ZURICH
Resilience Solutions

Climate Resilience

Safeguarding Our Energy Future: Protecting Europe's Energy Infrastructure Against Climate Risk

Clean, reliable and affordable energy is essential to mitigating climate risks and securing future economic success.

The energy transition is not simply a climate imperative. It is a strategic necessity for economic stability, national security, industrial competitiveness, and long-term prosperity. This is driving the ambitious transformation of energy infrastructure across Europe. As governments and energy companies work to deliver the clean energy revolution, the falling costs of renewables in the generation mix means that it is these assets in particular that are set to dominate electricity generation in the future.

At the same time, physical climate risks, in the form of extreme weather events, are increasing in frequency and severity. These pose material risk to all forms of energy generation, but renewable generation and storage assets are particularly vulnerable to climate perils such as strong winds, flood, hail and drought. While recent extreme weather events, such as Storm Darragh in 2024, or the European Floods of 2021, have highlighted the risks posed to energy infrastructure, for the most part these physical climate risks remain under-assessed and under-addressed. With physical climate risks set to increase even if net-zero targets are met, action to secure the resilience of energy infrastructure will be essential for a successful energy transition.

This report sets out to show the value of closing that assessment gap and securing a resilient energy transition. Understanding risk is the first step to delivering resilience and resilience in turn will be essential for insurability. Using proprietary modeling and risk engineering insights, Zurich Resilience Solutions (ZRS) has used publicly available data to map and assess the climate risk exposure of energy generation and storage assets across five European countries (France, Germany, Italy, Spain and the UK) to 2030 and 2050 under a 2°C warming scenario. Given the criticality of renewables to the future energy mix across these countries, our analysis has focussed on solar, onshore wind and hydropower assets, as well as battery and pumped hydro storage. Our report provides insights as to how physical climate risks will impact Europe's energy system in both the short and longer term. Unaddressed, physical climate risks will act as a brake on clean energy investment at the scale and speed required.

Our analysis highlights that across Europe, physical climate risks are already posing a threat across all energy assets. However, it is clear from our analysis that renewable generation and storage assets are relatively more exposed to physical climate risks compared to conventional fossil-fuel assets. By 2030, nearly half (46 percent) of the total renewable generation capacity will fall into our critical-risk category, of which well over half (58 percent) are solar assets. The story is similar for storage assets, with

82 percent of total energy storage capacity (pumped hydro and battery) falling into critical-risk categories. Without action, energy generation and storage infrastructure across Europe will face significant physical and financial risks.

Failing to deliver on the clean energy transition is not an option given the increased climate risks and energy insecurity which would come with inaction. While our modeling shows a relatively higher risk for renewable generation assets than conventional generation assets, the IPCC scenario we have carried out our assessment against is one that assumes 2°C warming by 2041 – 2060. This is the outcome which underpins most countries' transition plans and assumes a successful transition to clean energy by 2050. Absent that transition, the change in physical climate risk would be much more significant across the considered time horizon, with consequences for all types of energy infrastructure and significant economic downsides.

The good news is that action on resilience adaptation measures can significantly mitigate potential risks, support further investment in clean energy and strengthen the resilience of Europe's energy grid now and for the future. In particular, the rollout of new energy infrastructure presents an opportunity to integrate resilience measures from the outset and to do so efficiently. With energy generation capacity from renewable assets set to increase by almost two-thirds (62 percent) by 2030, there is also an opportunity to make the clean energy transition resilient by design.

Tried and tested resilience solutions to reduce risks and avoid damage are available. As shown here, insurers have the capabilities to model climate risks and identify where resilience interventions would be most beneficial. By working with companies and the public sector to deploy these insights more consistently, there is an opportunity to better quantify the value of investment in resilience, secure the promise of renewable generation and storage capabilities (affordability, security and efficiency) and avoid billions of euros of costs.

Successful delivery of enhanced energy infrastructure resilience will require a combination of national planning and coordination, with localized assessments and tailored solutions. Close collaboration between public and private sector will be essential to deliver supportive policies and aligned incentives.

To inform that process and advance resilience in the energy sector, action is recommended in the following five areas:

1. Address resilience gaps for existing energy assets
2. Stress test new generation assets against dynamic climate scenarios
3. Embed resilience in planning and design
4. Improve availability of resilience relevant data
5. Unlock investment in resilience measures

Overarching insights from the Zurich Resilience Solutions' analysis are captured below, with detailed country by country risk assessments contained in separate chapters.

The changing face of Europe's energy system

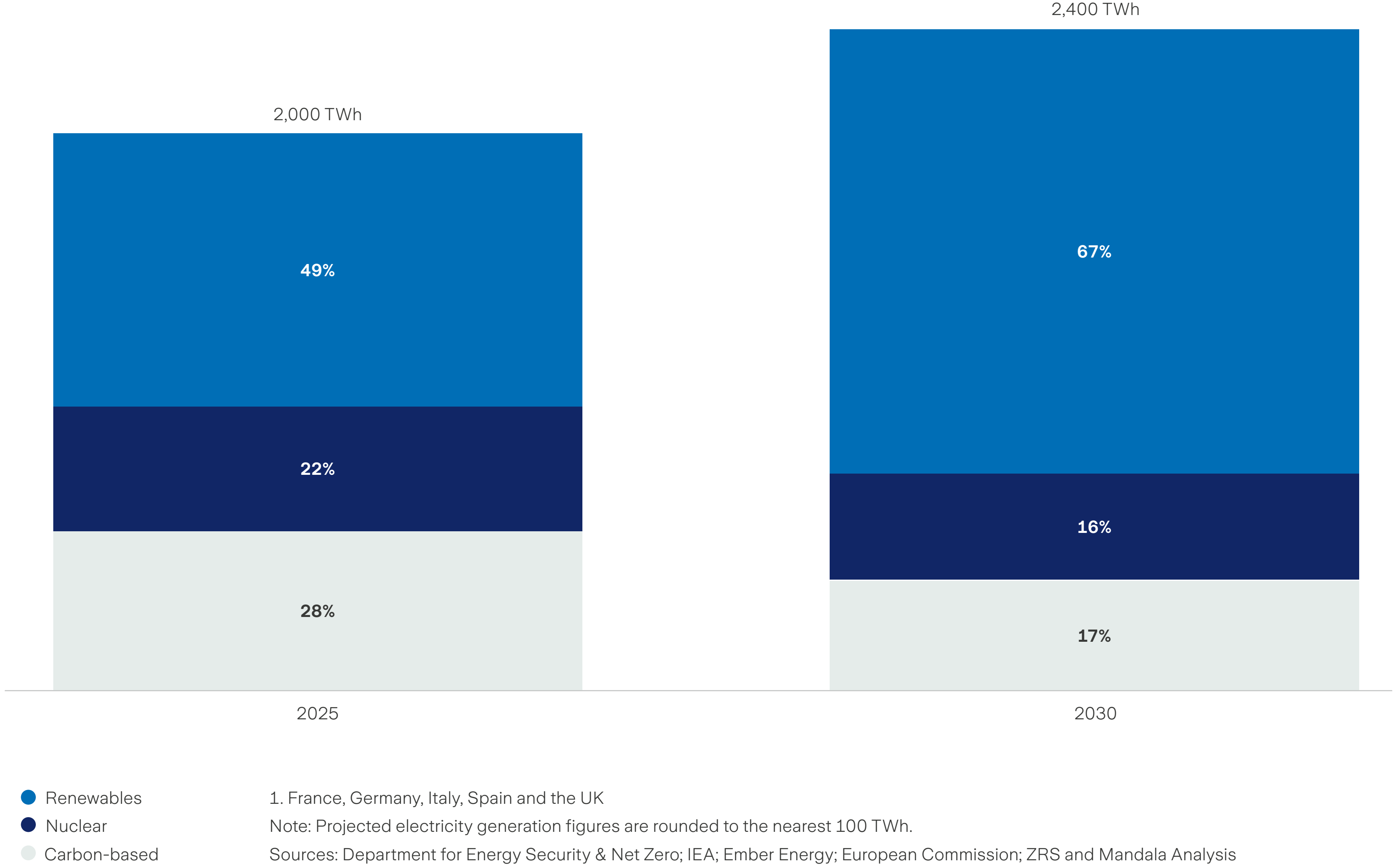
Europe is undergoing a rapid shift to clean energy generation, driven by net-zero commitments and the need to achieve security in energy supply.

Overall, electricity generation is projected to increase by almost a fifth between 2025 and 2030 across the five countries analyzed in this report (France, Germany, Italy, Spain and the UK), as the demand for electricity within economies increases. This may well be an underestimate given the expected further growth in energy demand to support the adoption of artificial intelligence (AI) across these markets.

This increase in demand will be met by an expansion in clean energy capacity, with the share of carbon-based generation falling:

- **Renewables:** The share of renewables (solar, wind, hydropower) in electricity generation is set to increase from 49 percent to 67 percent by 2030 (moving from nearly 1000 TWh to nearly 1600 TWh, or approximately 60 percent growth).
- **Nuclear:** The share of nuclear is set to decrease slightly from 22 percent to 16 percent by 2030.
- **Fossil fuel:** The share of coal, gas and oil is set to decrease from 28 percent to 17 percent by 2030.

Projected electricity generation across Europe[1]
2025 – 2030



1. France, Germany, Italy, Spain and the UK

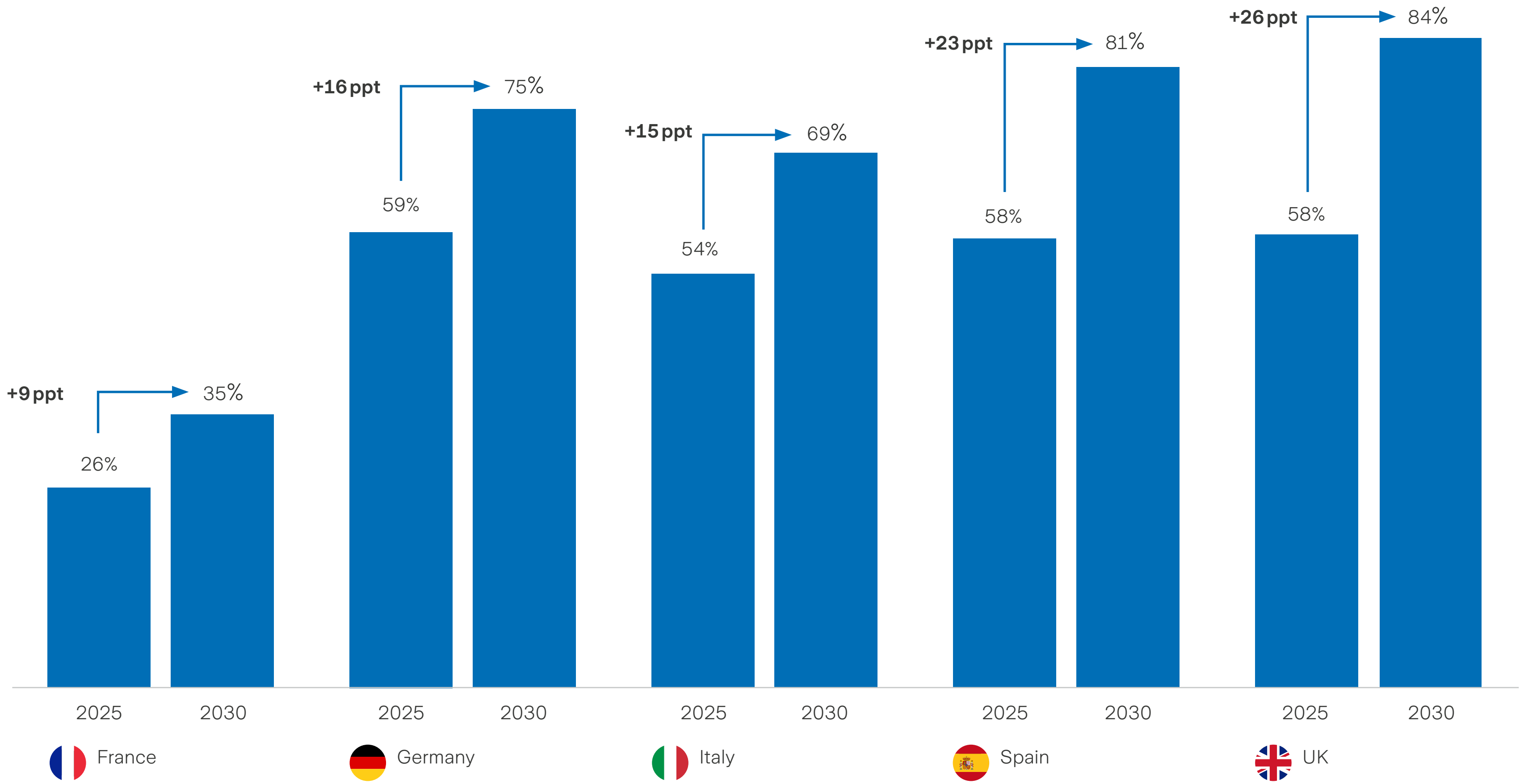
Note: Projected electricity generation figures are rounded to the nearest 100 TWh.

Sources: Department for Energy Security & Net Zero; IEA; Ember Energy; European Commission; ZRS and Mandala Analysis

The growth of renewable generation through 2030 is particularly significant. Across each of the five countries analyzed, we can clearly see the increasingly important role that renewables will play in the energy mix. France's clean energy generation includes nuclear as a core component of its carbon-free energy mix. This analysis is a deep dive on renewables only, excluding nuclear, and therefore does not capture the full magnitude of France's clean energy transition.

Security of energy supply across Europe will increasingly be dependent on renewable and storage assets. Understanding potential risks to renewable generation assets, and how to mitigate them, will be essential.

Renewable energy generation by country as a percentage of total generation
in percent, 2025 – 2030



Source: Department for Energy Security & Net Zero; IEA; Ember Energy; European Commission; ZRS and Mandala Analysis.

Extreme weather risks and energy generation

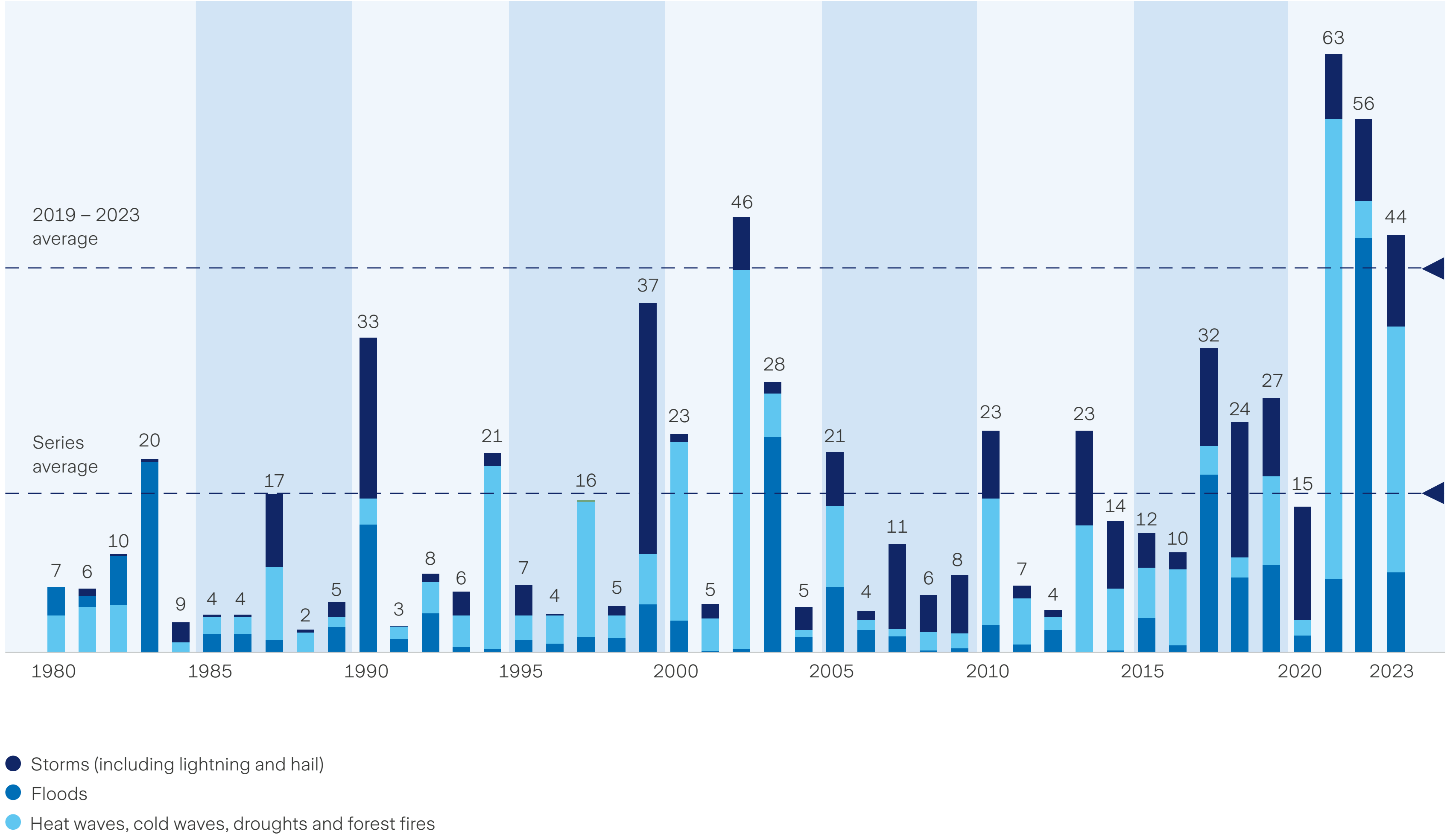
Climate-driven extreme weather events are reshaping the risk landscape across Europe, with extreme weather and natural catastrophes no longer being outliers.

In Europe, average annual losses from weather and climate-related events have climbed from EUR 8.5 billion in the 1980s to EUR 16 billion in the 2000s, and approximately EUR 45 billion in the 2020s – a clear sign of rising financial exposure.

These figures were calculated by the European Environment Agency, based on recorded estimates of economic losses from extreme weather events. The analysis covers all EU member states, offering a broader context beyond the countries profiled in this report.

Climate models tell us that this pattern is set to continue, with increases in the frequency and intensity of hazards, such as storms, floods and droughts, putting more assets at risk.

Economic losses from weather- and climate-related extremes
in € billions (2023 prices), 1980 – 2023



Source: European Environment Agency; ZRS and Mandala Analysis.

Examples of physical climate risks and their impacts across Europe

1. Hail

Event description

- **Hailstorms caused severe damage to solar panels across Northern Italy** in 2023, ranging from microcracks to visible shattering of glass layers.

Damage

- Complete short-term disruption to local generation during recovery and investigation.
- Short-term capacity loss while damaged solar panels were replaced.

Key learning

- Damage to solar panels in the region highlights the need to account for increasingly frequent extreme weather when planning energy assets. Climate risks such as hail should be integrated into risk models and adaptation strategies.

2. Flood

Event description

- **Severe flooding brought by the 'Bernd' low-pressure weather system** in 2021 forced many hydropower plants out of operation in Western Europe.

Damage

- Complete short-term disruption to generation during flooding.
- Short-to-medium-term capacity loss, with most power stations restored within eight weeks.

Key learning

- The unprecedented flooding in a region typically suited for hydropower highlights the importance of planning for unlikely, but catastrophic climate events. There is a growing need for elevated control systems and modern turbine technology that can manage extreme flow rates.

3. Wind gust

Event description

- **High winds from Storm Ignatz** in 2024 caused severe damage at Nattheim wind farm in Southern Germany, breaking a rotor blade off a wind turbine.

Damage

- Complete short-term disruption to generation during recovery and investigation.
- Short-term capacity loss while the damage was assessed and investigated.

Key learning

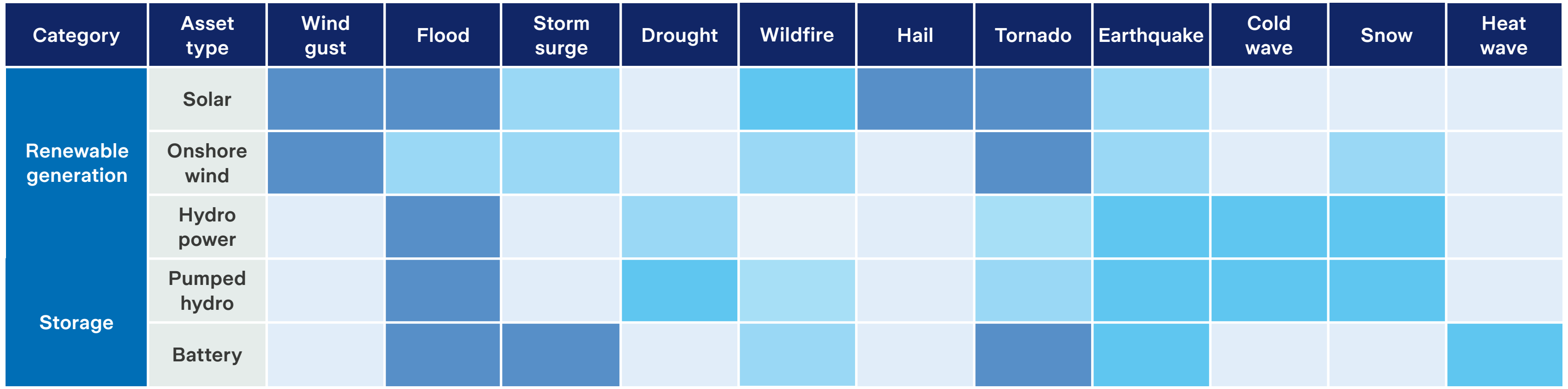
- The damage to the wind farm underscores the importance of resilience planning for extreme weather events. Wind gusts along with severe storms are becoming more intense and frequent.

Source: ZRS and Mandala Analysis.

Managing physical climate risks effectively is going to be an essential component of a successful energy transition. The good news is we know how to meet this challenge. Insurers have the modeling capabilities to map the evolving risks to specific assets over time and the risk expertise to identify the resilience interventions that will address those risks. Understanding risk is the first step to resilience – and insurability.

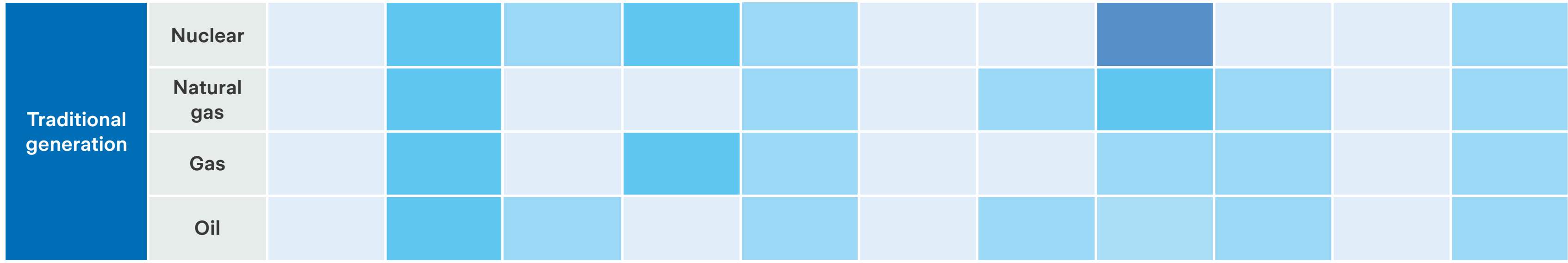
These insights are already being deployed in work with asset owners, but more needs to be done and quickly if we are to avoid unnecessary costs, weakened energy security and erosion of public trust in the transition to clean energy. At the moment these risks are under-assessed and under-addressed. The analysis in this report sets out to show how we can address that gap and work with energy companies and governments to secure a resilient and clean energy system for Europe's future.

Hazard impact assessment for renewable generation and storage assets across Europe



Renewable generation and storage are relatively more vulnerable to climate perils compared to traditional generation.

Each asset type faces a unique risk profile, as different climate hazards affect them in distinct ways.



Low ● ● ● ● Very high

Note: Exposure to loss was quantified using Total Insured Value (TIV) per MW, which represents asset replacement costs plus business interruption exposure, derived from proprietary insurance data where available or calculated using public asset values adjusted for hazard impact ratings where benchmark data was unavailable.

Source: Zurich Resilience Solutions; ZRS and Mandala Analysis.

Assessing the risks

To better understand the potential exposure to physical climate risks of Europe's future energy system, ZRS worked with economic modeling consultancy Mandala Partners to gather data on generation assets. We then used ZRS' geospatial climate modeling data and methodology to assess physical climate risks over time and to classify generation and storage assets by risk level.

Focusing on five large and geographically dispersed European markets – France, Germany, Italy, Spain and the UK – we used publicly available information to develop a dataset of over 25,000 existing and planned energy generation and storage assets. This captured details on location, status, capacity and technology. This dataset was then processed using ZRS' proprietary tool, which allowed the mapping of individual assets to ZRS data which models the evolution of 15 different climate hazards over short- and medium-term horizons (2030 and 2050) using IPCC aligned scenarios and drawing on unique insight into historic loss and damage.

For the purposes of this analysis, the IPCC scenario used was SSP2-4.5, which assumes a warming level of 2°C by 2041 – 2060 and aligns with the net-zero transition plans of most countries, as the outcome that a transition to clean energy in Europe is designed to achieve. Physical climate risk refers to the risk of physical damage or service disruption to a generation or storage facility from a climate peril (e.g., flood, drought), determined by the severity of the peril and the materiality (impact) on the technology.

Having mapped assets to ZRS modeling of future hazard evolution, risk engineering experts from ZRS' sustainable energy and climate team, assessed the potential severity of the risk posed by each climate hazard to different types of generation and storage assets. This expert assessment was combined with modeling outputs to create a hazard impact score, using a synthetic index showing the frequency and the severity of climate hazards and allowing classification of assets into five risk categories.

The impact of risk in categories 3 and above are significant and for the purposes of this analysis we have therefore defined those assets above category 3 as high risk and those falling into categories 4 and 5 as critical risk.

Risk categorisation[2]

Category 1	Assets in Category 1 face a ~ 20 percent chance of experiencing a climate event by 2030.
Category 2	Assets in Category 2 face a ~ 30 percent chance of experiencing a climate event by 2030.
Category 3	Assets in Category 3 face a ~ 40 percent chance of experiencing a climate event by 2030. Such events could cause a temporary outage lasting up to a week, a short-term (1 – 4 weeks) reduction in capacity of up to 25 percent, and damage up to 10 – 20 percent of the asset's value.
Category 4	Assets in Category 4 face a ~ 45 percent chance of experiencing a climate event by 2030. Such events could cause a temporary outage lasting 1 – 2 weeks, a medium-term (1–6 months) reduction in capacity of up to 25 percent, and damage up to 40 – 50 percent of the asset's value.
Category 5	Assets in Category 5 face a ~50 percent probability of experiencing a climate event by 2030. Such events could lead to outages lasting more than two weeks, long-term (6+ months) capacity reductions of up to 50 percent, and damage up to 60 – 70 percent of the asset's value.

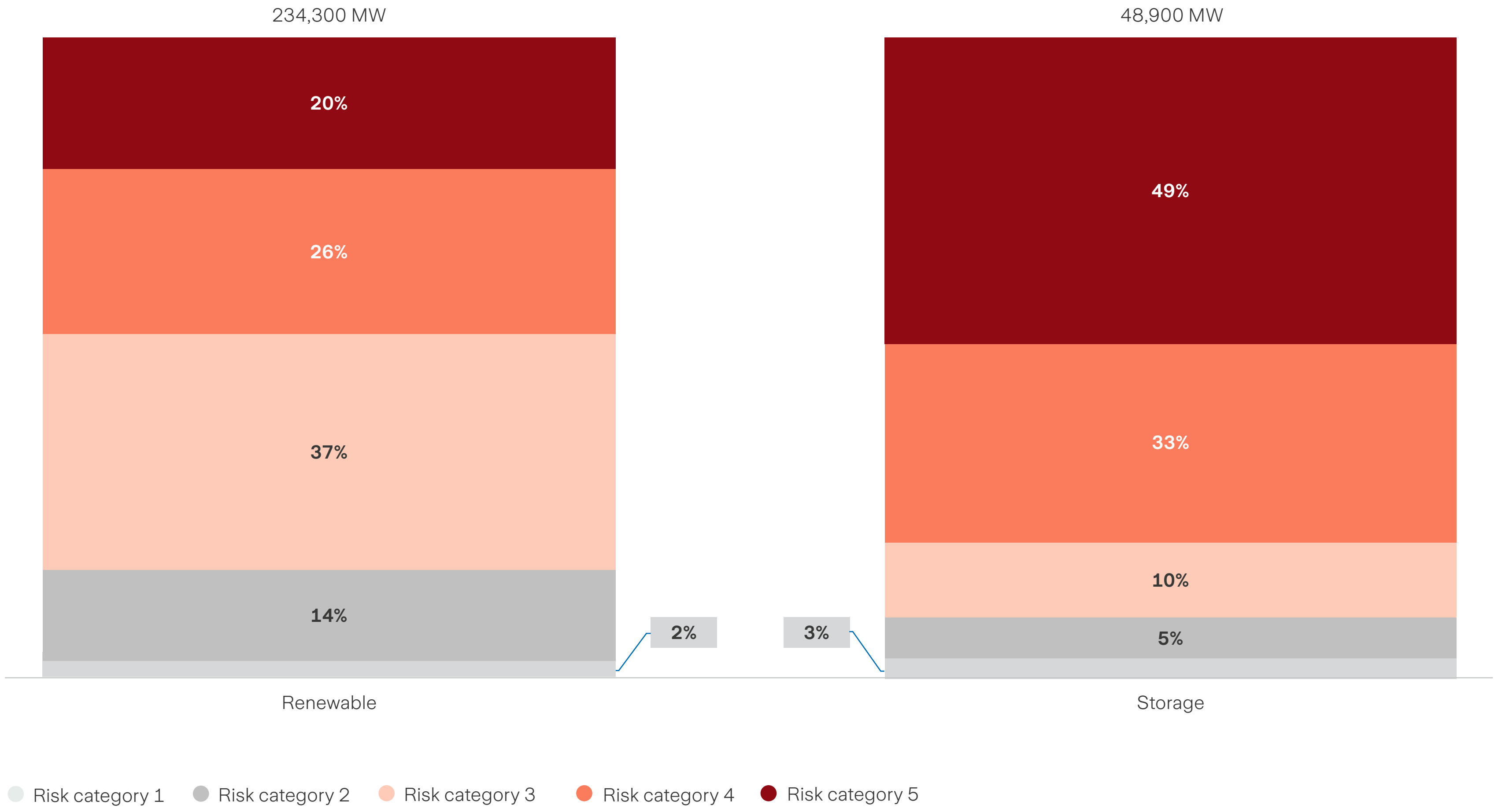
2. Risk categories 1-5 have climate event probability of ~ 70 percent, ~ 75 percent, ~ 85 percent, ~ 90 percent, and ~95 percent respectively between 2030 and 2050, see detailed methodology in the appendix.

Our analysis shows that while a proportion of all energy generation assets are vulnerable to climate risks – conventional fossil fuel, nuclear and renewable – the majority of renewable generation and storage assets are vulnerable to physical climate perils. In the next five years, the share of all energy generation facing heightened climate risks will increase.

Across the countries analysed 83 percent of operating renewable capacity falls into the high-risk category. Storage assets are even more vulnerable with 92 percent being high risk.

Of the existing renewable capacity, almost half (46 percent) are in the critical risk categories. Solar assets have the greatest vulnerability, comprising well over half (58 percent) of renewable capacity in critical risk. Onshore wind and hydropower both have material vulnerabilities with roughly a fifth of generating capacity (21 percent and 20 percent respectively, see next page) categorised as critical risk, with onshore wind accounting for half of all current generating assets across the countries assessed.

Energy generation and storage by risk level across Europe[3] under SSP2-4.5 (2°C warming scenario)
in percent, operating assets weighted by capacity



3. Countries include France, Germany, Italy, Spain and the UK.

Note: Includes near-term asset risk 5 years to 2030 only. Total capacity figures are rounded to the nearest 100 MW.
Refer to the next slide for a further breakdown of critical-risk capacity. Refer to each individual country report for more in-depth analysis.

Source: Global Energy Monitor data; Zurich Resilience Solutions; ZRS and Mandala Analysis.

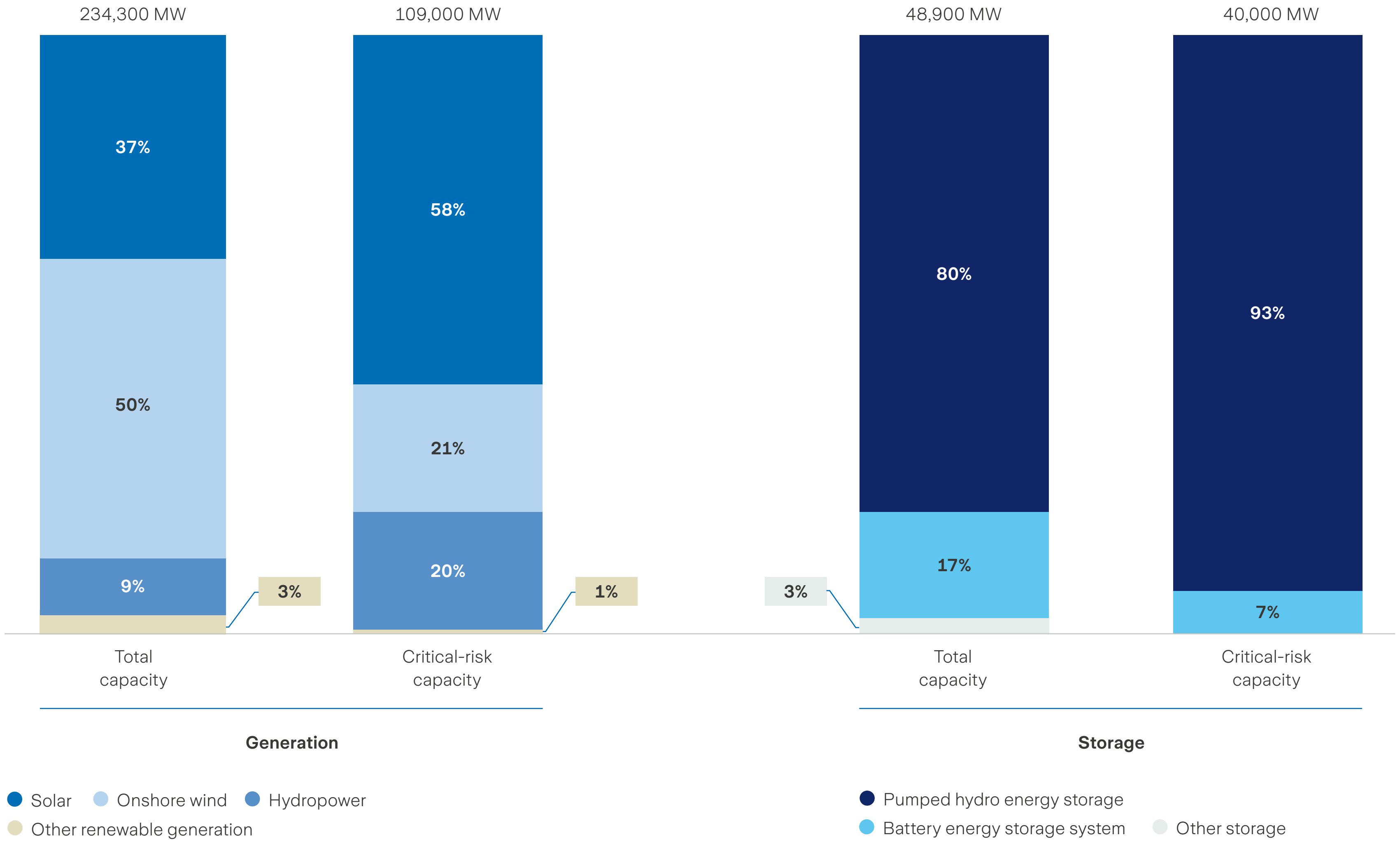
Extreme weather events pose significant risk to assets, threatening physical damage and dispatchability. A large proportion of renewable generation and energy storage assets across Europe are considered critical risk, with extreme weather events capable of causing mass destruction and disabling capacity across asset types.

Wind gusts, wildfires, hail and tornadoes pose the greatest threat to the key generation asset types of solar and onshore wind. Solar and onshore wind together make up nearly four-fifths of all critical-risk generation and these threats can cause very significant damage to installations.

Hydropower is critically exposed to polar opposite hazards, with flooding that can overwhelm reserves and damage infrastructure, while severe droughts can eliminate generation entirely.

Pumped hydro dominates energy storage at 80 percent of total capacity and faces the same vulnerabilities as conventional hydropower, with floods, droughts and cold waves. Battery storage systems, hailed as the future of energy storage, are vulnerable to heat waves and floods that can trigger cascading failures across storage facilities.

Breakdown of operating renewable generation and storage assets' exposure to climate perils across Europe under SSP2-4.5 (2˚C warming scenario) in 2030



Source: Global Energy Monitor data; European Energy Storage Inventory data; Zurich Resilience Solutions; ZRS and Mandala Analysis.

Given the dynamic rollout of renewable capacity and growing importance of renewable assets to overall energy generation by 2030, there is both a pressing need and clear opportunity to ensure renewable energy infrastructure is resilient.

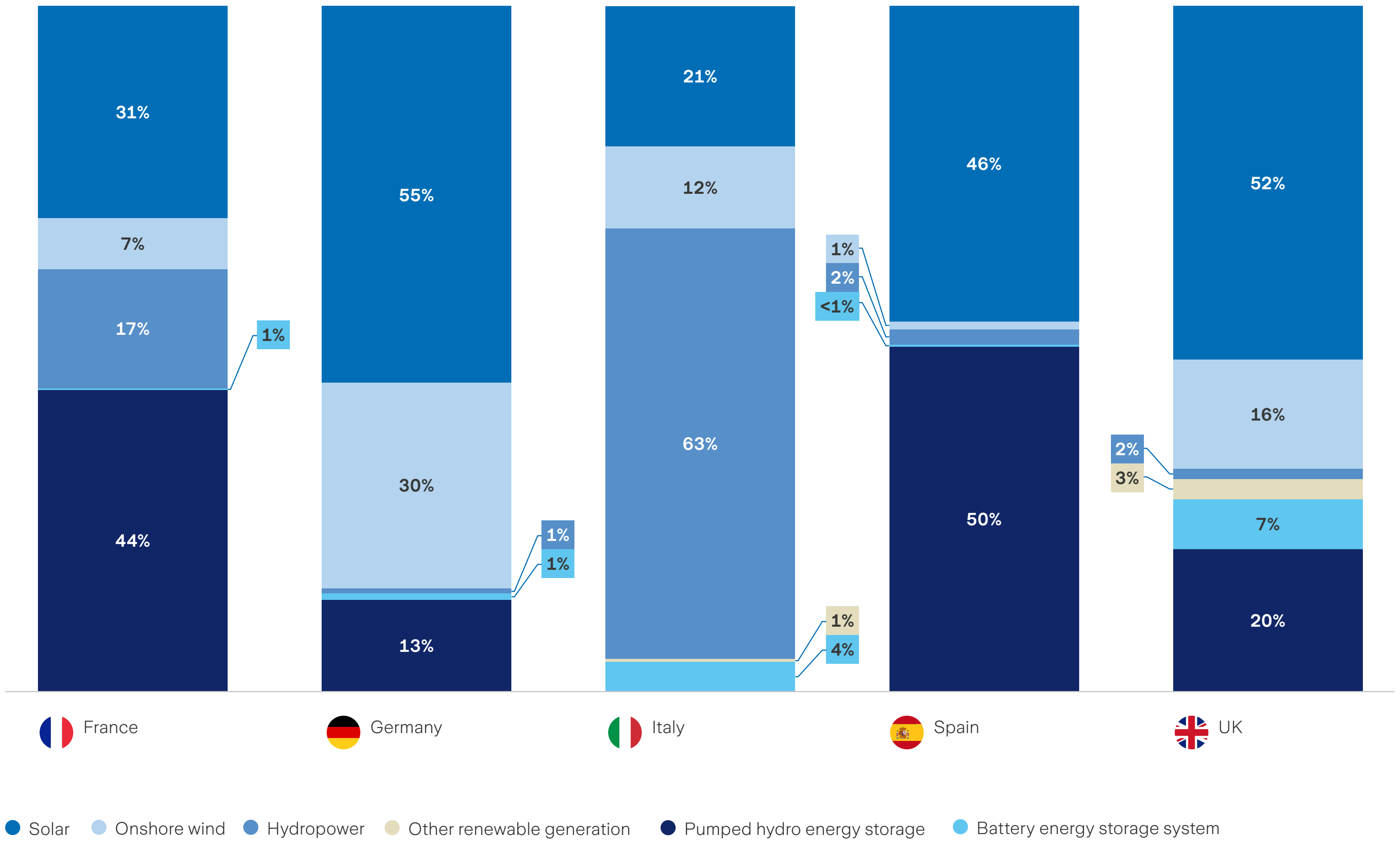
Looking at the distribution of risk across different asset types, solar energy generation is highly exposed to physical climate risks. In all countries except Italy, solar accounts for the largest share of critical-risk capacity, with hail and wind events like tornadoes and high-speed gusts driving risk.

Italy's energy generation climate risk is concentrated in its hydropower assets, representing almost two thirds (63 percent) of all generation and storage capacity falling into the highest two risk categories. Italy classifies pumped hydro as a generation asset rather than storage, which differs from other European countries. This means Italy's hydro risk appears in the generation category, while similar pumped hydro risks appear in the storage category for other countries. These hydro assets face significant exposure to frost, cold waves and droughts, which impact both equipment and generation efficiency.

With solar and onshore wind set to play a critical role in energy generation by 2030 for all of the countries assessed, while there may be different materiality to different hazards (e.g., wildfire in Spain versus wind in the UK), there should be scope for common approaches and shared practice when looking to mitigate the risk of damage to assets.

Critical-risk renewable generation and storage assets in 2030 under SSP2-4.5 (2°C warming scenario)

Proportion of renewable generation and storage assets in critical-risk categories (4 & 5), by asset type



Note: Other renewable generation includes bioenergy, energy from waste and geothermal.

Source: Global Energy Monitor data; Eugenerationropean Energy Storage Inventory data; Zurich Resilience Solutions; ZRS and Mandala Analysis.

Renewable generation and storage assets will face higher climate risks through to 2050 even under a 2°C warming scenario, increasing the benefits of action in the short term to accelerate investment in resilience.

Without action to enhance resilience, by 2050 solar generation will account for a very large share of renewable (and total) generation capacity at critical risk.

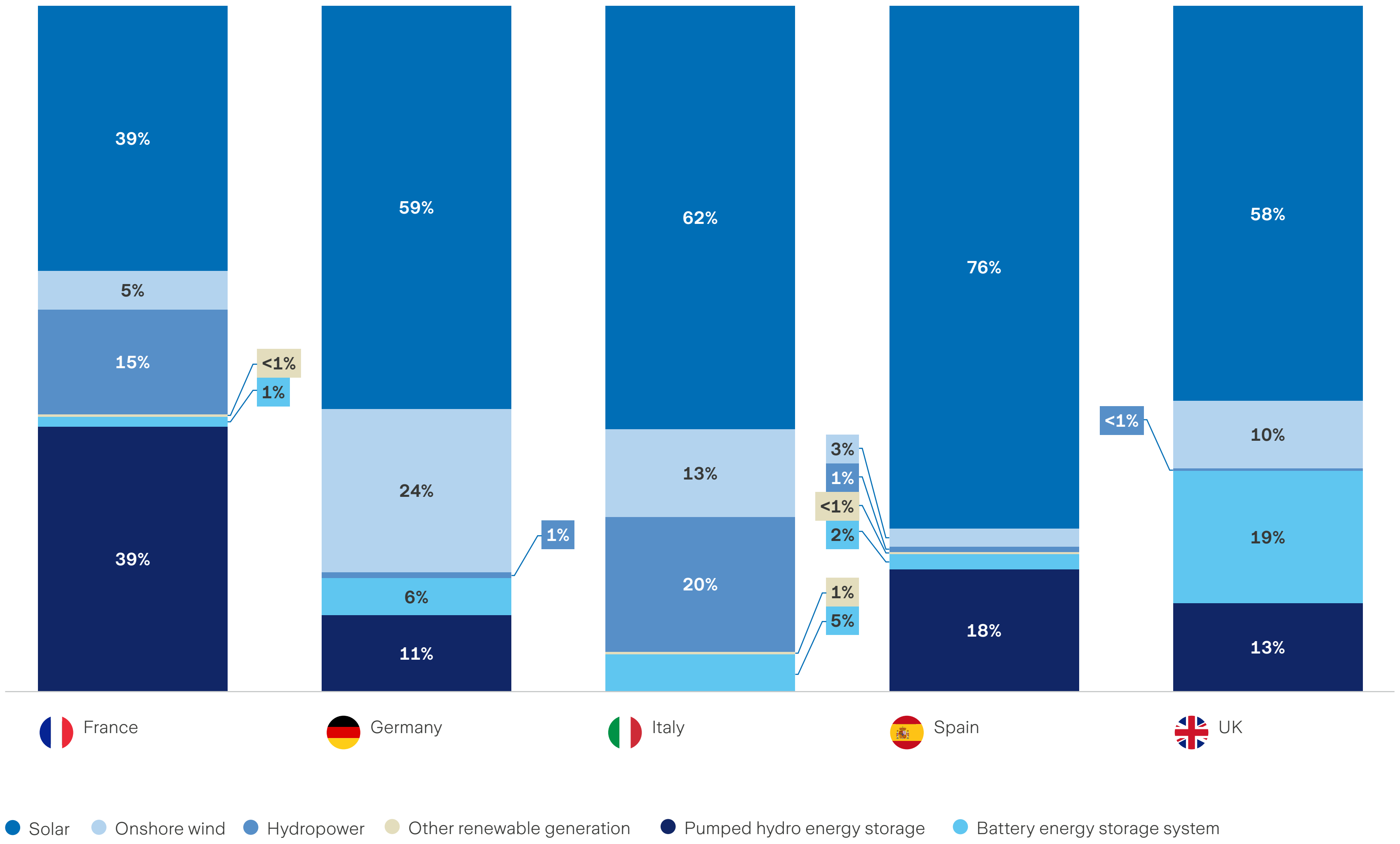
Total renewable generation and storage capacity at risk will increase substantially across European countries between 2030 and 2050, significantly worsening risk profiles of energy supply grids and transmission networks, due to a large pipeline of climate-vulnerable renewable projects. While existing assets show only marginal risk increases under the SSP2-4.5 scenario, the high climate vulnerability of planned energy projects will substantially alter Europe's risk landscape. Early action to address this risk is essential.

Italy faces a particularly significant increase in vulnerable capacity as solar becomes the dominant renewable technology. The country's critical-risk renewable generation and storage capacity is projected to more than double from 2030 to 2050.

Along with Italy, Germany and Spain face particularly large increases in solar capacity vulnerable to wind gusts, wildfires and hailstorms.

Storage capacity also faces heightened risks to 2050, with pumped hydro storage representing a significant share of critical-risk capacity across France, Germany, Spain and the UK. These facilities face geographic constraints that make it difficult to avoid their climate risk exposure.

Critical-risk renewable generation and storage assets in 2050 under SSP2-4.5 (2°C warming scenario)
Proportion of renewable generation and storage assets in critical-risk categories (4 & 5), by asset type

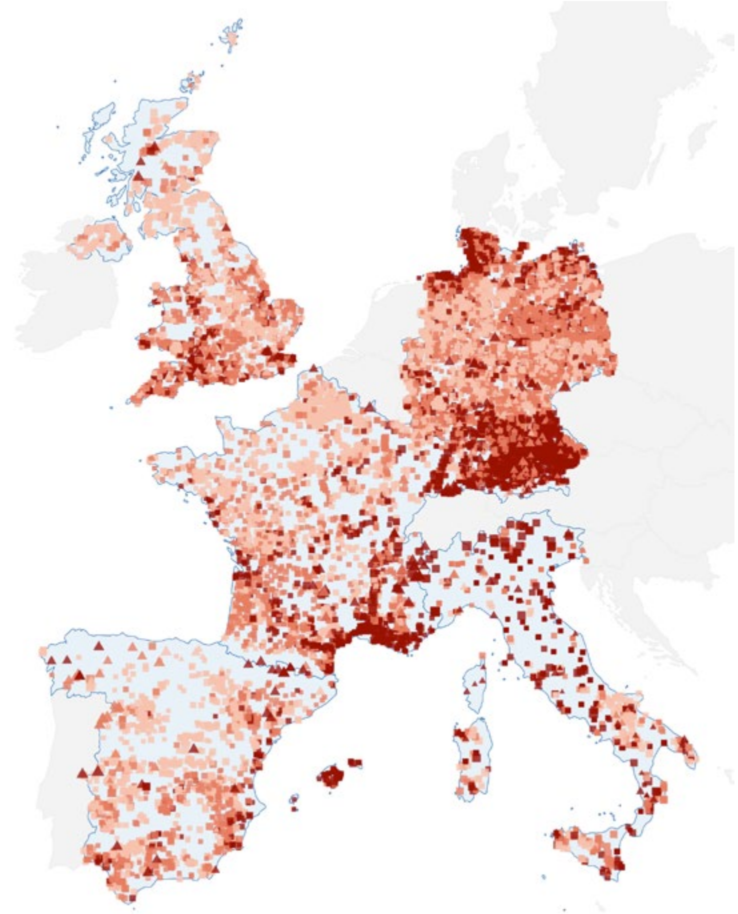


Note: Other renewable generation includes bioenergy, energy from waste and geothermal.
Source: Global Energy Monitor data; European Energy Storage Inventory data; Zurich Resilience Solutions; ZRS and Mandala Analysis.

Visualizing the risk exposure of both generation and storage assets across Europe shows the higher density of capacity at risk alongside a shift in mix of type of asset exposed

Renewable generation & storage assets in risk categories 3, 4 and 5, in 2030

Operating renewable generation and storage assets; color of asset denotes risk level; shape denotes asset type

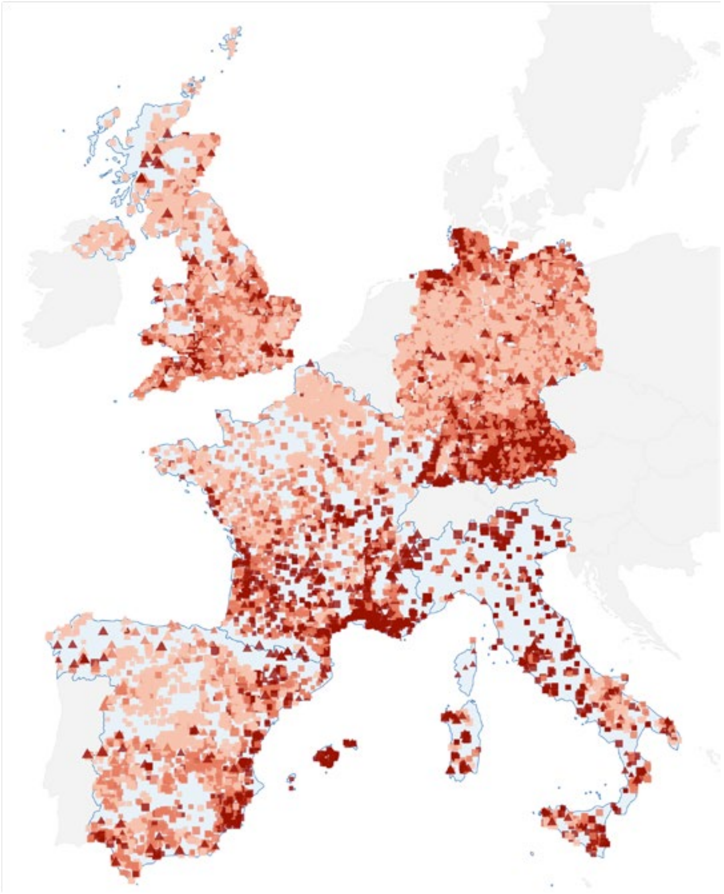


Share of assets in top three risk categories

Generation	Storage
92.7%	86.0%

Renewable generation & storage assets in risk categories 3, 4 and 5, in 2050

Operating and pipeline renewable generation and storage assets; color of asset denotes risk level; shape denotes asset type



Share of assets in top three risk categories

Generation	Storage
93.7%	90.7%

Risk category 1
Risk category 2
Risk category 3
Risk category 4
Risk category 5

Storage
Generation

Note: Size of the shape indicates relative size of capacity, with bigger shapes for larger assets.

Source: Global Energy Monitor data; European Energy Inventory Storage data; Zurich Resilience Solutions; ZRS and Mandala Analysis.

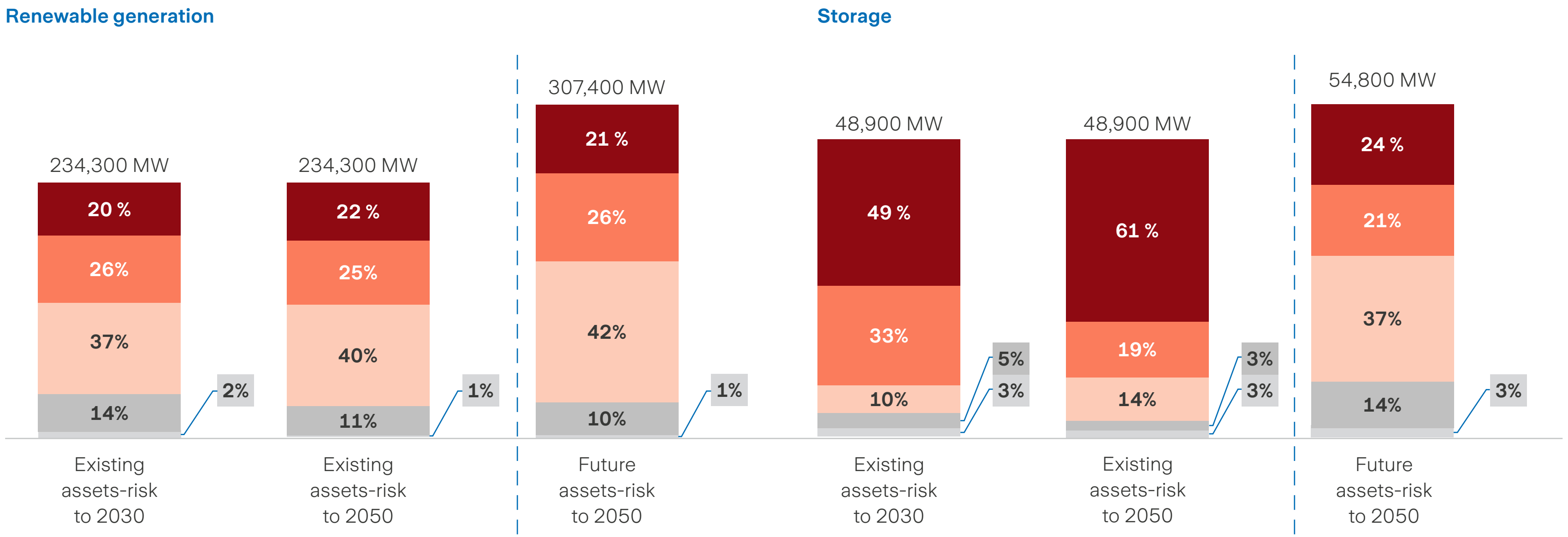
Action on resilience for energy infrastructure

Our analysis makes clear the need for action to protect energy generation and storage assets across the UK, Germany, Italy, France and Spain. Current risk exposures are uncomfortably high and are set to get worse.

A combination of intensifying climate impacts and increasing deployment of renewables in energy systems across Europe will see the number of generation and storage assets at high or critical risk increasing materially by 2050. The importance of those assets to the overall stability of future energy systems across the five large countries assessed, means that this will not only result in a significant increase in the value at risk, but that there will be a heightened risk of much broader economic disruption and business interruption resulting grid failures, such as that experienced in Spain (April 2025).

Renewable generation and storage by risk level over time under SSP2-4.5 (2°C warming scenario)

in percent, renewable generation and storage assets weighted by capacity



Key drivers of risk
Existing solar makes up the largest share of highest-risk (category 5) assets to 2030, followed by hydropower. By 2050, solar remains the dominant high-risk asset, with a slight increase in solar capacity classified as category 5.

Future assets have higher climate risk than existing assets in 2050. Solar and wind dominate the high-risk categories for future assets.

Key drivers of risk
Existing pumped hydro storage assets are the biggest component of storage assets. Pumped hydro storage also dominates the high-risk category assets. By 2050, more pumped hydro assets shift into the top risk category, driving the increase in proportion of capacity in risk category 5.

Of future storage capacity, 24 percent is in the highest category risk 5. Batteries comprise more than 60 percent of category 5 future assets, with the rest being pumped hydro storage assets.

Risk category 1 Risk category 2 Risk category 3 Risk category 4 Risk category 5

Note: Total capacity figures are rounded to the nearest 100 MW. Refer to each individual country's report for more in-depth analysis. Refer to the next slide for a cross-country asset level breakdown for asset risk to 2050.
Source: Global Energy Monitor data; Zurich Resilience Solutions; ZRS and Mandala Analysis.

Without action on resilience, our analysis projects over EUR 270 billion of losses related to energy generation and storage assets because of extreme weather events by 2050.

The chart illustrates the outsized positive impact of effective prioritization of investment inresilience measures. Through asset-specific insights into the mitigating effect of individual resilience measures for both operating assets and climate hazards, a limited spend can reduce expected losses by up to 50 percent (up to 20 times the original spend).

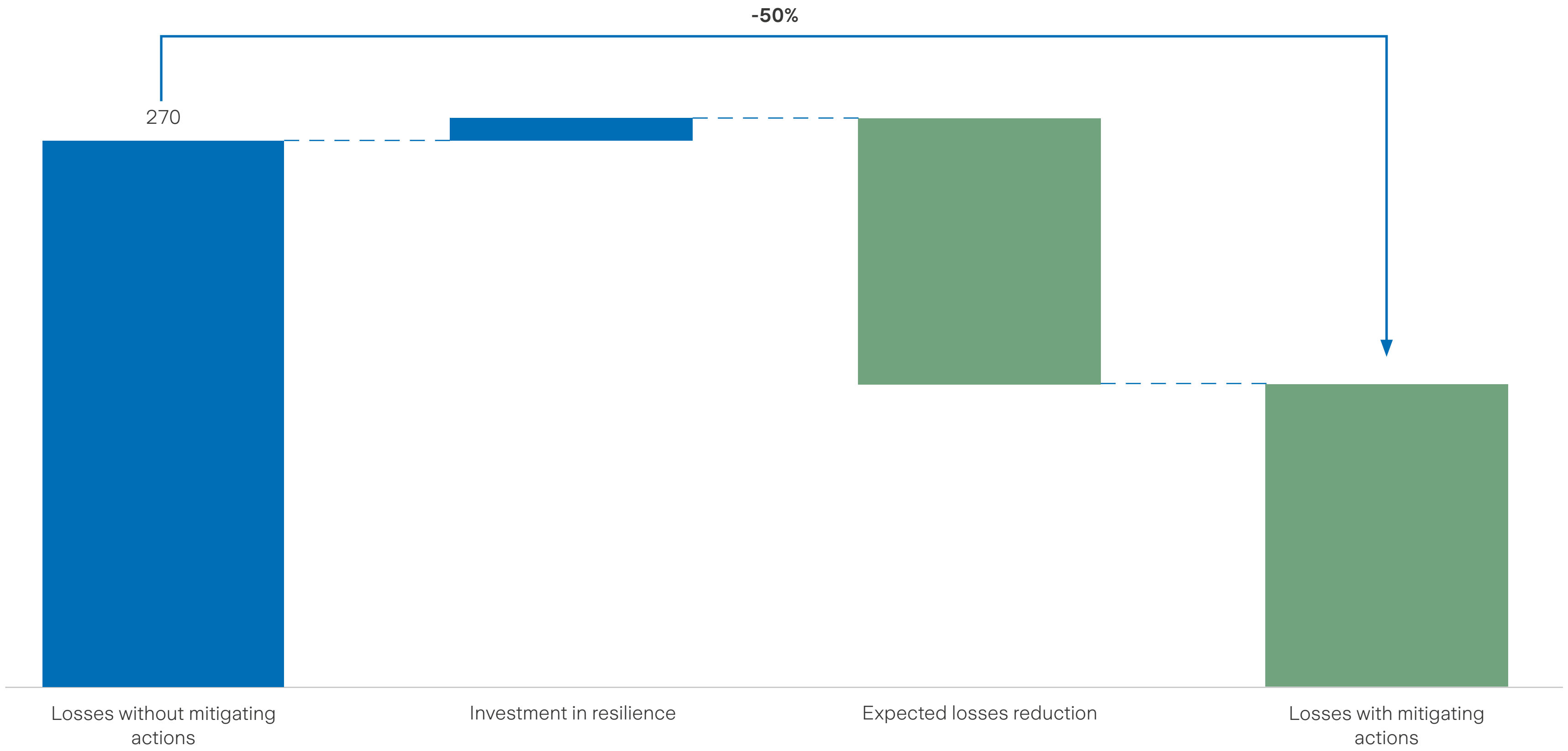
To achieve this will require a shift in the way in which we deploy risk insights to deliver resilience. We need to identify the key risks, and actions that will really matter in addressing them.

As the analysis in this report has shown, insurers have the modeling and risk engineering insights to provide a quantification of these risks at both the local and national level. We also have the capability to quantify the cost of actions to mitigate those risks.

The challenge we face is not what to do – interventions to reduce risk are understood – it is the prioritization and coordination of action to accelerate their delivery that we need to address.

We see the opportunity to help companies and municipalities assess their vulnerabilities across multiple climate hazards and advise on action. In addition, we can quantify the positive impact of individual resilience measures, inform investment decisions and unlock the investment needed to safeguard our energy future.

Potential losses due to climate perils by 2050
euro values are in present value terms (2025); in EUR billions



It includes:
- Costs from physical damages to assets
- Costs from business interruption

It does not include potential additional costs on the overall energy system driven by externalities (e.g., recent grid breakdown in Spain)

Source: Global Energy Monitor data; European Energy Storage Inventory data; Zurich Resilience Solutions; ZRS and Mandala Analysis.

Recommendations

The solutions are available but in order for them to be deployed consistently and efficiently there will need to be collaboration across public and private sectors and a coordinated push to improve awareness, align incentives for action and to unlock investment in resilience.

Action in the following five areas will create the policy context and market momentum to deliver the resilient energy infrastructure Europe needs:

1. Improve climate resilience of existing assets
Risk preparedness is the first line of defense, and lowering exposure and vulnerabilities to evolving physical climate risks will help companies that own energy generation assets avoid losses and improve insurability. There is a role for policymakers to look at opportunities to incentivize investment in resilience measures.

2. Adopt climate stress testing for new generation and storage assets
Understanding future risks and modeling the development of climate hazards should be a key part of any design decisions for new energy infrastructure. Companies across the whole value chain should adopt a resilience by design approach, whilst governments should shape a policy environment that encourages scaling of engineering innovations that enhance resilience.

3. Embed resilience in planning and design processes
A clear, stable and predictable policy environment which embeds resilience as a key principle in the roll out of new energy infrastructure will support investment and encourage innovation.

4. Improve data access and quality
Better access to public data will help refine risk modeling and enhance the development of open-source datasets on climate hazards. Public authorities must improve the availability and usability of resilience relevant data (e.g., location of planned assets; zoning decisions; climate peril exposures). There are countries in Europe that do this already and best practice should be shared.

5. Unlock investment in resilience measures
A greater focus on resilience should secure insurability and support investment. However in order to ensure the future security of energy systems in the face of increasing physical climate risks, policymakers should look at ways of leveraging blended finance mechanisms to crowd in investment and collaborate with industry and investors to ensure a pipeline of investible resilience assets.

Country Reports

Individual country level analysis, covering evolving risks and the opportunities to enhance the resilience of energy systems, can be downloaded using the links below.

Country Report France

Country Report Germany

Country Report Italy

Country Report Spain

Country Report UK

Methodology

Zurich Resilience Solutions' geospatial climate risk modeling was used to assess physical climate risks to generation and storage assets

Definition

Physical climate risk refers to the risk of physical damage or service disruption to a generation or storage facility from a climate peril (e.g., flood, drought), determined by the severity of the peril and the materiality (impact) on the technology. **This analysis includes only land-based assets, excluding offshore wind.**

Method

1 Asset data collection

- Mandala developed a dataset of more than 25,000 energy generation and storage assets through desktop research including sources such as the European Commission and Global Energy Monitor.
- This dataset consisted of the location of each asset, its operational status (e.g., announced, in construction, operating), capacity and the generation/storage technology (e.g., solar, nuclear, battery, flywheel).
- The analysis in this report is based on energy asset data available as of May 2025.

2 Mapping data to Zurich climate modeling

- ZRS's proprietary climate data was used to determine the climate risk faced by each asset, based on IPCC definitions of climate scenarios, scaled to the asset-level under a range of time horizons.
- ZRS' Climate Spotlight digital platform was used to analyze and visualize the combination of climate and asset datasets. The hazard ratings were expressed qualitatively from low to very high, for 15 hazards.
- The most likely climate scenario of SSP2-4.5 (2°C warming by 2050) with near-and-medium-time horizons was selected as it aligns with current emission trends and typical renewable asset lifespans.

3 Impact assessment

- In coordination with ZRS energy and climate specialists, an impact assessment was developed that determined the materiality of each climate hazard on technology types
- The potential impact of each hazard type was assigned a value of 'low' to 'very high', reflecting the impact a particular climate peril would have on an asset. This was to ensure that assessment of climate risk would reflect the probable likely impact on an asset.

4 Total hazard-impact score

- A total score was then developed for each asset site in the database. This calculation converted the ratings of hazard and impact, which were categorised as low to very high, to a 1 to 4 scale.
- The value of the hazard and impact for each asset was then multiplied.
- For example, if a solar farm has a 'very high' hazard level for hail (a value of 4) and a hail impact score of very high (a value of 4), the total hazard-impact score for that solar farm would be 16.

5 Risk Categorisation

- Assets are grouped into five categories (1 to 5) using z-scores, where 1 represents less risky assets and 5 represents highly risky assets. Z-scores measure how far each asset's hazard-impact value deviates from the mean.
- The impact of risk in categories 3 and above are significant and, for the purpose of this analysis, we have therefore defined those assets above category 3 as high risk and those falling into categories 4 and 5 as critical risk.
- The probability of experiencing a climate event is calculated using the return period for each asset and then averaged across all assets within each category.

Note: Shared Socioeconomic Pathways (SSPs) are climate change scenarios of projected socioeconomic global changes by the UN Intergovernmental Panel on Climate Change

Source Zurich Resilience Solutions; ZRS and Mandala Analysis.

Probability of climate peril occurrence at an asset location

First statistical step: Converting return periods to probability

Extract return period for each climate hazard from ZRS' data

→

Use the probability mass function for Poisson's distribution to calculate the probability of the peril not **taking place** in the next five years

Example: If the return period of occurrence for a wind gust peril is 100 years (μ = 0.01), then the probability of no occurrences in five years is:

$$P(r;t) = \frac{(\mu t)^r}{r!}e^{-\mu t} \longrightarrow P(r=0;t=5) = \frac{(5/100)^0}{0!}e^{-5/100} \approx 95.12\%$$

Intermediate step: Finding the cumulative probability of a climate event NOT taking place at an asset location in the next five years

When both the hazard level from ZRS' database and the risk impact score from the impact matrix exceed threshold 'L', the 5-year non-occurrence probability becomes one of the factors multiplied together in the cumulative probability calculation.
Note: This multiplication approach assumes all climate perils are statistically independent events, providing a simplified but practical basis to determine probability of climate events taking place

Probability any climate peril DOES NOT take place at that asset location in the next 5 years **=** Probability that **climate peril A** does not take place in the next 5 years **×** Probability that **climate peril B** does not take place in the next 5 years **×** Probability that **climate peril C** does not take place in the next 5 years **×** Probability that **climate peril...** does not take place in the next 5 years

Final probability: Finding the probability that a climate event DOES take place at an asset location in the next five years

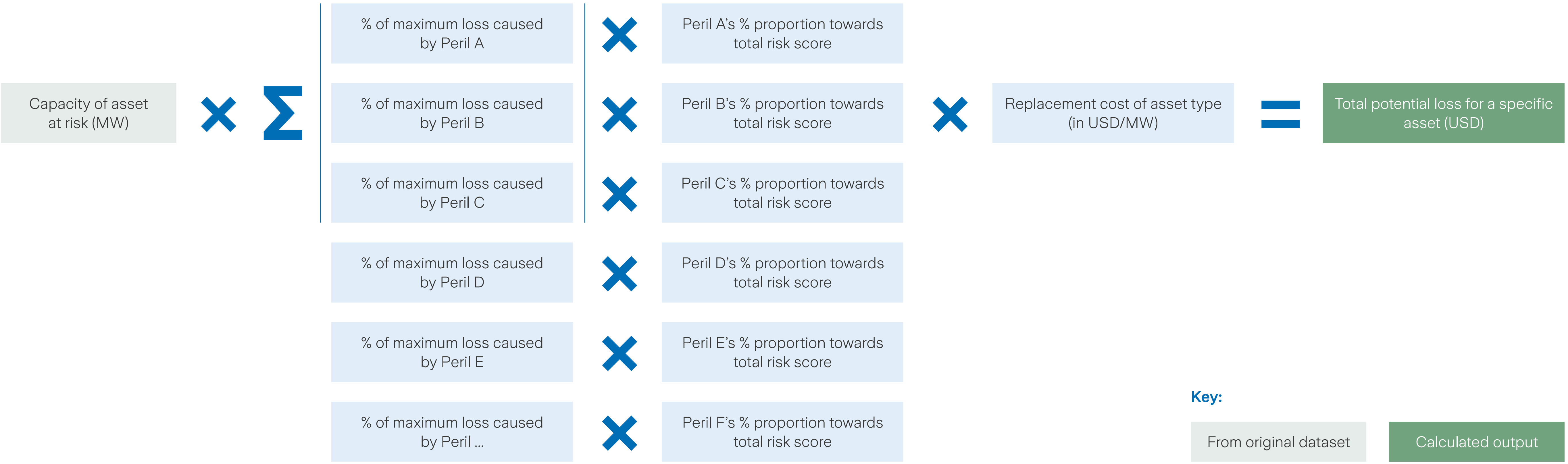
Probability a climate peril DOES take place at that asset location in the next 5 years **= 1 –** Probability that climate peril A does not take place in the next 5 years

Key:

Intermediate output

Calculated output

Potential losses methodology



Important note: Perils A, B, and C are not the same for every asset. Rather, they represent the top three perils that have the highest product of (% maximum loss × % proportion towards risk score) for each specific asset. This means:

- Different assets face different combinations of top perils
- The "Peril A" for one asset might be hail while for another it could be wind
- Assets are evaluated against their own unique risk profile
- The calculation prioritises the perils that pose the greatest financial risk to each specific asset

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Mandala Partners

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