Extreme weather events and property values

Assessing new investment frameworks for the decades ahead

A ULI Europe Policy & Practice Committee Report

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Urban Land Institute

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ISBN: 978-0-87420-338-7
Recommended bibliographic listing:
Bienert, Sven. Extreme Weather Events and Property Values: Assessing New Investment Frameworks for the Decades Ahead. London: Urban Land Institute, 2014.

Introduction

Extreme weather events and their effects on property values

Assessing new investment frameworks for the decades ahead

Today, the real estate industry is increasingly having to address the causes of climate change, of which it is a main contributor, through an evolving range of requirements that include regulatory controls on CO_2 emissions, environmental and sustainability strategies; and the 'greening' of property investment portfolios and developments.

However, to a large degree, a major consequence of climate change - extreme weather events - has yet to be seriously addressed by the industry. Many real estate investors and associated players are simply not aware that these events - the escalation in their occurrence and magnitude of which is all too evident - pose a rising, compelling and more immediate threat to property value, and are therefore overlooking the related risks within their investment decision-making.

In this report, the threat of extreme weather events and their impact on real estate and property value is analysed, and a new tool is introduced to show how expected losses can be calculated. In also giving an outlook on the future development of events, this paper highlights why weather risks should be considered as a key emerging driver to future investment strategies. It looks to stimulate debate by presenting new valuation-related methodologies and by making clear recommendations for market participants that range from the future-proofing of portfolios to the re-thinking of asset allocation.

Executive summary

The escalating threat of extreme weather events

- Real estate values are being increasingly threatened by extreme weather events, such as storms, hail, flooding, droughts, tropical cyclones, and landslides.
- These events have far greater relevance for real estate investors than the more frequently discussed effects of creeping climate change, such as rising mean temperatures.
- The number of extreme weather events has doubled globally since the 1980s to an average of over 800 events per year during the past decade.
- The occurrence of such events is therefore escalating and is likely to continue to do so until the end of this century (and beyond), as climate change becomes more severe.

Their effects on real estate markets and values

- New financial uncertainties caused by extreme weather are affecting the highest and best use of real estate throughout the world. As real estate values account for about 3.5 times the GDP in developed countries, even relatively small changes in values will have an enormous financial impact on economies.
- Monetary losses related to real estate and infrastructure and resulting from severe weather events have tripled globally during the past decade, with direct losses recorded by reinsurance companies amounting to US$150 billion (€109.5 billion) per year. In severely affected regions, losses have reached up to 8 per cent of GDP.
- Estimates based on the latest climate data, as well as loss ratios calculated by the newly-developed tool introduced in this report, indicate that expected monetary losses for buildings are likely to double in some places in the near future, affecting building insurance premiums and total occupancy costs as a result.

- More significantly, it might become impossible to insure against severe fundamental changes resulting from extreme weather - and from intensive events in particular.
- Total losses from extreme weather events are being seriously underestimated as tracked data only accounts for direct losses and not consequential losses (e.g., a reduction in tourism) or indirect losses (e.g., reduced turnover and rent). The depreciation of natural capital is also being ignored.
- A greater frequency of extreme weather events will lead to more people leaving affected regions, thereby affecting property values at both ends of the migratory path.

An inadequately prepared real estate market

- The financial uncertainties caused by extreme weather are being considerably underestimated by real estate investors. Until recently, their portfolio allocations have rarely taken into account the science of climate change.
- This is probably due to the absence of comprehensive risk models/ tools; a lack of ready-to-process data that can be used in real estate forecasting models; and, to some extent, continued uncertainty on the forecasts for greenhouse gas emissions, and therefore climate change.
- Real estate market participants are also tending to underestimate risks from weather events that have a very high potential for acute monetary losses but have a very low probability of occurring.

Calculating expected losses from extreme weather events

- The risks from events are either not being integrated into real estate investments or valuations, or are only being addressed indirectly by adjusting input parameters such as rents, yields, or costs on a more qualitative basis.
- From a real estate industry perspective, the risk from natural hazards should be understood as only being one-sided: downside with no potential upside.
- The calculation of annual expected losses as a measure of risk for property values is derived from the hazard of the respective extreme weather event, an empirically-validated damage function (vulnerability), and a value.
- Through the use of data from climate models and insurance companies (concerning historical damages), as well as from cost-based valuations, far-reaching conclusions can be made regarding the future development of property values in a specific situation.

Recommendations for real estate investors

- Regard sustainability initiatives as more than just a cost driver, and make more intensive efforts to ensure that assets and the respective allocation of these assets are “future-proofed”. Fulfilling today’s regulatory requirements is just the starting point on a much longer and broader route to a successful sustainability strategy.
- Ensure a higher awareness of risks related to climate change so that, corporation-wide, they are treated as a strategic issue.
- Evaluate the annual expected loss for properties or portfolios caused by future climate change and extreme weather events.
- Be alert to the broader indirect and consequential effects of severe weather on real estate.
- Rethink asset allocation in terms of regions, asset subclasses, and micro-locations. In addition, re-evaluate core and other assets in locations that may currently be treated as a “safe haven” for investments.
- Increase the adaptation of existing building stock if the outcome of an asset analysis is “hold”. Some properties can be made more resilient through relatively minor retrofits (such as improvements to facades, roofs, site infrastructure, windows and doors, connections between building parts, etc.).
- Develop proper risk-management tools that focus on climate change, and integrate them into existing controlling functions and processes.
- Improve awareness of potential new regulation of greenhouse gas emissions as part of stricter climate policies.
- Consider mitigating potential severe weather impacts through use of weather derivatives or portfolio diversification.
- Think on a regional or even property-specific level because natural disasters are best treated with regional climate data and models.
- Act now to reduce risk from climate extremes with measures that might range from incremental steps to transformational changes. Extreme weather events are already impacting financial returns in the real estate industry and in the future will continue to do so on a far greater scale.

Why climate matters

Today, man-made climate change is widely accepted to be the cause of rising global temperatures, the melting of the Arctic ice cover, changing weather patterns and related impacts to the natural environment and ecosystems.

Despite global political efforts, levels of harmful emissions are increasing without effective restraint and, if this remains the case, the acceleration in climate change is likely to continue unabated.

The looming economic consequences of climate change will have a significant and growing impact on the real estate industry, which makes it ever more important for market participants across most real estate disciplines to be proactive in mitigating and adapting to its effects.

In 2011 and 2012 the highest-ever average temperatures were recorded in Europe and the world for two consecutive years.[1]

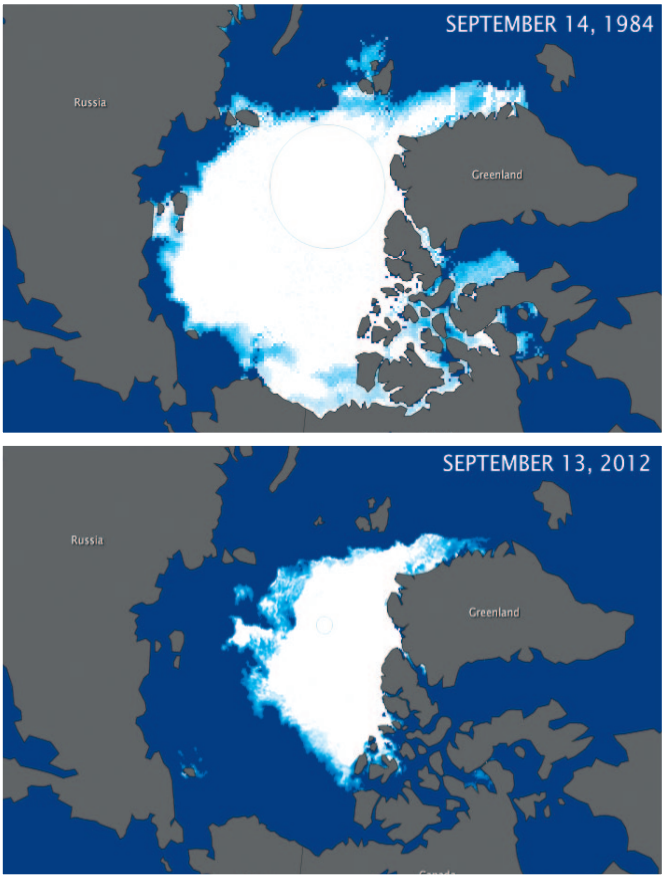
Proof of considerable global warming: record high temperatures are being reported.

The consequences of climate change, and the changes in the global average temperature associated with it, are far-reaching. The Arctic ice cover has decreased from over 8 million square kilometres in 1980 to under 5 million square kilometres in 2012–2013.[2] And the water released by the melting ice is one of the main reasons why sea levels have risen by 20 centimetres since 1880.[3]

Leading scientists agree that most climate change has been caused by man (anthropogenic climate change).[4] Despite worldwide efforts, global greenhouse gas emissions (measured in carbon dioxide equivalents) rose 3 per cent in 2012 to about 32 gigatons per year, the highest level ever measured.[5]

1 MüRe, 2013, p. 40ff / IPCC, 2013, p. 4.
2 Peterson et al., 2013, p.20 / IPCC, 2013, p. 5.
3 Rahmstorf, 2007, p. 1ff / IPCC, 2013, p. 6.
4 MüRe, 2008, p. 6 / Latif, 2009, p. 153 / Peterson et al., 2013, p. IV / IPCC, 2013, p. 8f, p. 12f. / Bouwer, 2011, p. 39f.

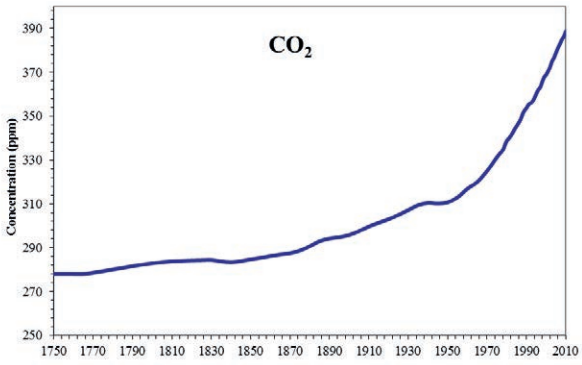
Arctic Sea Ice Minimum Comparison 1984 - 2012



Source: NASA Earth Observatory

In 2013, the concentration of greenhouse gases in the atmosphere exceeded what is considered the critical level of 400 parts per million (ppm), compared with 280 ppm during the pre-industrial era.[6] Against this background, and even with the greatest efforts being made, it is almost impossible for continuing political attempts to limit global warming to 2°C to succeed.[7]

Atmospheric Concentration of CO_2 (EEA) 1750-2010



Source: EEA Europe

5 MüRe, 2013, p. 40.
6 National Oceanic and Atmospheric Administration (NOAA), 10. Mai 2013 / IPCC, 2013, p. 7.
7 Note: "Doha Climate Gateway" negotiations with mandatory regulations from 2020 on still refer to the 2 degree Celsius goal at the Doha climate conference in December 2012.

Climate change is already causing massive changes in ecosystems and will have further serious consequences as global temperatures continue to rise. This will impact many areas of society and the economy, including health, food production, and urban development. Measures must therefore be taken to simultaneously limit the drivers of climate change while adapting to its effects in all areas of life.

This paper concentrates on a real estate-based economic approach to global warming and pursues the following questions:

- What are the financial implications for real estate assets of an increasing number of extreme weather events?
- How might the frequency of extreme weather events change?
- Why should the real estate industry intensively address climate change now?

Climate change massively reduces real estate related income potential in the form of ground rent.

Real estate is bound by location, and real estate values are always based on the highest and best possible use of a location. The protection of real estate against the hazards of natural disaster and the loss of use is therefore clearly vital - whether it is safeguarding the income-generation of agricultural and forestland (and the quality of life), the investment and occupancy credentials of commercial and residential buildings or the durability of infrastructure facilities.

An initial, purely qualitative analysis that focuses on the various drivers for real estate market value - as suggested by the valuation technique "comparison approach" - shows that many features of a site relevant for valuation are directly linked to environmental conditions, and are therefore also exposed to the risks of climate change. These features include:

- Macro-and micro-locations - climatic conditions, especially illumination, wind, emissions (noise, smoke, dust), and rainfall; and
- Soil conditions - surface formation, natural cover, bearing capacity, groundwater conditions, mudslide areas, and exposure to risks (flooding, avalanches, storms, hurricanes, etc.).

And some more recent impacts of climate change on environmental conditions are only gradually emerging. For example, Northern Russia's regions are seeing an increasing impact from the thawing of the permafrost, with the cooler temperatures preventing the air from absorbing the water vapour generated; as a result, the amount of moisture in the soil is constantly increasing, forming small lakes. This is having a substantial impact on regional ecosystems, as well as buildings and infrastructure, which in some places no longer stand on solid ground.

The loss of the potential use of the real estate automatically leads to lost value, which has negative consequences for an economy as a whole. In developed economies, the value of property amounts to an average of 3.5 times a country's GDP.[8] Thus, even small changes in value can lead to large monetary damages. Moreover, in real estate valuation, present value is regularly considered in assessing future potential benefits. Therefore, even relatively moderate reductions in value can lead to big losses in annual expected returns.

Due to the wider economic significance of property values, even relatively small drops in value will constitute massive economic losses.

This and other impacts of climate change are likely to continue to predominate and result in massive adjustments in the real estate industry until a new balance is struck. On the other hand, a few in the real estate industry could actually benefit from climate change. For instance, agriculture will be feasible in regions previously considered too cold, allowing, for example, vineyards to move farther north; likewise, warmer temperatures at more northern latitudes will raise property prices as climate refugees migrate and encourage more tourists to visit high mountain areas.

The profitability of real estate will be increasingly influenced by climate protection regulations.

However, it would be misleading to portray the real estate industry only in terms of its vulnerability to climate change because, through development, it is one of the primary contributors to the problem; with buildings accounting for 30 to 40 per cent of all energy use, the industry is one of the main sources of CO_2 emissions.[9] As a result, a multitude of political initiatives to reduce emissions are currently aimed at the construction and real estate sectors - and the introduction of initiatives will continue.[10] The industry will also be affected by measures required to adapt to climate change and related legal frameworks. Those impacts are not addressed in this report.

Critically, due to its vulnerability,[11] the real estate industry must urgently study the drivers and dynamics of climate change so it can adapt proactively to the changes or contribute to their mitigation. It is a challenge that affects and must be addressed by a number of subdisciplines within the industry, including real estate valuation, risk management, investment, and project development/construction.

[8] Brandes, 2013, p. 9: Estimated Value of Insured Coastal Properties amount in the United States to US$27.000 billion in 2012.
[9] WBCSD, 2009, p. 6.
[10] Bosteels et al., 2013, p. 6.
[11] Guyatt et al., 2011, p. 15: Real estate is very sensitive to climate impacts. / Leurig et al., 2013, pp. 5, 7

Extreme weather events and their effects on property values

Extreme weather events caused by climate change - including storms, hail, flooding, heatwaves, and forest fires - often lead to severe damage and must be differentiated from long-term change, such as rising mean temperatures.

The annual average number of extreme weather events has more than doubled globally since 1980.

The total global damage caused by extreme weather - mainly to property and infrastructure - is rising dramatically and now exceeds US$150 billion (€109.5 billion) per year. Furthermore, these losses, which are those registered by reinsurance companies, by no means constitute all losses related to real estate.

For example: first estimates of forests lost to more frequent fires in Russia and the United States top €600 billion in present values; and there is a corresponding impact on the income-generating potential of relevant property. Similar calculations could be made for other extreme weather events, regions, and property types.

The real estate industry has tended to be reactive and is only now taking its first steps towards preparing for foreseeable climate changes. To date, awareness has not been strong, partly because few quantitative studies on real estate in the context of extreme weather events have been undertaken.

The impact of climate change on property and its value is complex. In this paper's introduction we addressed the impacts of long-term climate change, such as rising mean temperatures, however this does not include the more immediate effects of extreme weather events, which can lead to significant losses in a very short period.[12] Climate change is also altering the frequency, intensity, spatial impact, duration, and timing of events; and in some instances the shifts are unprecedented. In particular, extreme weather events - natural disasters that include storms, hail, flooding, heatwaves, droughts and forest fires – are having a significant effect on those sectors that are closely linked to climate, such as infrastructure, water, agriculture, forestry, and tourism, as well as real estate in general (see figure 1).[13]

This study takes an in-depth look at extreme weather events and their impact on property values. For the market these events – which only represent a downside risk - can result in real estate investments[14]:

- Being subject to price rises due to increased insurance premiums or altered construction methods - known as adaptation costs - or deteriorating returns on capital; or
- Losing value due to limited usability (where the highest and best use may no longer be feasible); or
- Being subject to expensive damages due to uninsured risks, and hence deteriorating returns.

Therefore, the real estate industry is inevitably exposed to the potential loss of property returns in locations that are vulnerable to extreme weather.[15]

Hurricane Katrina property damage

Source: Free Images, Palmer Cook

[12] World Bank, 2013, p. 94: Reduced property values.
[13] Guyatt et al., 2011, p. 61 / Cruz et al., 2007, p. 492: Effects on tourism might be massive. / Lamond, 2009.
[14] ULI, 2013, p. 14ff: Recommendation 16: Accurately price climate risk into property value and insurance.
[15] Guyatt et al., 2011, p. 58.

Figure 1. Effects of climate change on property values

Climate Aspect	Commercial and Residential Real Estate	Forestry	Agriculture	Infrastructure
Rise in temperature	Reduced ground rent (lower potential revenue, in the case of regional population changes; also, increased need for cooling, and thus higher operating costs)	Reduced ground rent (in the case of increase in forest fires, pest infestation, extinction of species)	Reduced ground rent (in the case of increasing drought, pest infestation)	Increased wear on installations; unstable ground
Water scarcity	Decline in attractiveness of a region/decline in ground rent; higher costs for water supply and treatment	Reduced revenues from forestry/increased danger of forest fires	Reduced harvests; increased costs for irrigation	Decline in bearing capacity of soil
Rising sea level	Reduced settlement area in coastal regions		Reduced agricultural land area/loss of potential revenues	Danger to port facilities
Increase in extreme weather events	1. Direct loss (e.g., hail damage to buildings) 2. Indirect loss (e.g., through gaps in production or rent after hurricanes) 3. Consequential loss (e.g., declining number of tourists in flood areas, rising insurance premiums)	1. Direct loss 2. Consequential loss 3. Depreciation of natural capital (permanent damage to ecosystems, extinction of species)	1. Direct loss 2. Consequential loss 3. Depreciation of natural capital	1. Direct loss 2. Indirect loss (infrastructure damages due to extremes in temperature, precipitation/ flooding/ overload of urban drainage systems/storm surges, which can lead to damage to roads, rail, airports, and ports; electricity transmission infrastructure is also vulnerable)
Increased regulation	Higher construction costs and running costs; higher costs, particularly in the case of carbon taxation			Higher construction costs and running costs
Increased adaptation costs due to climate change	Higher adaptation costs to protect properties and to make buildings energy - and resource efficient	Higher adaptation costs	Higher adaptation costs	Higher adaptation costs

Source: IREBS University of Regensburg

According to reinsurance statistics, total losses from extreme weather events already exceed €109.5 billion per year.

The economic implications of extreme weather become evident if one considers that global losses caused by weather-related natural disasters in 2011 and 2012 exceeded US$150 billion (€109.5 billion) in both years, ranking them among the five most costly years since 1980.[16] However, from a broader perspective, these total losses (which are frequently cited in reinsurance statistics) are, in fact, far below the actual financial losses suffered.

To elaborate, financial losses can be broken down into four categories:

- Direct losses include[17] all types of tangible assets (private dwellings, and agricultural, commercial and industrial buildings and facilities); infrastructure (e.g., transport facilities such as roads, bridges, and ports; energy and water supply lines; and telecommunications equipment); and public facilities (e.g., hospitals and schools).
- Indirect losses may include higher transport costs, loss of jobs, and loss of income (both rent and revenue lost due to business interruption).
- Consequential losses - or "secondary costs" - arise through repercussions such as declining tourist numbers or lower direct investments, which reduce economic activity, and thus lower GDP.
- Losses related to natural capital include damage to ecosystems and the depreciation of natural resources (adverse ecological impacts).

[16] MüRe, 2013, p. 53.

[17] Kron et al., 2012, p. 542: Direct losses are immediately visible and countable (loss of homes, household property, schools, vehicles, machinery, livestock, etc.).

However, it is only direct losses that are effectively tracked in loss estimates – all the other categories, which also include adaptation costs incurred for protecting buildings from extreme weather events, and the monetisation of personal injury and the damage to historic structures and cultural heritage[18], are not included or adequately incorporated into estimates.[19] Yet all these aspects are of major importance for real estate markets as they can be directly linked to income and values.

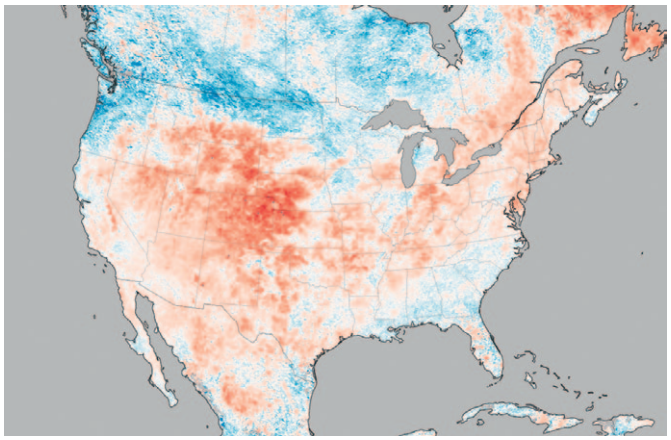
True damage costs are therefore much higher than estimates, which highlights the need for the real estate industry to widen its perspective beyond just direct losses.

Official statistics dramatically underestimate real estate-related damage.

In the case of forest fires in the United States, for example, the damage to the natural capital - i.e., trees and other plants - is not incorporated in damage data collected by reinsurance companies. However, in terms of the long-term income-generating potential from forestry and the attractiveness of the affected area, this damage is far more relevant than the loss of any buildings to fire.

Examining this particular example in more detail, rainfall in the United States in 2012 was much lower than the annual averages for 1961 to 1990, and the year was also marked by a large-scale heatwave and a period of severe drought. This resulted in as much as a 40 per cent reduction in average agricultural production[20] and a consequent decline in the gross income generated by the affected plots through the reduction of ground rent. In wooded areas, the drought was accompanied by forest fires that destroyed 3.7 million hectares, the third highest figure since records began.

Heat wave map via NASA June 17/24, 2012



Source: NASA

An analysis of long-term U.S. averages in the pre-and post-climate change situation reveals interesting details. A comparison of 1970-1986 and 1987-2003 shows that during the latter period, which was severely affected by climate change, four times as many forest fires occurred and six times as much forestland fell victim to flames, and the forest fire season lasted on average 50 per cent longer. It can be estimated that over 330 million cubic metres of wood was destroyed in 2012, in the process lowering both resource productivity and land values. This is irrespective of damage to forest ecosystems, the destruction of buildings and infrastructure, agricultural losses, or the long-term decline in the attractiveness of the affected regions.

Forest fires near Chalkidiki, Greece 2006

Source:Shutterstock/ Ververidis Vasilis

At an average price of €85 per cubic metre, this corresponds to more than €28 billion burned and therefore wasted resources, and this is data for just one year, one country, and the tree inventory of forests.

Compared with the historical average for the pre-climate change period, this represents an increased loss of about €23 billion per annum due to the sharp rise in forestland lost to fire. Translated in terms of an income stream, and discounted at an interest rate of 5.0 per cent, this would represent a loss of forestland of over €460 billion in present values[21] due to forest fires in the United States.

Heat combined with aridity is also an increasing problem in other parts of the world. Russia's southern and western regions likewise experienced extreme forest fires in 2012, topping record highs that had been set as recently as 2010, a trend which over the past 10 years has seen the area in Russia affected by forest fires grow from 750,000 to more than 1.75 million hectares per annum.[22] If the same valuation method is applied as for the United States, Russian forest fires have incurred a loss in present value of more than €150 billion.

18 IPCC, 2013, p. 270.
19 Kron et al., 2012, p. 535f, p. 542f.
20 MüRe, 2013, p. 42
21 Note: The assumption of a perpetuity serves only to illustrate the extent of the situation and does not claim to be scientifically conclusive as to the facts.
22 MüRe, 2010, p. 33, p. 37.

More frequent fires have destroyed over €600 billion in present values from forests in the United States and Russia alone - and have reduced land values accordingly.

In a different "extreme", Thailand experienced its worst flooding in 50 years in 2011, causing estimated economic losses of €40 billion. Most of the losses came from property damage and the loss of ground rent, with commercial and industrial areas, roads, other infrastructure and agriculture being particularly hard hit. Two million people were forced from their homes, 1 million houses were destroyed or severely damaged, 10 million farm animals were evacuated or killed, and 1.6 million hectares of agricultural land - 10 per cent of the country's total - was largely destroyed. About 25 per cent of the total harvest for the year - in particular rice - was lost.

Thailand floods 2011

Source: Wikimedia Commons

These examples indicate the huge volumes of long-term income-generating real estate potential being destroyed by extreme weather events. Yet no structured record of this damage exists, nor is it incorporated in insurance statistics. What is more, the affected regions will be hit by human migration flows[23] which will further reduce residential and commercial real estate values.

The number of extreme weather events is increasing considerably. A total of over 800 events occur on a 10-year average, compared with only 400 in the 1980s.

Countless other examples exist of the increasing frequency of extreme weather events - floods after torrential rains in China, the highest floodwaters in New York City in 100 years, cyclones and drought in Australia, and flooding in large areas of Germany, Austria, and their neighbours - all evidence of ongoing climate change leading to a verifiably significant increase in extreme weather.[24] Globally, 840 weather-related natural disasters occurred in 2012[25], and studies by Munich RE have shown that the number of disasters has more than doubled globally between 1980 and 2012 (see figure 2).[26]

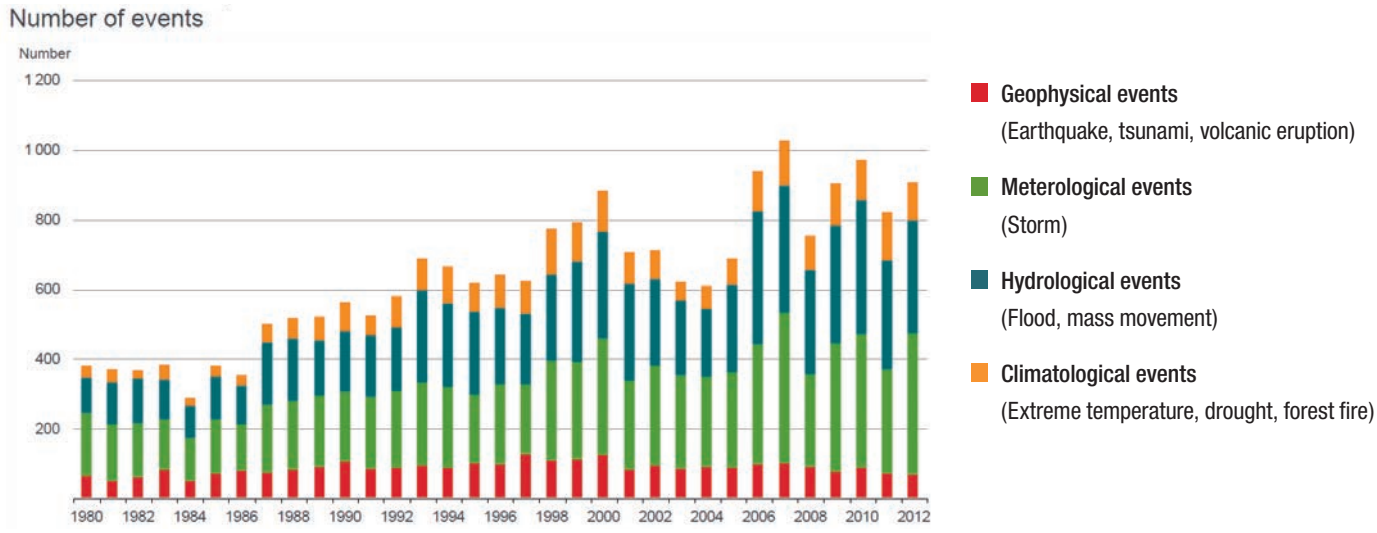
[23] Cruz et al., 2007, p. 488.

[24] IPCC, 2012, p. 7: In regard to the changes which have occurred so far, the IPCC has determined that "at least medium confidence has been stated for an overall decrease in the number of cold days and nights and an overall increase in the number of warm days and nights at the global scale, length or number of warm spells or heatwaves has increased, Poleward shift in the main Northern and Southern Hemisphere extratropical storm tracks, there has been an increase in extreme coastal high water related to increases in mean sea level."

[25] GDV, 2011, p. 1 / MüRe, 2013, p. 52 / Mechler et al., 2010, p. 611ff.

[26] MüRe, 2013, p. 3ff.

Figure 2 : Development of the number of natural disasters throughout the world from 1980 to 2012



Source: Münchener Rückversicherungs-Gesellschaft, Geo Risks Research, NatCatSERVICE - As at January 2013

Flooding in Greater Bangkok 2011

Source: Wikimedia Commons

Flood damage

Source: Free Images, Nurettin Kaya

A similar trend is evident in respect to the total damages resulting from these events, which has more than tripled from 1980 to 2012, from US$50 billion to over US$150 billion per year (€36.5 billion to €109.5 billion).[27] Furthermore, a 2012 report by the Intergovernmental Panel on Climate Change (IPCC) concluded that in areas most affected by extreme weather, average costs amounted to up to 8 per cent of GDP.[28] From a macroeconomic viewpoint regarding real estate, the question of the proportion of losses insured[29] is largely secondary because property prices will increase regardless of rising premiums or even as a result of the claim itself. What does require explanation, however, is why losses in property value are higher in percentage than the increase in severe weather events.

Increased settlement of high-risk areas, combined with socio-economic growth, partly accounts for the higher real estate losses.

There are two main reasons. Firstly, the losses caused by climate change are being exacerbated by man-made changes in the affected areas, with increased losses arising from denser settlement, increased urbanisation of high-risk areas[30] (e.g., the Florida coast), higher construction costs and quality, and, in some cases, the increased use of materials susceptible to damage, such as facades using thermal protection materials in areas prevalent to hailstorms.[31] Secondly, the losses are not adjusted in relation to global socio-economic growth; initial studies adjusting for this show "only" a linear increase in total losses of €1.7 billion per year over the past 30 years.[32]

27 MüRe, 2013, p. 52.
28 IPCC, 2012, p. 270 / Guyatt et al., 2011, p. 14: Cost of physical climate change impact could reach US$180 billion per year by 2030 (€131.4 billion pa)
29 Mills, 2005, p. 1040f / Mills, 2012, p. 1424f / Mechler et al., 2010, p. 611ff.
30 Howell et al., 2013, p. 46: Greater concentration of properties in risk zones.
31 Naumann et al., 2009, p. 228 / MüRe, 2008, p. 4.
32 MüRe, 2013, p. 58.

There is a lack of quantitative research regarding extreme weather events and the real estate industry.

The amount of literature on socio-economic development in connection with extreme weather events is growing rapidly.[33] However, relatively few quantitative research results exist[34] that cover the interface between natural hazards and real estate, due mainly to the fact that only in the past few years have the number of events and volume of damage increased significantly. The IPCC finds that "[o]nly a few models have aimed at representing extremes in a risk-based framework in order to assess the potential impacts of events and their probabilities using a stochastic approach, which is desirable given the fact that extreme events are non-normally distributed and the tails of the distribution matter."[35] Other authors have also stressed the challenges related to this factor.[36]

The following section goes into greater detail in this context by describing an innovative contribution to research implemented as part of the ImmoRisk project.[37] Specifically, it presents an approach to calculate annual expected losses (AELs) due to extreme weather events. This approach, based on future-oriented climate models, can be used to determine an approximate increase in expected losses. This allows conclusions to be derived regarding the future performance of a property (or portfolio) and, if necessary, adjustment of the allocation of assets in terms of selection of regions, property uses, etc.

33 IPCC, 2012, p. 265.
34 Note: See the Appendix for an extended overview of the current state of research.
35 IPCC, 2012, p. 266.
36 Wilby, 2007, p. 42 / Guyatt et al., 2011, p. 1ff: Traditional asset allocation does not account for climate change. There is a small amount of research which focuses on the investment implications of climate change. / Brandes, 2013, p. 12ff: The rise of modeling and future risk scenarios.
37 Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.

Calculation methodology for expected losses from extreme weather events

The risks from extreme weather events are either not being integrated into real estate investments or valuations, or are only being addressed indirectly by adjusting input parameters such as rents, yields, or costs on a more qualitative basis. Likewise, despite its relevance, climate data is also being excluded.

From a real estate industry perspective, the risk from natural hazards should be understood as being only one-sided: downside with no potential upside. In general, the risk is measured by the likelihood of the occurrence of a specific monetary loss within a certain time frame.

The calculation of annual expected losses (AELs) through extreme weather events as a measure of risk for property values is derived from (1) the hazard of the respective extreme weather event, (2) an empirically validated damage function (vulnerability), and (3) a value. The modeling is extremely complex, and the requirements concerning the quality and quantity of data are very high.

Through the use of data from climate models and insurance companies (concerning historical damages), as well as from cost-based valuations, far-reaching conclusions can be made regarding the future development of property values in a specific situation.

The core task in the risk analysis of climate impacts is to derive probability distributions for the occurrence of specific extreme weather events, and to determine the damage functions concerning the extent to which the respective property is affected.

For the real estate industry, questions have arisen based on the risks of climate change in general and extreme weather events specifically. These include:

- Dynamics regarding property values: What impacts on the values of existing investments can be expected in the future?
- Investment and divestment decisions: Which regions will be positively or negatively affected by continuing climate change? What conclusions can be drawn for future investment decisions?
- Property types/sectors: Are certain types of property use more affected by extreme weather than others?
- Portfolio management: How can investments be allocated to achieve a diversified property portfolio, thereby protecting against possible increased climate-related risks? What is the best allocation of investment to real estate within a broader multi-asset portfolio when climate risks are taken into account?
- Externalities: What can the real estate industry contribute towards internalising negative externalities,[38] and to what extent can irreversible damages be avoided?

From an investor's viewpoint, the potential impact of extreme weather on property values is probably the most fundamental concern, so it will be addressed here first. (The future development of extreme weather events will be discussed in the following chapter, which will help to build a greater understanding of likely changes.[39])

To assess the possible impact on property values, this study introduces a risk-based research approach, using a bottom-up methodology that quantifies the risk in the form of expected losses through observation of a single property.

[38] Note: An external effect is, for example, air pollution caused by energy consumption that affects a third party (e.g., the society in general) that was not responsible for that emission. The externality is "uncompensated" for the polluter because the cost will be borne by others unless the externality is "internalised" through regulation (e.g., taxes).

[39] ULI, 2013, p. 17: Market value drives land use.

Performance with regard to potential capital losses is only the first issue when natural hazards are considered in real estate decision making.

To determine a decline in value that may only occur in the future, it is essential to explore the interaction among parameters, structural characteristics, and other factors that affect the property in question in the form of causal chains.[40] Risks with a low probability of occurrence and high loss potential tend to be underestimated in most analyses[41] and, in practice, investment decisions are usually made on the basis of historical data and corresponding time series (e.g., rents, vacancies, etc.).[42] This observation has great relevance for assessing extreme weather events expected in the future, and for the implications of those events, because there is strong evidence that the relevance of low-probability risks is still underestimated - not least by professional market participants, such as property insurers and investors (Lansch, 2006).

Investment decisions today are often made solely on the basis of historical data series.

Natural hazards are part of the performance risk which takes effect on the supply side[43], and in most markets these risks can be covered by natural hazard insurance. The resulting annual insurance premiums are included in the operating costs of the property, and can generally be charged to the tenant as non-allocable operating costs. Despite the fact that they can be apportioned, these costs nevertheless do have an impact on value in the medium to long term from the owner's perspective, because rising utility bills, as a wider example, may increase the total occupancy costs in the view of the tenant and ultimately limit a property's potential to generate a higher net rent.

Against this backdrop, from the perspective of the real estate industry, extreme weather events constitute the downside risk of a monetary loss occurring in the future.[44] This Expected Loss (EL) is derived from a combination of the probability of a certain extreme weather event occurring (to be understood in the sense of environmental science as the reciprocal of a certain return period), and the amount of damage it would cause if it did occur. This fundamental relationship is illustrated in figure 3.

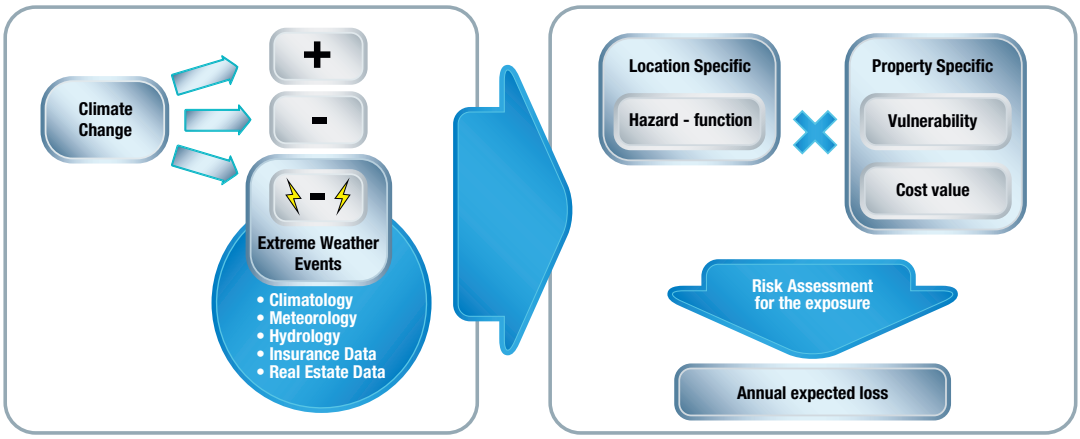
Thus, the core tasks involved in the risk assessment[45] of climate change impacts in the real estate industry are (1) deriving probability distributions for the occurrence of certain extreme weather events (*hazard*), and, similarly, (2) determining reliable damage functions (*vulnerability*[46]) regarding the impact on a specific property. These two areas represent the key elements of the risk model.[47] In regard to the impact, the model generally works with relative shares, in percentage (2a, relative losses) of a total value (2b, absolute losses). Therefore, (3) it is also important to derive cost-based property values (exposure). These are determined according to the insurable value,[48] in compliance with the procedures in regard to insurance of property, using the replacement-cost approach.[49]

The hazard, vulnerability, and cost-based value elements determine the expected loss.

Hence, for a property g, at a location r, at a point in time t, the risk can be described by the following functional relationship among hazard, vulnerability, and (cost-based) value:

$$Risk\ (r,g,t) = Hazard\ (r,t) * Vulnerability\ (g,t) * Cost\ Value\ (g)$$

Figure 3: Real estate risk assessment approach for extreme weather events

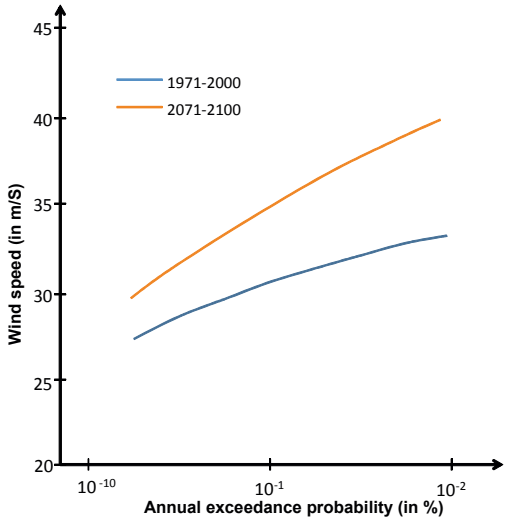


Source: IREIBS, University of Regensburg with reference to Bienert/Hirsch/Braun, 2013, p.1ff: ImmoRisk Tool for BMVBS.

40 IPCC, 2013, p. 10: climate feedbacks.
41 Osbaldiston et al., 2002, p. 46 / Ozdemir , 2012, p. 1ff.
42 Wilby, 2007, p. 42: "Above all, there is an urgent need to translate awareness of climate change impacts into tangible adaptation measures at all levels of governance." / Guyatt et al., 2011, p. 1: Standard approaches rely heavily on historical data and do not tackle fundamental shifts.
43 Lechelt, 2001, p. 28.
44 Büchele, 2006, p. 485 / Kaplan, Garrick, 1997, p. 93.
45 UNDHA, 1992, p. 64: "Risk are expected losses (of . . . property damaged . . .) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability."[45] ULI, 2013, p. 17: Market value drives land use.
46 Thywissen, 2006, p. 36 / UNDHA, 1992, p. 84: "Degree of loss (from 0% to 100%) resulting from a potentially damaging phenomenon."
47 Heneka, 2006, p. 722 / Büchele, 2006, p. 493.
48 Insurable value according to International Valuation Standards (IVS): The value of a property provided by definitions contained in an insurance contract or policy.
49 European Valuation Standards (EVS), 2012..

Hazard functions originate from the results of Global Climate Models (GCMs), which generally have no direct relation to the real estate industry. Climate models are able to forecast future changes in the probability of occurrence, the intensity, and the typical duration of extreme weather events - for example, of a particular wind speed being reached or volume of hail falling.[50] In order to get a location-specific hazard function, GCMs must be downscaled to a regional level (a Regional Climate Model or RCM), sometimes taking into account the very specific characteristics of the surroundings.[51] The already apparent increase in the probability of occurrence of extreme weather events can be derived visually with the help of figure 4, which shows real climate data and predictions.

Figure 4: Sample wind hazard function for a location in Northwest Germany, present vs. future



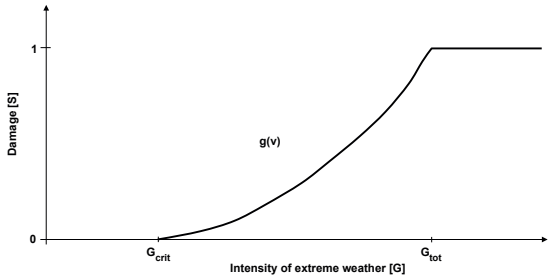
Source: IREIBS, University of Regensburg with reference to Bienert/Hirsch/Braun, 2013, p. 1ff: ImmoRisk Tool for BMVBS / see also Hofherr et al., 2010, p. 105ff.

In the context of vulnerability analyses, functional relationships between the intensity of the extreme weather event and the resulting monetary losses must be obtained for every event. The loss function then describes the relationship that is determined, based on the analysis of a large number of historical losses. Loss functions thus represent the connection between the intensity of an event and the resulting loss in the value observed (vulnerability function).[52] For example, experience indicates that a certain wind speed can mean that 30 per cent of a particular type of building could be destroyed. This is generally determined by empirically-based evidence from historical insurance data or by an expert's opinion.[53] Once relative losses are established, monetary losses only arise in combination with the value of a specific property.

[50] IPCC, 2013, p. 10, 14f / Khan et al., 2009: Storm risk functions / Leckebusch et al., 2007, p. 165ff / Mohr et al., 2011 / Waldvogel et al., 1978, p. 1680ff.

[51] Fleischbein et al., 2006, p. 79f / Linke et al., 2010, p. 1ff / Orlowsky et al., 2008, p. 209 / Rehm et al., 2009, p. 290f: Model for wind effects of burning structures / Rockel et al., 2007, p. 267f / Sauer, 2010 / Thieken at al., 2006, p. 485ff: Approaches for large-scale risk assessments.

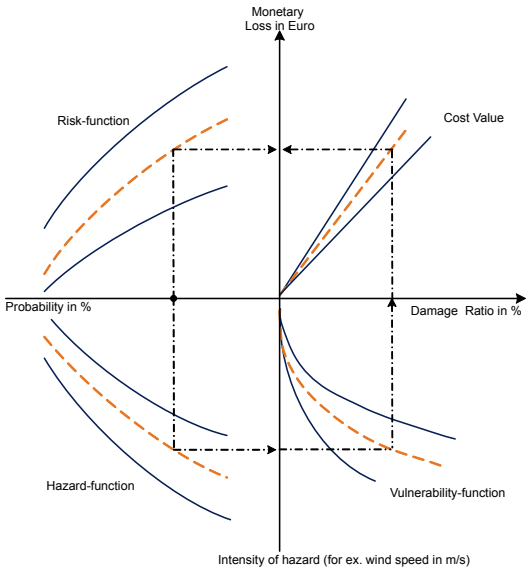
Figure 5: Loss function which correlates intensity with storm damage.



Source: IREIBS, University of Regensburg with reference to Heneka, 2006, p. 724 / see also Unanwa et al., 2000, p. 146.

The determination of the expected loss resulting from the interaction between individual elements is illustrated by figure 6.

Figure 6: Integrative calculation of the risk of natural hazards in the case of uncertainty on all levels of observation.



Source: Bienert/Hirsch/Braun, 2013, p.1ff: ImmoRisk Tool for BMVBS with reference to www.cedim.de and Heneka et al.

Closer inspection reveals that an (expected) total loss must always be related to one specific time interval (e.g., one year) and include all possible risk scenarios of a particular extreme weather phenomenon (e.g., wind) - that is, it must be weighted according to its individual probability of occurrence.

[52] Corti et al., 2009, p. 1739f / Corti et al., 2011, p. 3335f / Granger, 2003, p. 183 / Pinello et al., 2004, p. 1685f / Sparks et al., 1994, p. 145ff.

[53] Golz et al., 2011, p. 1f: Approaches to derive vulnerability functions. / Hohl, 2001, p. 73f: Damage function for hail. / ICE, 2001: Source-Pathway-Receptor-Consequence-Concept / Jain et al., 2009 / Jain et al., 2010 / Kafali, 2011 / Klawa et al., 2003, p. 725f / Matson, 1980, p. 1107 / Naumann et al., 2009a, p. 249f / Naumann et al., 2009b: Flood damage functions. / Naumann et al., 2011 / Penning-Rowsell et al., 2005 / Schanze, 2009, p. 3ff.

In this context, it would be expedient to calculate an annual expected loss (*AEL*) - i.e., to define one year as a relevant time interval. As the hazard can take on not only single, discrete characteristics - for example, "in 4% of the cases the wind speed reaches 8 metres/second" - but also constitute part of a continual distribution, the hazard function must be integrated:[54]

$$AEL(j) = \int_{x_{min}}^{\infty} f(x)S(x)Wdx = \int_{0}^{1} S(p)Wdp$$

f = probability density function of the hazard (hazard function)
S = loss function
W = value of building property
x = intensity/form of hazard (e.g., wind force or water depth)
x_{min} = lower integration limit, above which damage is to be expected
p = probability of reoccurrence
$AEL(j)$ = annual expected loss (in a specific extreme weather event, j)[55]

To obtain a complete picture of the *AEL* of a particular property, all partial results of the different extreme weather events (e.g., wind, hail, flood, etc.) are added up:

$$AEL = \sum_{j=1}^{n} AEL(j)$$

with *AEL*= annual expected loss (sum), and *AEL(j)*= annual expected loss (in a specific extreme weather event, *j*).

From a real estate valuation perspective, the annual expected loss could now be subject to present value considerations by implementing a risk-adequate cap rate *(i)*:

$$PV\ (Risk) = \frac{AEL}{i}$$

with *PV*= present value (of the risk), and *AEL*= annual expected loss (here, identical for all years) with *i*= cap rate.

To account for the most realistic case in which (at least) the hazard changes, it is useful to differentiate between different *AEL* assumptions, and different time frames. In contrast to perpetuity, it would then make sense to do the calculation with one reversionary annuity for different annual expected losses:

$$PV\ (Risk) = \sum_{t=1}^{n} \frac{AEL_t}{(1+d)^t}$$

with *PV*= present value (of all expected losses) representing the risk, and *AEL*= annual expected loss (in *t*) with *d*= discount rate.

This value could also be used as part of a property valuation, and in risk management and portfolio management. As climate risks have been implicitly taken into account in the input parameters of valuations to date, care must be taken to avoid redundancies; to refer to the total present value as a deduction would therefore probably not be constructive. On the other hand, it would make sense to take the present value of a future increase in the annual expected losses compared to the initial value - such as the average of the previous periods, for example.

$$PV\ (Increased\ Risk) = \sum_{t=1}^{n} \frac{(AEL_t - AEL_0)}{(1+d)^t}$$

with *PV*= present value (of all expected losses that exceed the historical benchmark) representing the risk, and *AEL*= annual expected loss (in *t*) with *d*= discount rate.

The meaningful aggregation of hazard, vulnerability, and cost data elements in an annual expected loss as a present value involves a great deal of computing time and requires an extensive database.

It should be noted that "cost" - and therefore also AEL - do not automatically equal "value" and this is why property value is often calculated using hedonic pricing models. These models attempt to separate the given property prices into their value drivers by using multiple regression models. Until now, however, researchers have mainly focused on the influence of infrastructure, population density, and other socio-economic aspects within the framework of hedonic pricing models, although some environmental factors such as crime, types of neighbourhood, earthquake risk, air pollution, and climate have also been analysed. Harrison and Rubinfeld (1978) and later Smith (1995), as well as Costa and Kahn (2003) and others, have investigated how the hedonic price of a non-market good like "climate" can be estimated. (This field of research that focuses on real estate can be called "cross-city hedonic quality of life literature".[56])

Even so, there are reasons why the use of hedonic pricing models to estimate the cost and impact of climate change has so far remained untouched as a research field. They are mainly because (1) hedonic pricing models analyse historical data, and climate change is a dynamic process with many of its results only visible in the future, (2) climate change is a complex topic with a range of interacting variables, and (3) uncertainty is inherent when talking about climate change.

[54] Kaplan, Garrick, 1997, p. 109: Therefore, information about the hazard is accompanied by a statement in regard to the relevant statistical certainty in order to show the certainty (e.g., 95 per cent) with which a defined degree of damage will not be exceeded.
[55] Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.
[56] Cragg et al., 1997, p. 261f / Cragg et al., 1999, p. 519f / Kahn, 2004.

However, hedonic pricing models can help a great deal. As they can disclose the value of "many severe storms" in one city and "no storms" in another, there are possibilities for establishing a "price" for an aspect of climate. Combining the models for climate change with a projection of future events enables a calculation of the impact of increasing risks of extreme weather events on the housing market in the given location. Nevertheless, the problems of interaction, uncertainty, time preference, and changing consumer preferences still need to be addressed.

In this context, the calculation model presented above can only be understood as a first step towards the deeper exploration of natural hazards. As yet it does not allow for several natural hazards occurring simultaneously and perhaps being subject to correlations[57]- for example, drought in combination with very high temperatures and low humidity typically increases the risk of wildfire. It also does not take into account that loss functions can also be subject to dynamics over time and can therefore change; extreme weather events today possibly increase the vulnerability of a given property to future extreme events due to a lower resilience. On the other hand, investments to increase the resilience typically occur after a first disaster has taken place. As a result, extreme weather events will affect the capability of the property to adapt in various ways. Furthermore, as well as the very complex modeling of the functional relationships, the limited availability of data represents a further restriction on deriving expected losses, and this generally exposes climate models to various uncertainties.[58]

The analysis is restricted by data availability and complex functional modeling of the facts.

It is therefore no easy task to perform a risk analysis of extreme weather events in relation to property values. The aforementioned topics must be dealt with in a structured manner, and the fundamental relationships in respect to risk management must be considered. Some of the key questions that arise are:

- What is the exact shape of the distribution of the specific hazard function for a given kind of extreme weather today? Which kind of distribution fits best to model the hazard, and which risk functions and extreme value statistics might apply?
- How will the risk change in the future in regard to the intensity and frequency of extreme weather events? How can density functions be derived today that are relevant for the future (e.g., 2020-2030) in this regard?
- How is damage caused to individual properties related to the intensity of an extreme weather event? How can corresponding damage functions be derived?
- What influence do technical progress and adaptation to expected losses have on future vulnerability?

In the next section of this report, the elements of vulnerability function and hazard function[59] are introduced. Figure 7 gives an overview of the origins of the data.

Figure 7: Elements for the derivation of expected losses

	Hazard	Vulnerability	Value
Database	Historical events, modelled data for the distribution	Data based on historical losses (empirical loss events) or data derived by experts for a specific building type (engineering aproaches)	Typical replacement costs for specific building type, comparative data
Forecast	Global and Regional Climate Models are the basis from which extreme value statistics are derived.	Only a few approaches exist to date. Changes of vulnerability are dependent on technical progress, adaptation measures, etc.	Cost inflation of given data for today's replacement costs are possible.

Source: IREIBS, University of Regensburg, 2013.

[57] Buzna et al., 2006, p. 132f.
[58] Cruz et al., 2007, p. 495f / Lindenschmidt et al., 2005, p. 99f / Merz et al., 2004, p. 153f / Merz et al, 2009, p.437f / Sachs, 2007, p. 6ff.
[59] Note: A more detailed scientific explanation of the two elements can be found in the ImmoRisk project reports.

Outlook on the future development of extreme weather events

Leading scientists are highly likely to assume in their scenarios that the overall risks from extreme weather events will continue to increase, ultimately leading to even higher losses. The corresponding risk functions are generally composed of the future hazard functions and the vulnerability of the affected properties.

In these scenarios, increasing losses will be driven in particular by the rising number of extreme events (hazard). There is no clear conclusion, however, regarding the development of the vulnerability of buildings and infrastructure. On one hand, resilience may improve due to major investments in adaptation measures; on the other, there are many reasons to believe the vulnerability of the property stock in general will rise further, such as the continued zoning for new construction in heavily affected areas.

In developing strategies to address the threat of extreme weather events for individual properties, a strong, regional differentiation is essential when considering the risks.

Furthermore, when it comes to real estate, it is increasingly important to pay attention to relevant psychological impacts. Even if people often do not give up their property until they have been hit by natural disasters repeatedly, these situations will occur more frequently in the future, and migration will intensify accordingly.

In regard to the vegetation in affected areas, trees and other plants with a long growth phase, in particular, will die out first, and this may happen more rapidly.

In terms of strategic real estate investment decisions, as well as observation of the current situation, it is important to analyse the development of all factors that potentially affect future returns and values as well as the underlying driving forces. In this respect, extreme weather events will become increasingly relevant and, in light of current research, it is assumed that the total number and intensity of different extreme weather events will continue to grow.[60]

Figure 8: Impact of projected climate change

Number of studies	Hazard type	Median estimated increase in loss in 2040 from 2000
9	Tropical storms	30%
6	Other storms	15%
6	Flooding	65%

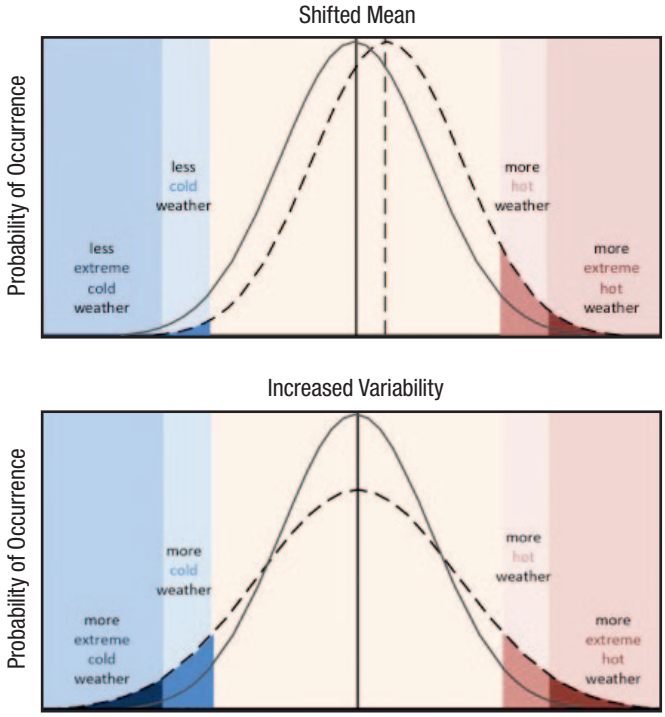
Source: IPCC, 2012 / Bouwer, 2010.

Calculations made by the ImmoRisk project concerning future time frames have reached the same conclusion, while all forecasts regarding the change in different hazard functions indicate a growing threat over time.[61] Figure 9 illustrates this result based on the example of a change in density function.

[60] Donat et al., 2011, p. 1351ff / Donat et al., 2010, p. 27ff / Naumann, 2010, p. 53 / World Bank, 2013, p. XVff / Guyatt et al., 2011, p. 58: Physical impacts will increase from 2050 on. / Howell et al., 2013, p. 4ff / IPCC, 2013, p. 4 / Kunz et al., 2009, p. 2294 / Pinto et al., 2007, p. 165f.

[61] See Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.

Figure 9: Change in the density function of extreme weather events



Source: IPCC, 2013, p.7

Note: The top graph shows the effects of a simple shift of the entire distribution toward a warmer climate. The bottom graph shows the effects of an increase in temperature variability with no shift in the mean.

Generalised statements are not constructive, however, because "confidence in projecting changes in the direction and magnitude of climate extremes depends on many factors, including the type of extreme, the region and season, the amount and quality of observational data, the level of understanding of the underlying processes, and the reliability of their simulation in models."[62]

Global trends are obvious; regional differentiation is necessary, however.

If substantial conclusions are to be drawn for individual properties or portfolios, further regional differentiation must be applied to the following statements that refer to general developments:[63]

- In developed countries "...exposure to climate- and weather-related hazards has increased, whereas vulnerability has decreased as a result of implementation of policy, regulations, and risk prevention and management (EEA, 2008; UNISDR, 2009)."[64] This trend will probably continue, whereas vulnerability might yet increase for less developed countries.[65]

- "Models project substantial warming in temperature extremes by the end of the 21st century. It is virtually certain that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale."
  "Across large parts of Europe, the 1961-1990 100-year drought deficit volume is projected to have a return period of less than 10 years by the 2070s."[66]

  In Mediterranean countries in particular, droughts will lead to increased economic losses (particularly when related to the danger of more intensive forest fires in terms of length, frequency, and severity) while heat extremes in Asia will also proliferate in the near future. Across the world, global warming will also put added pressure on agricultural yields.[67] In this context experts also point to the mounting concerns about increasing heat intensity and other climate-related threats in major European cities.[68]

  Warming will lead to an increase in the lack of water in the affected regions[69] and cause the Arctic ice mass and glaciers to retreat further.[70]

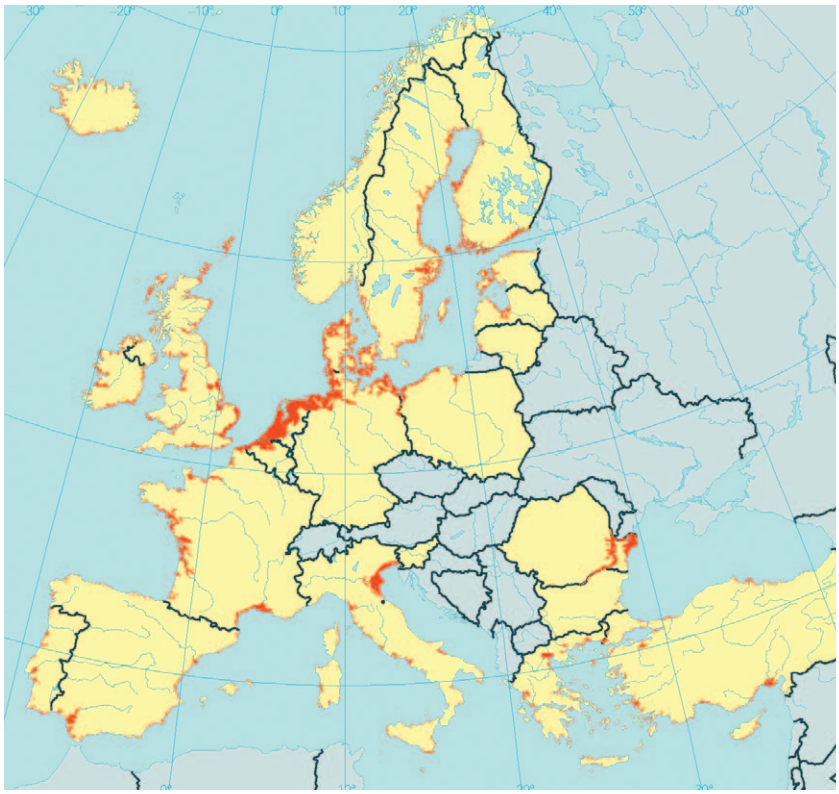
- "It is likely that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe.... [F]uture flood losses in many locations will increase."[71]
  "Heavy rainfalls associated with tropical cyclones are likely to increase with continued warming."[72]
  "It is very likely that mean sea level rises will contribute to upward trends in extreme coastal high water levels in the future."[73]

  For Europe, the sea level can be expected to rise by another 0.46 metre by 2080, leading to further severe damage to property and infrastructure in coastal regions. Total monetary damage due to flooding, salinity intrusion, land erosion, and migration could rise from a current €1.9 billion to €25.3 billion in 2080 annually.[74] For Asia, experts warn that the sea-level rise could be as much as 1 metre by 2100 if the temperature rises by 4°C.[75]

  "There is high confidence that changes in heatwaves, glacial retreat, and/or permafrost degradation will affect high mountain phenomena such as slope instabilities, movements of mass, and glacial lake outburst floods. There is also high confidence that changes in heavy precipitation will affect landslides in some regions."[76]

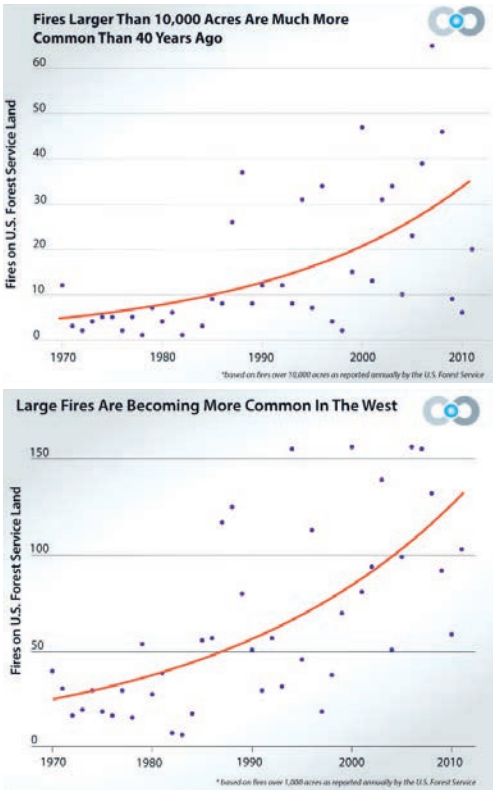
62 IPCC, 2012, p. 9 / Guyatt et al., 2011, p. 62.
63 IPCC, 2012, p. 12ff / IPCC, 2013, p. 15ff.
64 IPCC, 2012, p. 255 / Schmidt et al., 2010, p. 13ff.
65 Satterthwaite et al., 2007, p. 15ff.
66 IPCC, 2012, p. 242 / Lehner et al., 2006, p. 1ff.
67 World Bank, 2013, p. XVII.
68 Wilby, 2003, p. 251ff.
69 World Bank, 2013, p. XVII.
70 IPCC, 2013, p. 17.
71 IPCC, 2013, p. 13.
72 IPCC, 2013, p. 19.
73 IPCC, 2013, p. 120.
74 Brown et al., 2011, p. 31.
75 World Bank, 2013, p. XVII / Leurig et al., 2013, p. 4.
76 IPCC, 2013, p. 114.

Lowland in coastal countries - below 5m elevation.



Source: European Environment Agency

The rise in wildfires reports in the last 30 years



Source:Climate Central

The overall picture from this most recent research is clear: extreme weather events will rise in number, no matter what kind of natural hazard is discussed. In particular, the incidence of forest fires, heatwaves, and droughts will continue to increase in many regions, while floods, hail, and severe storms will occur with greater frequency. Likewise mudslides, avalanches, and other examples of severe erosion will become even more common, especially in mountainous areas, while flash floods will grow in regularity and the migration of people from severely affected areas will escalate.

Experts assume that, above all, Russia[77] and the United States[78] will be affected to an increasing extent. Of specific note are heatwaves, their accompanying droughts and forest fires, and the resulting losses for forestry and agriculture, as discussed earlier. For the Western United States, for example, Spracklen et al. (2009) assume that the average area burned in forest fires each year will more than double within the next 40 years. If rainfall decreases, the dryness of the soil will increase, especially in those areas that rely on mountain meltwater.

[77] MüRe, 2013, p. 40.

[78] Brandes, 2013, p. 4: based on the "Draft National Climate Assessment Report", U.S. Global Change Research Program, January 2013.

It is widely accepted that a significant increase in frequency and intensity of extreme events - and therefore in damage - is highly likely.

It is also expected that disasters associated with climate extremes will have an increasing influence on population mobility and relocation. Even so, it should be noted that people might not immediately give up their homes as a result of a disaster, but may choose to do so if the event happens again. For example, in parts of Austria an increase in real estate sales was only noticed when the same region was flooded for a second time - a couple of years after the first occurrence.

As severe weather events occur with greater frequency or magnitude, or both, some localities may be considered increasingly marginal as places to live. Intensity and recurrence of natural disasters will therefore have a great influence on location decisions made by people, yet only when certain tolerance levels have been reached. The resulting migration will not only impact the places being left behind, but clearly also the areas that people move to. It is likely that the areas most affected by the loss of population will be coastal settlements, small islands, mega-deltas, and mountain settlements.[79]

[79] IPCC, 2012, p. 234f.

Studies have also demonstrated that periods of severe drought can also lead to the rapid local extinction of certain plants in affected areas - a development that is set to intensify.[80] In particular, this affects trees with a long growth phase that cannot adapt fast enough to the changing environment, as shown by the case of the Colorado pinyon (Pinus edulis) in the 2000-2003 U.S. drought.[81]

Frequently recurring extreme weather will intensify human migratory flows. In the plant world, trees with a long growth phase will die out first.

In Greenland, the presence of heat islands with increasingly rising temperatures could cause the ice cover to continue to recede on a large scale. However, it is questionable whether the ice in the Arctic will continue to retreat at its very high average rate of 11.3 per cent per decade in summer (based on the overall difference in ice cover in 2012 compared with 1980). In the Southern Hemisphere it can be assumed that the annual sea ice extent (Antarctic without inland ice) will continue to increase - although at the slower rate of 2.8 per cent per decade in the southern summer, as recorded to date (based on the change from 1980 to 2012). The rising temperatures will also cause stronger winds around the Poles.

The Intergovernmental Panel on Climate Change (IPCC) asserts that various alternative emission scenarios and the climate models based on them represent “a substantial multi-century climate change commitment created by past, present and future emissions of CO2.”[82] Because most of the impacts related to climate change will persist over many centuries, even if emissions are stopped today, it is clear that many consequences of climate change are not foreseeable, despite state-of-the-art forecasting techniques. For example, the possibility that the Atlantic Meridional Overturning Circulation (AMOC) - the large-scale ocean circulation created by surface heat and freshwater fluxes - might collapse after the 21st century, cannot be ignored.[83]

The limits of climate models are reached when thresholds and tipping points related to social and/or natural systems are exceeded.[84] For example, Fischlin et al. (2007) analysed 19 studies and concluded that up to 30 per cent of plant as well as animal species might be at an increased risk of fast extinction if temperature rise exceeds 2°C to 3°C - which is a realistic scenario.[85] Such fundamental changes to the environment will have significant but, as yet, unpredictable effects on the economy.

[80] World Bank, 2013, p. XVII.: Drought-induced die-off of plants and trees.
[81] IPCC, 2012, p. 244. / Granier et al., 2007, p. 124f.
[82] IPCC, 2013, p. 19.
[83] IPCC, 2013, p. 17.
[84] Dawson et al., 2009, p. 96
[85] Dawson et al., 2009, p. 244.

The continuous deterioration of the ecosystem and ongoing climate change could lead to critical tipping points being reached more frequently.

Thus, a clear trend towards more severe and more frequent extreme weather events - with corresponding effects on real estate and the broader economy - must be anticipated. In contrast, no uniform trends can be derived concerning vulnerability of real estate to extreme weather. It is generally to be expected that the exposure of real estate portfolios to extreme weather events will see a relative decrease worldwide due to adaptation measures to combat such events - though the adaptation needed will probably be simultaneously connected to substantial investments.

The exposure of real estate to climate change-related risk is closely connected to socio-economic developments, such as the continued rise in population and economic growth, improved social welfare, and the location of new settlement areas. In this regard, it will be necessary in the future to be much more sensitive when designating existing natural areas as building zones.[86] Positive actions in this direction can already be observed in developing countries, where building regulations and land-use planning are increasingly taking into account the need to reduce the vulnerability of buildings to the effects of climate change.[87] Intelligent warning systems are also increasingly being installed that can help protect people and prevent property damage.

It is impossible to derive clear information regarding the development of vulnerability.

Meanwhile, threats to real estate from severe weather remain in the form of unbridled growth, uncontrolled construction of settlements in poor countries, and use of modern construction materials and elements, such as certain facades or fragile solar panels on roofs that could be damaged by hail or other storm damage. Moreover, recent studies focusing on port cities with more than 1 million inhabitants, for example, have estimated that real estate assets in these cities that might be exposed to a once-a-century extreme event could grow tenfold to around US$35 trillion by 2070 (€25.5 trillion).[88]

[86] Cruz et al., 2007, p. 491f: Weak land use planning and enforcement are increasing vulnerability to extreme weather as well as climate change in general.
[87] Feyen et al., 2009, p 217f.
[88] Nicholls et al., 2008, p. 8ff / World Bank, 2013, p. XXI, p. 33ff, p. 82ff: Regarding coastal cities in general.

Case Study: Increased insurance premiums / annual expected loss

In this case study, a hypothetical property is processed with the data of damage functions as well as (future) hazard functions to derive an annual expected loss (AEL) of the property for different time periods. The characteristics of the hypothetical property are shown in figure 10.[89]

Figure 10: Property details

Hazard Type	Windstorm
Property type	Single-family house (detached)
Construction	Solid construction/stone
Year of construction	2010
Gross external area	250 sq metres
Levels above ground	1
Height of building	3.25 metres
Type of roof	Flat
Roofing	Soft roofing
Standard of fittings	Very high
Special exposure to hazards	None
Year of assessment	2013

Source: IRE|BS, University of Regensburg.

The risk of windstorm hazards is typically expressed as the frequency of the occurrence of storm events which exceed a certain wind speed ([exceedance] probability). At this property's location, we assume there is a storm event every 10 years (return period), with squalls (wind gusts) of up to 31.6 metres per second (114 km/h) to be expected. The corresponding function describing this relationship - that is, the return period of windstorm intensities (wind speeds) - can be stated as follows:[90]

$$x(T) = \beta - \alpha * \left(\ln \left(-\ln \left(1 - \frac{1}{T} \right) \right) \right)$$

Here, x is the wind speed and T is the recurrence interval. In this example, α (3.31) and β (24.12) are the extreme value statistical parameters of the Gumbel-distribution[91] reflecting the current situation (based as a proxy on the latest available data set regarding hazards that occurred within the time period 1971-2000).

Taking into account the specific building and location characteristics, the following empirically derived storm-damage function can be applied. This is a power function of

$$S(x) = a * (1 + x)^b$$

with S as the relative damage to the property caused by a given wind speed, x. The parameters a and b are derived from empirical damage functions (based on real insurance data of historical losses that occurred in connection with certain storm events in the past). In this case,

$a = 3.3 * 10^{-19}$ and $b = 10.0$ // [92]

The functions also account for the fact that the damages for very low wind speeds (up to about 30 metres per second) are close to zero. However, with higher wind speeds, they increase strongly. Other factors - such as how long the windstorm lasts, gustiness,[93] or trees that might surround the building - are not explicitly modelled here.

According to this damage function, the storm for a return period of 100 years, with wind speeds of about 39.3 metres per second, would, for example, lead to damages of about 0.377 per cent of the total building's cost value; the percentage related to the overall value reflects mainly the repair work needed for the partially destroyed roof cover, damaged windows, and other relatively fragile building parts that will be exposed to storm events. It should be noted that because of the high-quality, robust construction of properties in Germany, severe, structural damages are usually the exception in storms.

To deduce the annual expected loss (AEL^*) in all possible storm events, this formula involving all recurrence intervals or probabilities must be integrated as follows[94]:

$$AEL^* = 0.637 * \int_0^1 S(x(p))dp$$

$$= 0.637 * \int_0^1 a*(1 + x(p))^b \, dp$$

$$= 0.637 * \int_0^1 a*\left(1+\beta-\alpha*\left(\ln\left(-\ln(1-p)\right)\right)\right)^b \, dp$$

$$= 0.637 * 0.293‰ = 0.187‰$$

[89] **Note: Case study was calculated by Jens Hirsch and Sven Bienert. The case study is for illustration only.**
[90] See Augter/Roos, 2010, p. 21f.
[91] Markose et al., 2011, p.35ff: Generalized Extreme Value (GEV) distribution. / Rootzen et al., 1997, p. 70f / Singh et al., 1995, p. 165ff.
[92] This damage function is for the purposes of illustration only, with reference to real data from the insurance industry.
[93] Wieringa, 1973, p. 424: Differentiation of gust factors.
[94] See Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.

Due to property-specific elements,[95] this result is adapted in regards to type of use, age, construction, and roofing, based on empirical values from the insurance industry; the resulting correction factor here is 0.637, and is integrated accordingly in the formula above.

Here, the annual expected loss is 0.187‰ of the value of the building. The AEL (in euros) is therefore calculated by multiplying the obtained AEL^* by the property value (based on cost data for the building only).

Since benchmark data is available in Germany (NHK, normalised replacement cost, 2010, which represents the average building costs per square metre),[96] it is possible to derive replacement costs per square metre for a given building; the benchmarks already include construction costs, value-added tax, and 17 per cent for related costs (e.g., design, planning approval, project management, etc.). After taking into account the building-cost index for inflation, and adjusting the figures according to local and regional pricing levels, the adjusted normal replacement costs round to €1,950 per square metre gross external area. The replacement cost of the property (without land), therefore, encompasses

$$NHK = 1{,}950\ \frac{€}{m^2} * 250.0m^2 = €487{,}500$$

The annual expected loss thus amounts to:

$$AEL = AEL^* * NHK = 0.187‰ * €487{,}500 = €91.16$$

This value largely corresponds to today's insurance premiums, but should be classified as "very high".

We now change the input parameters based on the information derived from Regional Climate Models (RCMs) regarding the hazard data, and use the extreme statistics parameter α (now 3.56) and β (now 25.82) as input for the Gumbel distribution applied in this case for the time period 2021-2050.

$$\text{The new } AEL^* \text{ is } 0.637 * 0.578‰ = 0.368‰;$$
$$\text{the new } AEL = 0.368‰ * €487{,}500 = €179.49$$

In this case, the insurance premium will therefore almost double in the medium term based on latest climate data.

When a 3 per cent interest rate is applied, a simplified consideration of a pure capitalisation of the annual difference results in[97]

$$PV\ (\text{Increased Risk}) = \frac{(AEL_t - AEL_0)}{i}$$

$$PV\ (\text{Increased Risk}) = \frac{(179.49 - 91.16)}{0{,}03}$$

$$PV\ (\text{Increased Risk}) = €2{,}944.33$$

with PV= present value (of all expected losses that exceed the historical benchmark) representing the risk, and AEL= annual expected loss (in t) with i= cap rate.

Therefore, although the increased risk seems relatively moderate and, when rounded, amounts to only less than 1 per cent of the total building value, one must take a couple of factors into account. First, several other hazard types related to extreme weather events must also be considered - hail, flooding, etc. - and these hazard functions might even correlate. Furthermore, besides direct losses due to extreme weather, there also are effects due to the gradual climate change that need to be reflected, as should indirect effects and consequential losses related to extreme weather. If all these (increasing) risks are taken into account, the overall impact on today's value might be significant enough to catch the owner's attention.

[95] Data based on experience: Gesamtverband der Deutschen Versicherungswirtschaft (GDV), German insurance companies association.

[96] See Bundesministerium für Verkehr, Bau und Stadtentwicklung, SW-RL, 2012, p.12ff.

[97] Note: The later increase based on the reference periods was not included in this illustration of the effect.

Conclusions

This report very much confirms that climate change is a reality and that its near-term consequences - in the form of extreme weather events - are growing in scale, intensity and frequency. For the real estate industry, which is already adapting to tackle the causes of climate change (of which it is a main contributor) in areas such as emissions and environmental controls, addressing these weather-related natural hazards and corresponding threats should not just be viewed as the 'next challenge' on the agenda. It should be part of a wider mindset that considers how climate change and all its effects will influence real estate location, building specification and cost, operating costs and, ultimately, value.

As highlighted, extreme weather events are now having, in some cases, a devastating effect on particular regions of the world with spectacular economic losses – and the impacts are not just being repeated more frequently but are widening to touch new geographies. With financial returns already being affected, a deeper understanding of the science of climate change and its impact on property value is therefore rapidly required; as is the adoption of new criteria within the investment-decision making process.

The real estate industry, critically, should not attempt to mitigate the increase in extreme weather events and the resulting increase in risk by merely relying on potentially rising (and non-allocable) insurance premiums. The direct and indirect effects on specific regions and asset classes may be so enormous, that investment locations currently seen as "safe havens" must be reconsidered. The result will be re-evaluations, building adaptation costs, and fundamentally different allocations of investment funds. Moreover, the dramatic regional differences in the expected impact from climate change requires an analysis of the real estate inventory in each region, and then individual recommendations made on it.

As part of the change in mindset, it is also essential that climate change and its risks are thoroughly understood and, where relevant, acted on at every stage of the property life cycle. For example, planning efforts that integrate climate change risks will be increasingly important for investors. At the same time, from an urban planning perspective, the extent to which the public sector adopts building adaptation measures and implements broader spatial planning concepts to address risks will become more important in a world of increasingly competitive international city markets.

In investment markets, managing climate risk will, among other things, most likely lead to an increased allocation of investment to real estate assets that are already future-proofed. Investors must therefore take significant steps towards improving the resilience of their portfolios while integrating risk assessments related to climate change in their portfolio management. Simultaneously, advisers and associated industry players will need to be at the same point, if not further up the climate change intelligence curve.

At present, research into the future of property values in the face of increasing weather-related natural hazards, and the implications for risk and portfolio management, is still in its infancy. This report is therefore a contribution towards heightening awareness and opening up discussion to a larger audience in the real estate industry. Pivotal to the debate is how weather-related losses can be accurately calculated and the risks assessed; the new loss calculation methodology featured in this paper seeks to provide the industry with a tool that will enable real estate investors to make far-reaching conclusions in regard to the future development of property values in a specific situation.

Extreme weather events will continue to multiply and intensify, and although improved forecasting will become stronger, there will always be an element of unpredictability in their nature and location. In reality, as these threats continue to escalate no one will be truly invulnerable. Acting now to future-proof assets, improve resilience and reduce risks is vital for the real estate industry across the world.

Appendix: Overview of the present state of research

Existing studies related to climate change, and that focus on extreme events, mainly deal with empirical values in specific regions or cities. Among these, for example, are the UNDRO survey for Manila (1977); the KATANOS report for Switzerland (1995); the Australian AGSO Cities project with its emphasis on geohazards (1999); and studies regarding Turrialba, Costa Rica (2002), and Toronto (2003). In addition to their regional focus, most of the studies concentrate on single-hazard research - that is an isolated consideration of a single natural hazard. [98] In particular, several studies from different regions have focused on the economic losses with respect to flood damage (e.g., L.M. Bouwer's 2010 study of the Netherlands). Simultaneous consideration of several extreme-weather hazards - for example, in the manner of the Australian research of Blong (2003) - has, up to now, been an exception. In view of the practical relevance of climate change, this is surprising.[99]

In regard to hazard research, the few studies that have addressed economic losses from hail damage have yielded mixed results. McMaster (1999) and Niall and Walsh (2005) found no significant effect on hailstorm losses for Australia, while Botzen et al. (2010) predicted a significant increase (up to 200 per cent by 2050) for damages in the agricultural sector in the Netherlands - the approaches used by the two studies varied considerably. The Rosenzweig et al. (2002) study reported on a possible doubling of losses to crops due to excess soil moisture caused by more intense rainfall.[100]

In vulnerability research, Dodman and Satterthwaite (2008) have focused on the vulnerability of residential property, and Satterthwaite has also analysed the effects of climate change on areas where the poor live in very elementary housing. In common with Douglas (2008), he found such housing to be highly vulnerable. Furthermore, Wilby (2003, 2007) has intensively examined the impact of climate change on highly developed cities such as London.

Climate change and population density has been especially addressed by Cutter et al. (2008), while Endlicher et al. (2008) have also focused on large cities, although the report concentrated on prospective heatwaves that will pose specific challenges for such areas. More specifically, McGranahan et al. (2007) have explored the relationship between windstorms and densely populated areas in coastal regions and found an increasing threat.

Risk Management Solutions (2000, 2012) has concentrated on certain construction materials and their vulnerability in case of windstorms, and Witharana et al. (2010) have used software to quantify building-content vulnerability.

[98] Grünthal et al., 2006, p. 21.
[99] Di Mauro et al., 2006, p. 1.
[100] IPCC, 2012, p. 272.

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Footnotes

1 MüRe, 2013, p. 40ff / IPCC, 2013, p. 4.

2 Peterson et al., 2013, p.20 / IPCC, 2013, p. 5.

3 Rahmstorf, 2007, p. 1ff / IPCC, 2013, p. 6.

4 MüRe, 2008, p. 6 / Latif, 2009, p. 153 / Peterson et al., 2013, p. IV / IPCC, 2013, p. 8f, p. 12f. / Bouwer, 2011, p. 39f.

5 MüRe, 2013, p. 40.

6 National Oceanic and Atmospheric Administration (NOAA), 10. Mai 2013 / IPCC, 2013, p. 7.

7 Note: "Doha Climate Gateway" negotiations with mandatory regulations from 2020 on still refer to the 2 degree Celsius goal at the Doha climate conference in December 2012.

8 Brandes, 2013, p. 9: Estimated Value of Insured Coastal Properties amount in the United States to US$27.000 billion in 2012.

9 WBCSD, 2009, p. 6.

10 Bosteels et al., 2013, p. 6.

11 Guyatt et al., 2011, p. 15: Real estate is very sensitive to climate impacts. / Leurig et al., 2013, pp. 5, 7

12 World Bank, 2013, p. 94: Reduced property values.

13 Guyatt et al., 2011, p. 61 / Cruz et al., 2007, p. 492: Effects on tourism might be massive. / Lamond, 2009.

14 ULI, 2013, p. 14ff: Recommendation 16: Accurately price climate risk into property value and insurance.

15 Guyatt et al., 2011, p. 58.

16 MüRe, 2013, p. 53.

17 Kron et al., 2012, p. 542: Direct losses are immediately visible and countable (loss of homes, household property, schools, vehicles, machinery, livestock, etc.).

18 IPCC, 2013, p. 270.

19 Kron et al., 2012, p. 535f, p. 542f.

20 MüRe, 2013, p. 42

21 Note: The assumption of a perpetuity serves only to illustrate the extent of the situation and does not claim to be scientifically conclusive as to the facts.

22 MüRe, 2010, p. 33, p. 37.

23 Cruz et al., 2007, p. 488.

24 IPCC, 2012, p. 7: In regard to the changes which have occurred so far, the IPCC has determined that "at least medium confidence has been stated for an overall decrease in the number of cold days and nights and an overall increase in the number of warm days and nights at the global scale, length or number of warm spells or heatwaves has increased, Poleward shift in the main Northern and Southern Hemisphere extratropical storm tracks, there has been an increase in extreme coastal high water related to increases in mean sea level."

25 GDV, 2011, p. 1 / MüRe, 2013, p. 52 / Mechler et al., 2010, p. 611ff.

26 MüRe, 2013, p. 3ff.

27 MüRe, 2013, p. 52.

28 IPCC, 2012, p. 270 / Guyatt et al., 2011, p. 14: Cost of physical climate change impact could reach US$180 billion per year by 2030 (€131.4 billion pa)

29 Mills, 2005, p. 1040f / Mills, 2012, p. 1424f / Mechler et al., 2010, p. 611ff.

30 Howell et al., 2013, p. 46: Greater concentration of properties in risk zones.

31 Naumann et al., 2009, p. 228 / MüRe, 2008, p. 4.

32 MüRe, 2013, p. 58.

33 IPCC, 2012, p. 265.

34 Note: See the Appendix for an extended overview of the current state of research.

35 IPCC, 2012, p. 266.

36 Wilby, 2007, p. 42 / Guyatt et al., 2011, p. 1ff: Traditional asset allocation does not account for climate change. There is a small amount of research which focuses on the investment implications of climate change. / Brandes, 2013, p. 12ff: The rise of modeling and future risk scenarios.

37 Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.

38 Note: An external effect is, for example, air pollution caused by energy consumption that affects a third party (e.g., the society in general) that was not responsible for that emission. The externality is "uncompensated" for the polluter because the cost will be borne by others unless the externality is "internalised" through regulation (e.g., taxes).

39 ULI, 2013, p. 17: Market value drives land use.

40 IPCC, 2013, p. 10: climate feedbacks.

41 Osbaldiston et al., 2002, p. 46 / Ozdemir , 2012, p. 1ff.

42 Wilby, 2007, p. 42: "Above all, there is an urgent need to translate awareness of climate change impacts into tangible adaptation measures at all levels of governance." / Guyatt et al., 2011, p. 1: Standard approaches rely heavily on historical data and do not tackle fundamental shifts.

43 Lechelt, 2001, p. 28.

44 Büchele, 2006, p. 485 / Kaplan, Garrick, 1997, p. 93.

44 UNDHA, 1992, p. 64: "Risk are expected losses (of . . . property damaged . . .) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability."

45 ULI, 2013, p. 17: Market value drives land use.

46 Thywissen, 2006, p. 36 / UNDHA, 1992, p. 84: "Degree of loss (from 0% to 100%) resulting from a potentially damaging phenomenon."

47 Heneka, 2006, p. 722 / Büchele, 2006, p. 493.

48 Insurable value according to International Valuation Standards (IVS): The value of a property provided by definitions contained in an insurance contract or policy.

49 European Valuation Standards (EVS), 2012.

50 IPCC, 2013, p. 10, 14f / Khan et al., 2009: Storm risk functions / Leckebusch et al., 2007, p. 165ff / Mohr et al., 2011 // Waldvogel et al., 1978, p. 1680ff.

51 Fleischbein et al., 2006, p. 79f / Linke et al., 2010, p. 1ff / Orlowsky et al., 2008, p. 209 / Rehm et al., 2009, p. 290f: Model for wind effects of burning structures / Rockel et al., 2007, p. 267f / Sauer, 2010 / Thieken et al., 2006, p. 485ff: Approaches for large-scale risk assessments.

52 Corti et al., 2009, p. 1739f / Corti et al., 2011, p. 3335f / Granger, 2003, p. 183 / Pinello et al., 2004, p. 1685f / Sparks et al., 1994, p. 145ff.

53 Golz et al., 2011, p. 1f: Approaches to derive vulnerability functions. / Hohl, 2001, p. 73f: Damage function for hail. / ICE, 2001: Source-Pathway-Receptor-Consequence-Concept / Jain et al., 2009 / Jain et al., 2010 / Kafali, 2011 / Klawa et al., 2003, p. 725f / Matson, 1980, p. 1107 / Naumann et al., 2009a, p. 249f / Naumann et al., 2009b: Flood damage functions. / Naumann et al., 2011 / Penning-Rowsell et al., 2005 / Schanze, 2009, p. 3ff.

54 Kaplan, Garrick, 1997, p. 109: Therefore, information about the hazard is accompanied by a statement in regard to the relevant statistical certainty in order to show the certainty (e.g., 95 per cent) with which a defined degree of damage will not be exceeded.

55 Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.

56 Cragg et al., 1997, p. 261f / Cragg et al., 1999, p. 519f / Kahn, 2004.

57 Buzna et al., 2006, p. 132f.

58 Cruz et al., 2007, p. 495f / Lindenschmidt et al., 2005, p. 99f / Merz et al., 2004, p. 153f / Merz et al, 2009, p.437f / Sachs, 2007, p. 6ff.

59 Note: A more detailed scientific explanation of the two elements can be found in the ImmoRisk project reports.

60 Donat et al., 2011, p. 1351ff / Donat et al., 2010, p. 27ff / Naumann, 2010, p. 53 / World Bank, 2013, p. XVff / Guyatt et al., 2011, p. 58: Physical impacts will increase from 2050 on. / Howell et al., 2013, p. 4ff / IPCC, 2013, p. 4 / Kunz et al., 2009, p. 2294 / Pinto et al., 2007, p. 165f.

61 See Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.

62 IPCC, 2012, p. 9 / Guyatt et al., 2011, p. 62.

63 IPCC, 2012, p. 12ff / IPCC, 2013, p. 15ff.

64 IPCC, 2012, p. 255 / Schmidt et al., 2010, p. 13ff.

65 Satterthwaite et al., 2007, p. 15ff.

66 IPCC, 2012, p. 242 / Lehner et al., 2006, p. 1ff.

67 World Bank, 2013, p. XVII.

68 Wilby, 2003, p. 251ff.

69 World Bank, 2013, p. XVII.

70 IPCC, 2013, p. 17.

71 IPCC, 2013, p. 13.

72 IPCC, 2013, p. 19.

73 IPCC, 2013, p. 120.

74 Brown et al., 2011, p. 31.

75 World Bank, 2013, p. XVII / Leurig et al., 2013, p. 4.

76 IPCC, 2013, p. 114.

77 MüRe, 2013, p. 40.

78 Brandes, 2013, p. 4: based on the “Draft National Climate Assessment Report”, U.S. Global Change Research Program, January 2013.

79 IPCC, 2012, p. 234f.

80 World Bank, 2013, p. XVII.: Drought-induced die-off of plants and trees.

81 IPCC, 2012, p. 244. / Granier et al., 2007, p. 124f.

82 IPCC, 2013, p. 19.

83 IPCC, 2013, p. 17.

84 Dawson et al., 2009, p. 96

85 Dawson et al., 2009, p. 244.

86 Cruz et al., 2007, p. 491f: Weak land use planning and enforcement are increasing vulnerability to extreme weather as well as climate change in general.

87 Feyen et al., 2009, p 217f.

88 Nicholls et al., 2008, p. 8ff // World Bank, 2013, p. XXI, p. 33ff, p. 82ff: Regarding coastal cities in general.

89 Note: Case study was calculated by Jens Hirsch and Sven Bienert. The case study is for illustration only.

90 See Augter/Roos, 2010, p. 21f.

91 Markose et al., 2011, p.35ff: Generalized Extreme Value (GEV) distribution. / Rootzen et al., 1997, p. 70f / Singh et al., 1995, p. 165ff.

92 This damage function is for the purposes of illustration only, with reference to real data from the insurance industry.

93 Wieringa, 1973, p. 424: Differentiation of gust factors.

94 See Bienert et al., 2013, p. 1ff: ImmoRisk Tool for BMVBS.

95 Data based on experience: Gesamtverband der Deutschen Versicherungswirtschaft (GDV), German insurance companies association.

96 See Bundesministerium für Verkehr, Bau und Stadtentwicklung, SW-RL, 2012, p.12ff.

97 Note: The later increase based on the reference periods was not included in this illustration of the effect.

98 Grünthal et al., 2006, p. 21.

99 Di Mauro et al., 2006, p. 1.

100 IPCC, 2012, p. 272.

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