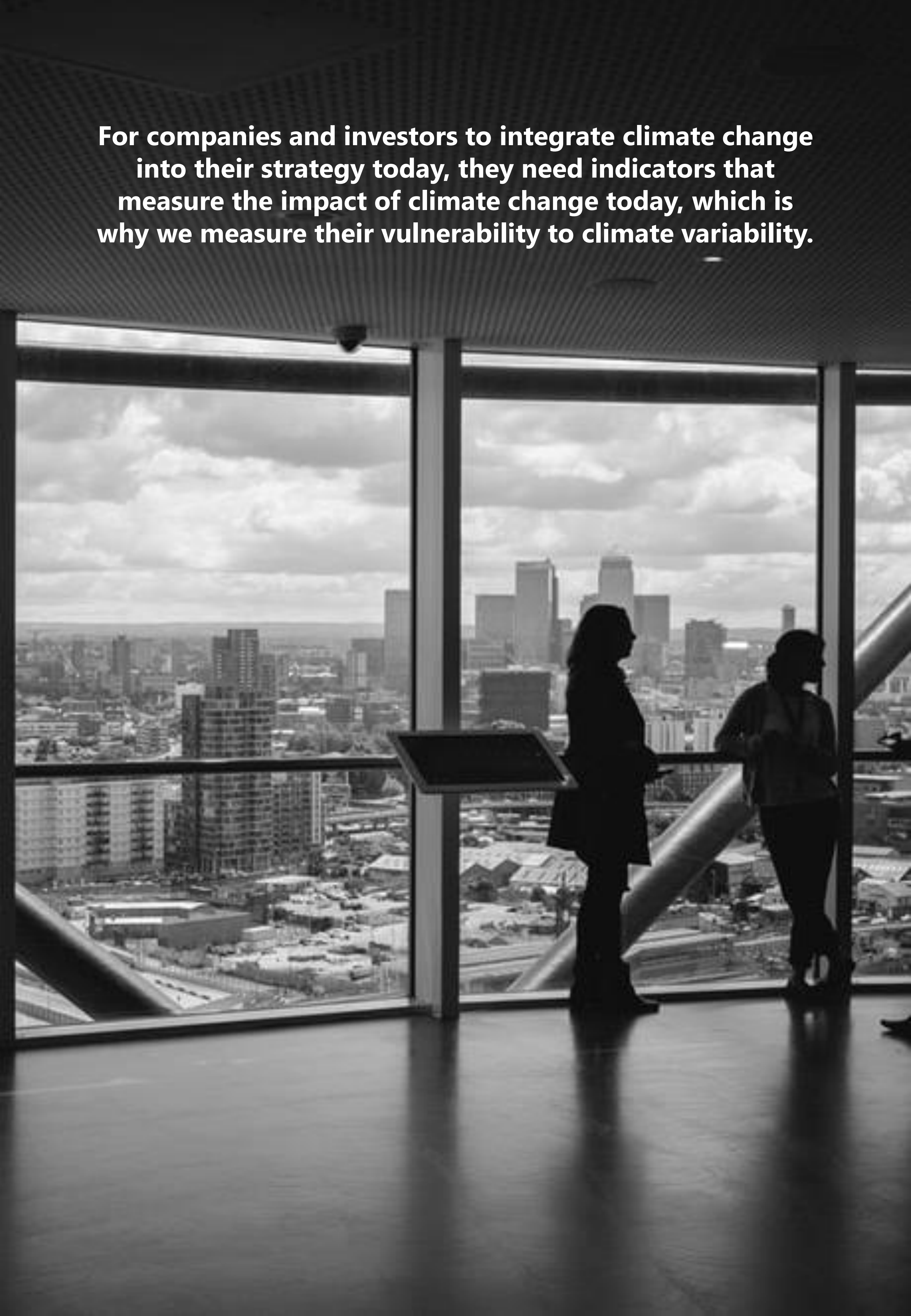
Against this background, the focus on climate variability provides a viable alternative to estimate how climate change is already impacting firms and activity sectors. The short-term perspective is all the more relevant since, with climate change, the number, duration and intensity of climate anomalies has increased, making the need to measure their impact on business activity more pressing.

In addition, analyzing the impact of climate variability on the private sector does not impose assumptions on the evolution of many variables, but simply requires relying on existing historical data.

The increase is not as pronounced in Q3, and the variability in Q1 and Q4 has remained relatively stable in a context of rising averages. The same observation can be made with respect to the variability of the quarterly cumulative precipitation, except for Spain and Italy.

In this research, we aim to evaluate whether aggregated business sectors of major European economies are impacted by climate variability. Next, we want to estimate the average impact per quarter and per year and compare them between countries. Finally, an important risk measure is the maximum potential loss due to adverse climate conditions.

For companies and investors to integrate climate change into their strategy today, they need indicators that measure the impact of climate change today, which is why we measure their vulnerability to climate variability.



THE STUDY

Research gap and Objectives

One of the objectives of this research is to introduce climate variability and its impact on economic activity as a relevant measure of climate impact. Another objective is to lay the foundation for future work aimed at producing climate vulnerability measures for each sector and sub-sector of activity, and for each listed firm.

The existing research on the effects of climate on European economies is scarce. We build from the work of Starr-McCluer (2000), Lazo et al. (2011), and Parnaudeau & Bertrand (2018) who analyzed the sensibility of retails sales, the 11 U.S. nongovernmental sectors, and UK retail sectors respectively, to temperature and precipitation.

The methodologies used by Starr-McCluer and Lazo et al., however, made the assumption that the sensitivity of an activity sector is constant over the course of a year, an assumption constrained by the absence of data other than annual data. By using the activity sectors that make up retail sales in the UK, which are published monthly, Parnaudeau & Bertrand (2018) have shown that the sensitivity of the same sector varies from one season to another. To illustrate this, they show for instance that sales in the clothing retail sector exhibit a sensitivity coefficient of 1.74%/°C in spring and −1.52%/°C in autumn. This means that a positive deviation of 1°C in spring contributes to an increase in sales of 1.74%, whilst the same positive deviation of 1°C in autumn contributes to a decrease in sales of 1.52%. An analysis looking at annual data would have failed to identify both sensitivities and would have led to the erroneous conclusion that the clothing sector is not sensitive to climate variability. This is what Starr-McCluer calls the *washout* effects.

In addition, both studies on US economic sectors did not measure the sensitivity to temperature anomalies, but instead to Degree-Days that are normally exclusively used by the energy sector to measure the need for heating during winter months (Heating Degree Days) and the need for cooling during summer months (Cooling Degree Days), the reference temperature being the same for both at 18°C. The reason was again lack of alternative weather data. Parnaudeau & Bertrand (2018) showed that HDD and CDD were not satisfactory proxies when used to model the exposure to temperature variability for other sectors, as each activity and each product exhibits different threshold and sensitivity profile to climate variability.

For the purpose of this research, we used data published by Eurostat on a quarterly basis, as the empirical basis of our work, which should allow us to overcome some of the washout effects. We also used daily temperature and precipitation data, as the basis for calculating quarterly anomalies.

Our objectives in this study are to test major European economies to climate variability, using temperature and precipitation anomalies, (1) to fill the existing gap and allow comparison with comparable research, (2) to estimate the impact of climate variability by quarter and on a cumulative annual basis, and (3) to evaluate the maximal potential losses caused by adverse climate variability based on historical observed climate conditions.

Data

Economic data

We used Gross Value Added (GVA) (ESA 2010, 9.31) as our economic dataset. GVA is defined as output value at basic prices less intermediate consumption valued at purchasers' prices. It is calculated before consumption of fixed capital. GVA is conceptually close to GDP (Gross domestic product) and is available by branch of economic activity.

GVA is available on a quarterly basis. It is published by Eurostat , the statistical office of the European Union.

We examined the period 2000-2020,. For the purpose of this study, we applied it to the five major European countries, namely Germany, France, the UK, Italy, and Spain.

The 10 sectors and their code are displayed on Table 1 below.

Code	Label
A	Agriculture, forestry and fishing
B-E	Industry (except construction)
C	Manufacturing
F	Construction
G-I	Wholesale and retail trade, transport, accommodation and food service activities
J	Information and communication
K	Financial and insurance activities
M_N	Professional, scientific and technical activities; administrative and support service activities
O-Q	Public administration, defence, education, human health and social work activities
R-U	Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies

Table 1: Classification of economic activities - NACE Rev.2

Weather data

We used Speedwell Weather as our main weather data provider.

Since weather affects consumers, who in turn affect sales, the relevant concept in creating national climate indices is to reproduce the average climate conditions *experienced by the consumers* in the considered country, not the conditions experienced by the country.

Following Quayle and Diaz (1980), Parsons (2001), and Dell and Olken (2014), the national climate indices are the weighted aggregate weather data of large range of ground weather stations using a set of population weights. The difference can matter. Dell and Olken (2014) explain for instance that in the year 2000, the average area-weighted mean temperature for the United States was 8.3°C, whereas the average population-weighted mean temperature for the United States was 13.1°C.

In addition, to avoid any bias in the calculation of climate anomalies measured as the difference between observed climate conditions and its long-term average, observations can be detrended. This is due to climate change and the rising temperatures that may lead to a biased distribution between negative and positive anomalies.

For modelling purposes, climate data must be reliable, consistent, independent, trustworthy, clean, and complete. In our data, there are no missing data or discontinuities arising from changes in the location, the environment or the equipment of weather stations.

Finally, to allow for the construction of probabilistic and frequency diagrams of the contribution of climate variability to economic sectors, it is also essential that data is recalibrated and consistent across the available historical database.

For the purpose of this research, we relied on a new methodology developed by Speedwell Weather to calculate population weighted indices. Instead of applying the population weight associated to the city where the ground station is based, which is what academics usually do, the indices are developed as follows. As a first step, in each country, weather stations that make up the index must comply with the following conditions : a long history of data, high quality observations, reliable feeds and the ability to produce forecasts. Gridded population statistics are then sourced to provide an understanding of population distribution and applied to climate data. These datasets are designed to be consistent across all regions and are updated on a regular basis.

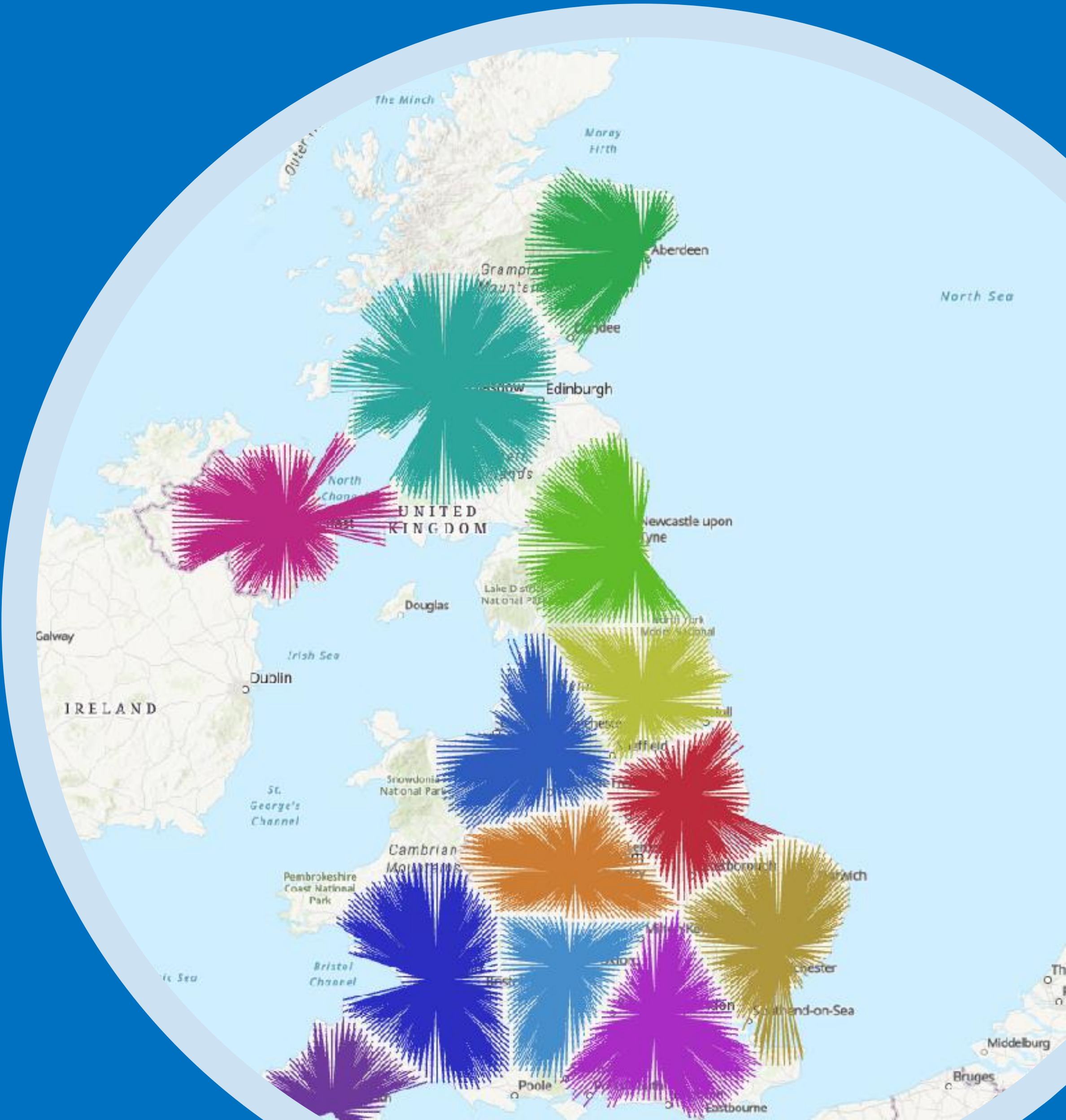
Using optimization modelling (geoprocessing) the combination of weather stations is selected to target the largest portion of the population.

Weights are computed as a ratio of each station’s targeted population vs. the total population of the administrative region.

Historical index data, ongoing feeds, and forecasts are created by combining the relevant weather station observations with their calculated weigh.

For each station and each population-weighted index, we produced climate data sheets that are summary reports of descriptive statistics and variables to be used in this research for modelling purposes.

Descriptive statistics include quarterly Temperature means and standard deviations, Temperature extremes, Occurrences of temperature critical days, Temperature anomalies, Precipitation means and averages, Precipitation extremes, Occurrences of precipitation critical days, Precipitation anomalies, HDD18 and CDD18 means and standard deviations, all of which can be used for impact modelling.



Anomalies	France Temperature	France Precipitation	Germany Temperature	Germany Precipitation	Spain Temperature	Spain Precipitation	United Kingdom Temperature	United Kingdom Precipitation	Italy Temperature	Italy Precipitation
Mean	-0.028855	0.004571	-0.021780	0.006704	-0.013316	-0.009914	-0.009168	-0.002605	-1.01E-15	0.015016
Median	-0.028955	-0.011665	-0.122640	-0.029589	0.245000	-0.688571	0.039935	-0.059850	-0.105452	-1.378636
Maximum	1.721446	1.344194	2.425133	0.901354	4.890000	8.893636	2.041065	1.435711	1.709823	18.26773
Minimum	-2.073249	-0.990621	-2.924645	-1.124867	-5.542381	-1.606364	-2.966000	-1.148301	-1.502977	-3.314091
Std. Dev.	0.954802	0.508346	1.108927	0.421995	2.530155	1.739164	0.839345	0.524320	0.739374	4.088554
Skewness	-0.142996	0.213823	-0.090540	0.053209	-0.239853	2.430163	-0.618333	0.474435	0.286041	2.444572
Kurtosis	2.249617	2.770046	3.168517	2.654619	2.371322	10.71747	4.164471	2.984165	2.492542	9.509956
Observations	85	85	85	85	85	85	85	85	85	85

Table 2: Descriptive statistics of population-weighted temperature and precipitation anomalies

For the purpose of this analysis, we produced quarterly population-weighted indices for both temperature and precipitation. For the period 2000-2020,for each country, models can be developed with 85 quarterly values. Descriptive statistics on temperature and precipitation anomalies are available in Table 2.

If we drill down this database to investigate differences between quarters and countries, we note that variability measured as the standard deviation is more important in Q1 and Q4 in all countries considered, and almost identical between Q2 and Q3.

More importantly, if we look at how temperature variability evolves over time between 2000 and 2020, we note that the volatility measured as the deviation from the mean has significantly increased between the first and the second decade but not in all quarters.

This is particularly true in Q2 with an average increase across countries of about 60 per cent. This also applies to precipitation. This is an expression of the rising climate variability highlighted repeatedly by the WMO and the IPCCand illustrated in Figure 1: climate change is the trend, climate variability is the standard deviation

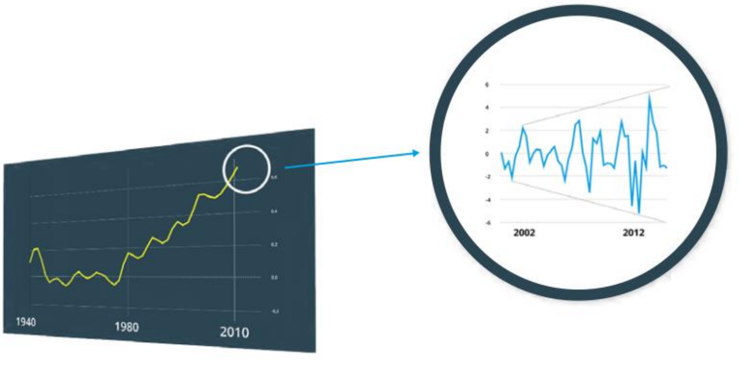


Figure 1: temperature anomalies since 1881 (left) and rising temperature variability Q2 (right)

Methodology

We build on the works of Starr-McCluer (2000), Pres (2009), Lazo et al. (2011), and Parnaudeau & Bertrand (2018) to develop a methodology that allows analysts to understand if and how climate conditions influence which sector in which country, estimate the impact due to climate variability, and evaluate the maximum potential shortfall based on observed historical climate conditions.

The methodology therefore aims at defining two elements: the sensitivity coefficient for both temperature and precipitation anomalies, and the impact.

For the purpose of this white paper, we only display the results related to temperature and precipitation anomalies. The methodology we use can be extended to test the sensitivity to other climate indices such as accumulation of specific conditions, thresholds, critical days (such as number of days for which maximum temperature is above 35°C), deviations or accumulations from a threshold or from critical days, and so on.

We first test for each quarter and each country and each sector the correlation between quarterly climate indices and GVA. This step mostly provides a basis for comparing our results with previous research and also serves to eliminate from the modelling step climate indices that do not exhibit a significant correlation with economic variables.

The parameters of the models are then estimated using ordinary least squares (OLS) regression and the significance of the parameters is validated using classical t-stats.

RESULTS & DISCUSSION

Results and Discussion

Within the framework of this research, we seek to highlight the impact of temperature and precipitation anomalies on each of the 10 sectors of activity for the 5 largest European economies. As a reminder, temperature and precipitation anomalies are calculated from daily, population-weighted data, averaged over each quarter, and compared to the long-term quarterly average.

The use of aggregated data in econometrics is not ideal because it does not facilitate the detection of statistically significant signals due to washout effects in the same category (see page 21), nor the interpretation of possible results. Eurostat's sectoral data are particularly aggregated and yet, despite the existence of compensatory effects in each category of activity highlighted in the academic literature, econometric analysis reveals statistically significant sensitivity relationships.

Sensitivity coefficients estimated in econometric models that meet the conditions of statistical significance are used to calculate the impact of quarterly anomalies. Anomalies observed between 2000 and 2019 are applied to the models so that average impacts can be established per quarter or per calendar year. Table 2 provides a first overview of the impact of quarterly climate variability by country.

In table 2, for each quarter and each country, the impact is estimated for each sector, and then arithmetically added together. In this way, by definition, each value in the table incorporates washout phenomena between sectors. Nevertheless, the aggregated results allow a first comparative analysis between the 5 main European economies.

Table 3 offers a different perspective of analysis since the most unfavorable climate anomalies observed between 2000 and 2019 each coefficient are applied to each model. The ratio of 1 to 17 between the average total impact in Table 2 and the total unfavorable impact in Table 3 offers an interesting perspective on the vulnerability of European economies to climate variability. It can be noted that this vulnerability concerns all quarters, almost uniformly, with the summer months being the least vulnerable (21%) and the autumn and early winter being the quarter most affected (30%).

Finally, Table 4 is interesting from a theoretical point of view as an attempt to estimate the maximum potential impact of both quarterly and annual climate variability. For each category of activity, the climate variability of each quarter is this time expressed without mathematical sign but estimated using absolute values. These absolute values are then added to each other, which removes washout effects.

This time the ratio between the arithmetically calculated mean climate variability impact in Table 2 and the variability calculated from the absolute values in Table 4 is 1 to 32. One method integrates all of the washout phenomena, the other does not integrate any. This illustrates the disadvantage of using highly aggregated data. The empirical truth lies somewhere in between, and a bottom-up analysis of the individual components of each sector of activity would make it possible to refine these estimates, which is not the purpose of this first white paper.

	France	Germany	Spain	UK	Italy	Total
Q1	-919	-1 212	-689	-549	-205	**-3 575**
Q2	-380	-763	524	-451	-102	**-1 172**
Q3	-927	-3 938	166	-346	-74	**-5 119**
Q4	-118	-456	-14	-316	251	**-653**
TOTAL	-2 344	-6 369	-13	-1 662	-129	**-10 518**

Table 2 : Climate Variability impacts on GVA (2000-2019)
Current prices, million euro

	France	Germany	Spain	UK	Italy	Total
Q1	-7 169	-20 639	-11 553	-4 941	-2 481	**-46 783**
Q2	-7 041	-14 227	-15 172	-3 044	-1 429	**-40 912**
Q3	-6 088	-15 924	-9 959	-2 584	-3 085	**-37 640**
Q4	-7 964	-22 546	-12 637	-6 794	-3 021	**-52 962**
TOTAL	-28 262	-73 336	-49 321	-17 363	-10 016	**-178 298**

Table 3 : Adverse Quarterly Climate Impacts on GVA (2000-2019)
Current prices, million euro

	France	Germany	Spain	UK	Italy	Total
Q1	10 433	45 969	19 410	8 690	5 124	**89 625**
Q2	7 422	32 377	21 077	5 674	2 609	**69 160**
Q3	8 710	43 799	18 976	6 126	4 765	**82 376**
Q4	9 719	40 163	18 310	7 544	6 438	**82 174**
TOTAL	36 285	162 308	77 772	28 034	18 936	**323 335**

Table 4 : Cumulative Absolute Value of Climate Variability impacts on GVA (2000-2019)
Current prices, million euro

The impact of climate variability represents between 2.3% and 4.2% of the Gross Value Added.

In any case and despite the limitations associated with the use of aggregate data, these results show unambiguously that the 5 major European economies are exposed to a significant level of climate variability.

Our results are consistent with those of Lazo et al. (2011). Relative to the nominal amount, and depending on the measures of climate variability considered, our results show that the annual impact of the impact of climate variability represents between 2.3% and 4.2% of the Gross Value Added.

The analysis of climate variability impacts by sector of activity (Table 5 and 6) does not escape the same drawbacks of having to analyze sectors in which numerous washout phenomena take place.

In addition, Gross Value Added is not necessarily the best indicator for all sectors of activity, and paradoxically, for certain sectors that are particularly exposed. This is the case for the Agriculture, forestry and fishery sector, which is undoubtedly a sector that is notoriously exposed to the fluctuation of climate conditions.

In agriculture, climate conditions have an influence on yields, and thus volumes. Prices are in turn negatively correlated with volumes. Thus, Gross Value Added which is the multiplication of volumes by prices absorbs most of the climate impact. This means that a decrease in volume is compensated by an increase in price, so GVA as dependent variable is not the best suited indicator to measure exposure to climate variability in the case of agricultural yields.

GVA Activity Category	France	Germany	Spain	UK	Italy	EU5
Agriculture, forestry and fishing	NS	-25	-17	-15	-8	**-64**
Industry (except construction)	-250	-1215	39	-270	-43	**-1 740**
Manufacturing	-167	-1132	49	-267	-42	**-1 559**
Construction	NS	-448	106	-213	28	**-528**
Wholesale and retail trade, transport, accommodation and food service activities	NS	-798	-50	-328	-45	**-1 221**
Information and communication	-120	-306	NS	-213	5	**-634**
Financial and insurance activities	-123	NS	NS	NS	NS	**-123**
Real estate activities	-419	-452	-50	NS	NS	**-920**
Professional, scientific and technical activities; administrative and support service activities	-568	-759	-29	-356	-23	**-1 736**
Public administration, defence, education, human health and social work activities	-722	-1104	-45	NS	NS	**-1 871**
Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies	24	-131	-16	NS	NS	**-122**
Total	**-2 344**	**-6 369**	**-13**	**-1 662**	**-129**	**-10 518**

Table 5 : Annual Cumulative Value of Quarterly Climate Variability Impacts on GVA (2000-2019)
Current prices, million euro – NS: Statistically Non-Significant

GVA Activity Category	France	Germany	Spain	UK	Italy	EU5
Agriculture, forestry and fishing	NS	415	1880	251	793	**3 339**
Industry (except construction)	3497	31068	6838	4559	4105	**50 066**
Manufacturing	2346	28134	3102	4497	3963	**42 042**
Construction	NS	10482	10651	3595	3008	**27 736**
Wholesale and retail trade, transport, accommodation and food service activities	NS	21203	14631	5539	4266	**45 639**
Information and communication	3846	7464	NS	3593	579	**15 482**
Financial and insurance activities	1723	NS	NS	NS	NS	**1 723**
Real estate activities	5867	11948	14520	NS	NS	**32 335**
Professional, scientific and technical activities; administrative and support service activities	7962	18530	8449	6000	2222	**43 164**
Public administration, defence, education, human health and social work activities	10110	29232	13162	NS	NS	**52 504**
Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies	934	3830	4539	NS	NS	**9 303**
Total	**36 285**	**162 308**	**77 772**	**28 034**	**18 936**	**323 335**

Table 6 : Annual Cumulative Absolute Value of Climate Variability Impacts on GVA (2000-2019)
Current prices, million euro – NS: Statistically Non-Significant

CONCLUSION

Concluding remarks and Contributions

Academic literature and corporate financial releases abound with evidence that climate conditions affect economic activity and financial performance, but cases where the contribution, impact or risk of weather is precisely identified and quantified are scarce.

Voluntary and mandatory risk reporting or risk mapping frameworks, whether voluntary or mandatory, do not give much consideration to climate risks. The information available to analysts and asset managers does not allow them to price the impact of climate change on the value of an asset or a portfolio.

The climate impact measures available to asset managers and analysts provide ratings that enable the vulnerability of two companies to be compared with each other, but they do not provide quantitative sensitivity measures that enable decision-makers to make investment decisions, adapt their portfolio allocation, or anticipate changes in the value of an asset as a function of weather conditions.

Finally, the long-term prism under which climate change and its financial consequences on sectors of activity or companies is approached in the existing literature implies the acceptance of a multitude of hypotheses and scenarios that are a source of uncertainty and that are a hindrance to decision-making, whether it be investment decisions on the asset management side, or decisions on the resources to be deployed by companies in an adaptation strategy.

An innovation of this paper is to propose a measure of climate risk based on the immediate impact of climate on each sector and each company, by analyzing the influence of climate conditions on past and current performance, thus removing the uncertainties inherent in using long-term projections.

By measuring the impact of climate variability on the sectors of activity of the main European economies, this research confirms the specific vulnerability of each sector of activity, shows that it is possible to determine a sensitivity coefficient that can easily be used to produce the actionable traditional metrics of financial risk management, namely the contribution of climate variability to earnings, a probabilistic distribution of this contribution, and the maximum potential loss, otherwise known as the climate value-at-risk.

These risk metrics can then be used and projected using IPCC scenarios, offering a possibility for each asset to put a specific price tag on climate change.

Future research we are already developing involves applying the same methodology to company-specific data to provide risk managers, analysts and corporate finance executives with an objective and quantitative estimate of climate vulnerability and climate change on which they can act.

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