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Rooftop solar: Emerging risk control needs for properties

Contents

Key takeaways

- Governments and authorities are keen to encourage the development of commercial and industrial (C&I) rooftop solar around the world. Demand for clean energy, fast-moving sustainability regulations and growing rooftop availability are driving solar adoption.

- The risks to rooftop solar photovoltaic (PV) systems are minimized if systems are properly designed, installed, tested and maintained. However, an increase in C&I installations brings a corresponding increase in value at risk. Not only are PV systems at risk, but rooftop fire could also cause property damage, damage to building contents and business interruption.

- Rooftop solar faces many perils. Fire is low in frequency but can be high in severity, particularly if it damages the roof and buildings below. Hail is higher in frequency in certain geographic areas and may be becoming more severe with climate change. Windstorms can cause damage, performance loss and water ingression; while earthquakes can cause both PV panel faults and structural roof damage.

- Specific mitigation measures can reduce extreme weather and fire risk to solar panels. Buildings can be designed and built for 'solar readiness' to reduce preventable incidents such as electric fires.

- The use of data and analytics can reduce potential risk. Risk indicators, including live data from sensors and weather stations, together with traditional indicators from project risk registers and manufacturers' operating manuals, will influence the resultant risk framework.

- Effective risk management needs the participation of qualified personnel, risk engineers, emergency response teams, researchers and regulators. Proper installation of good quality equipment will reduce loss events and limit damages. Involvement of risk engineers in the design phase of a solar installation can help in hazard identification at an early stage.

- The insurance sector can function as a risk reduction enabler by supporting standard setters; encouraging the development of holistic regulations across the lifetime of an installation; and ensuring insured parties adhere to these regulations. Applying their long experience in risk control and risk quantification, the insurance sector can support financial decision makers to create an evidence-based approach to better manage both established and emerging solar risks.

Energy transition: Role of rooftop solar PV in clean energy growth

The building sector is a large energy consumer, accounting for over 40% of total global CO_2 emissions[1] and 30–40% of final energy consumption.[2] Rooftop solar photovoltaic (PV) systems help enable structures to qualify as climate adapted buildings. PV systems have the added advantage of generating power that can be used on-site without long-distance transmission losses. Unleashing the potential of available roof space can be a cornerstone of energy transformation strategies. Unreliable electric supplies and stronger regulatory emissions reduction requirements are additional drivers for powering the installation of roof-mounted solar panels.

Figure 1
Factors characterizing rooftop PV growth

Evolving regulations

- Growing policy incentives
- Growing corporate interest
- Coupling with energy storage
- Poor installer certification

Growing value at risk

- Higher property and BI exposure
- Potential increase in system risk
- Gap in on-field durability standards
- Possible liability exposure

Need for increased resilience

- Prevent high severity fires
- Protect from extreme weather (hail, snow, wind storms)
- Prepare for impact of changing climate

Source: Swiss Re Institute

Fast moving regulations

The current rate of rooftop PV adoption is low. For example, just 0.93% of potential buildings in the US have solar installations.[3] Authorities are therefore keen to encourage growth. The EU revised its Energy Performance of Buildings Directive (EPBD) to require solar installations on all new public and commercial buildings by 2026; on non-residential buildings that are renovated by 2027; and on all existing public buildings by 2030.[4]

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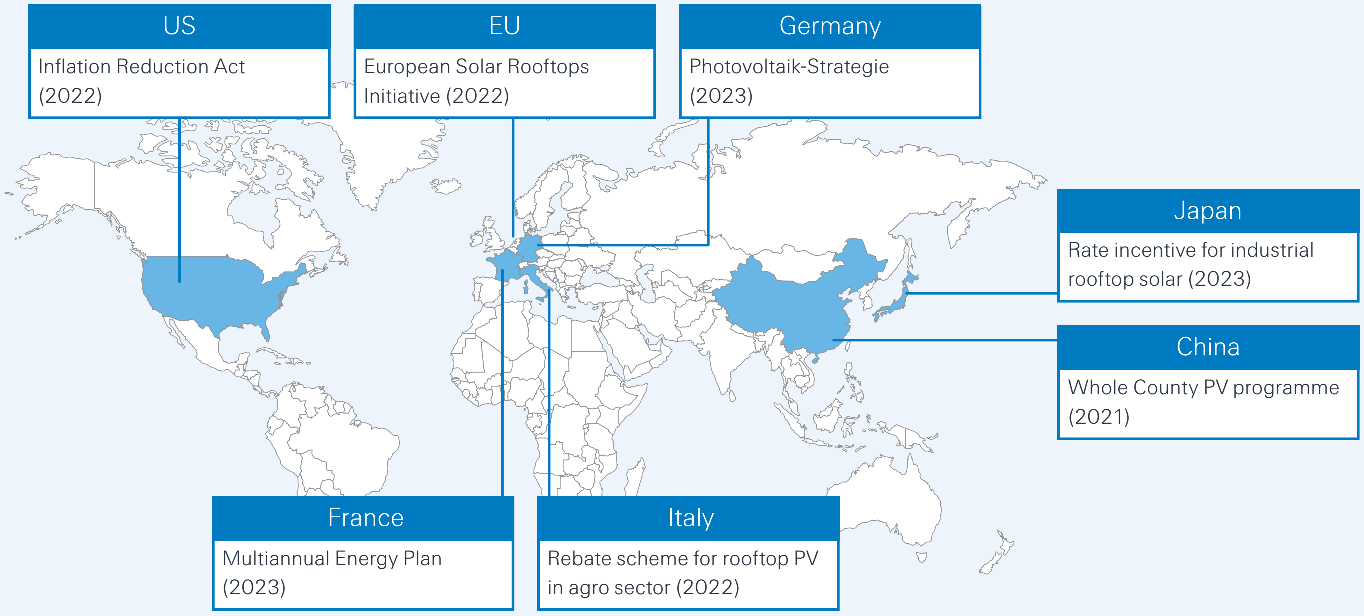
[1] *Building Materials and the Climate: Constructing a New Future*, United Nations Environment Programme, Yale Center for Ecosystems + Architecture, 2023.

[2] *World Energy Outlook*, International Energy Agency, October 2023.

[3] Lemay, A.C., et al, *Current status and future potential of rooftop solar adoption in the United States*, Energy Policy, 2023.

[4] *Statement: European Parliament agrees on the EU Solar Standard*, SolarPower Europe, March 2024.

Figure 2
Government initiatives on C&I rooftop solar

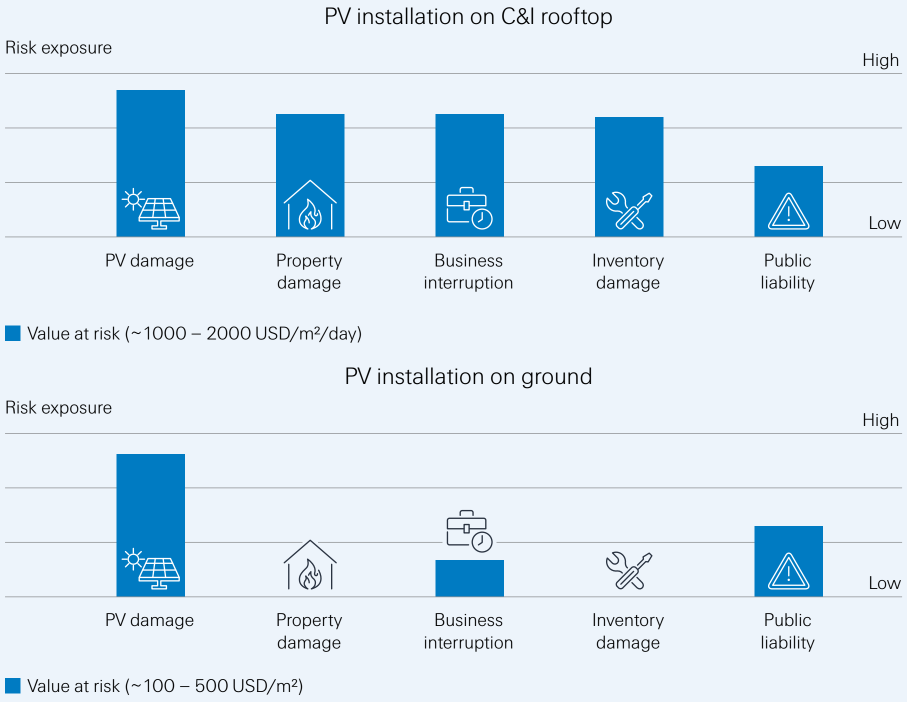


Source: Swiss Re Institute

Growing value at risk

Under normal operating conditions, rooftop PV systems do not pose health, safety or environmental risks, if properly designed, installed and maintained. Even so, the total value at risk associated with rooftop PV systems can be higher than for ground mounted systems (see Figure 3). This is because PV installations installed on commercial and industrial (C&I) buildings, including warehouses and production units, have additional property and inventory exposure, with damage potentially resulting in liability and business interruption (BI) losses.

Figure 3
Variations in value at risk for rooftop and on-ground installations



Source: Swiss Re Institute

Damages to panels and roofs can collapse into buildings and damage their contents, as well as trigger BI losses. For example, a recent solar panel fire at a Lidl distribution centre in Peterborough, UK, resulted in a three-day business closure.[5] Depending on the extent of property damage, BI losses could be prolonged. For instance, We the Curious museum in Bristol, UK, was shut for more than 20 months as building contents were damaged by the fire sprinklers following a rooftop solar panel fire incident.[6] The number of incidents involving PV systems has risen in recent years; and although still relatively infrequent, can be of high severity.

Table 1
Fire incidents involving solar panels

Year	Country	Installation type	Incident	Cause	Loss/BI
2024	USA	On-ground	Palm Bay Florida Power & Light Company (FPL) Solar Farm Fire (283 280 m^2)	Brush fire	Heat and fire damage to solar panels. No property damage reported.[7]
2023	Australia	On-ground	Beryl Solar Farm fire (110 MW)	Grassfire	Heat and fire damage to solar panels. No property damage reported. Resumed partial operations in one day.[8]
2023	Australia	On-ground	Grassfire – Cohuna Solar Farm, 820 000 m^2 site with 87 000 modules (27MW)	Grassfire	PV equipment damage disrupted power generation for one month before resuming operations at 75% capacity.[9]
2023	Italy	Rooftop PV	Fire at layer poultry farm with panel atop 1 500 m^2 roof area	Fire from PV system – probable cause	More than 20 000 birds killed.[10]
2023	Switzerland	Rooftop PV	Fire at industrial hall in Vétroz	Not known	Industrial building destroyed.[11]
2021	Netherlands	Rooftop PV	Solar-powered warehouse	Not known	Damaged building, solar panel shards spread up to several kms.[12]
2020–2021	USA	Rooftop PV	Amazon rooftop fires in six facilities	Multiple: mismatched connectors, improper installation, poor wire management, and water intrusion in the inverters	An average of USD 2.7m for each fire incident.[13]
2012–18	USA	Rooftop PV	Walmart rooftop fires (seven store rooftops between 2012 and 2018)	Improper installation – probable cause	8-day closure in the case of Beavercreek incident, damaged property, and inventory.[14]

Source: Swiss Re Institute

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[5] *Fire breaks out in solar panels on roof of £70m Lidl warehouse in Peterborough*, ITV News, 25 February 2024.
[6] *We The Curious in Bristol evacuated due to fire*, BBC News, 9 April 2022.
[7] *70-acre brush fire burns at FPL solar farm in Palm Bay, firefighters say*, clickorlando.com, 11 May 2024.
[8] *Fire at NSW solar farm*, pv magazine, 26 April 2023.
[9] *Cohuna solar plant resumes operations after Energy Safe shutdown*, pv magazine, 22 December 2023.
[10] *PV-equipped poultry farm destroyed by fire in Italy*, pv magazine, 9 August 2023.
[11] *Fire hits industrial building, PV system in Switzerland*, pv magazine, 17 July 2023.
[12] *Major fire at solar-powered warehouse in the Netherlands raises concerns among nearby residents*, pv magazine, 26 May 2021.
[13] *Fires on Amazon warehouse roofs seemingly caused by faulty PV installations*, Building Design + Construction, 14 September 2022.
[14] *Walmart sues Tesla over solar panel fires at 7 stores, including Beavercreek*, Dayton Daily News, 21 August 2019.

Need for resilience as upscaling impacts risk profile

The use of PV installations on buildings can pose specific challenges. Even though the effect of the PV module as a fuel load is limited, a combination of factors, such as PV infrastructure (cables, connectors, mounting system, combiner boxes, inverters) could act as a catalyst or facilitator for fire, especially electric fires.[15] Smoke from the fire can enter the building through ventilation systems harming people. Further, as solar panels become coupled with battery energy storage systems, both maintenance and emergency response teams require added training.

Table 2
Loss drivers and factors driving its severity[16]

Factors affecting loss severity	Subcategories	Hail	Fire	Wind	Snow load	Earthquake	Water ingress
Roof combustibility	Roof membrane type	□	■	□	□	□	□
Roof design	Wind/snow/ potential load, fire load*, roof structure, drainage	▨	▨	■	▨	□	■
Choice of location	Extreme weather exposure, fire brigade proximity	■	▨	■	■	■	■
Building type	Occupancy, sprinklers, height, cladding, structural integrity	□	■	■	□	■	□
PV system properties	Module hail/wind/fire rating, quality of frame, materials, components	■	■	■	■	□	□
Installation/ panel geometry	Gap height, panel inclination, access pathways, BESS, mounting#	■	■	■	▨	□	■
Maintenance/ service	Regular monitoring	■	■	■	■	□	■

■ High impact ▨ Medium impact □ Low impact

*Presence of electric components, inverters, Heating, ventilation and air conditioning (HVAC), isolators; # Ballasted, penetrative/non-penetrative
Source: Swiss Re Institute based on literature survey

Low frequency but high severity fires could drive property damage and BI losses

Rooftop combustibility and design are pivotal in determining 'solar readiness' of buildings. An appropriately designed, non-combustible surface substantially improves the chances of containing the fire on the roof, preventing its spread into the building. The building location could also play an important role in fire control as proximity to fire brigades could improve chances of immediate fire suppression before it spreads into the building and triggers BI. However, irrespective of where the source of ignition is located, a fire on a combustible rooftop fitted with panels could mean a greater risk of roof collapse and faster spread of fires over and into the building. Emergency response teams may refuse to climb combustible roofs to fight fires at close quarters.[17] Instead, firefighters may be forced to fight fires from a distance using ladders, which could reduce the ability to direct accurate water jets and cause increased water damage.

Wind speed and direction could also influence fire dynamics at the time of ignition, though its effect is negligible in spreading the fire under the panels. Once fire is established, the rate of flame spread under the panels is more influenced by the panel

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[15] Kristensen J.S., et al, *Experimental Study of the Fire Dynamics in a Semi-enclosure Formed by Photovoltaic (PV) Installations on Flat Roof Constructions*, Fire Technology, 2022.

[16] Qualitative analysis

[17] M.R. Ramali, M.R., et al, *A review on safety practices for firefighters during photovoltaic (PV) fire*, Fire Technology, 2022.

properties than the direction of the wind.[18] The structural integrity of the roof matters nevertheless, as its capacity to handle the wind, fire or water load determines the extent of loss to the rest of the building. The inclination of the rooftop is also important in ensuring proper water drainage. Studies indicate that roof inclination could influence initial flame spread, though it has minimal effect post ignition.

Table 3
PV module fire resistance class rating (IEC 61730-2)[19]

Module rating	Class A	Class B	Class C
Burner rating (kW)	378	378	325
Flame exposure period (mins)	10	10	4
Flame spread should not exceed (m)	**1.82**	**2.4**	**3.9**

Source: International Electrotechnical Commission (IEC)[20]

The effectiveness of fire suppression also largely depends on the quantity and quality of the roof PV system. Class A and B panels (see Table 3) are recommended for Highly Protected Risk (HPR) facilities. Proper installation, in this context, would mean setting up panel arrays with proper access and ventilation pathways based on the roof size and adequate setback from ridges for easy access. As the demand for battery energy storage systems (BESS) grows, PV systems should have rapid shutdown mechanisms, and a readily accessible, disconnected means to isolate the PV systems from all other wiring including BESS.

Changing fire dynamics when introducing PV modules

Installing a new PV system on the roof can affect the fire resistance and alter the fire dynamics of the building. The geometry of the solar panel, including its inclination and gap height may impact fire spread rate, heat feedback, smoke and heat accumulation, irrespective of the fire resistance capacity of the roof and modules.[21] A roof with adequate mitigation layers could prevent fire from spreading when panels are absent. However, fire spread studies indicate that these same roofs burn readily when PV modules are present (see Figure 4). This is because inclined panels can promote faster spread of fire under the panels. In the case of critical gap height,[22] changes by even a couple of centimeters could result in significant changes in the acceleration of fire spread.

[18] Kristensen J.S., et al, *Experimental Study of the Fire Dynamics in a Semi-enclosure Formed by Photovoltaic (PV) Installations on Flat Roof Constructions*, Fire Technology, 2022.

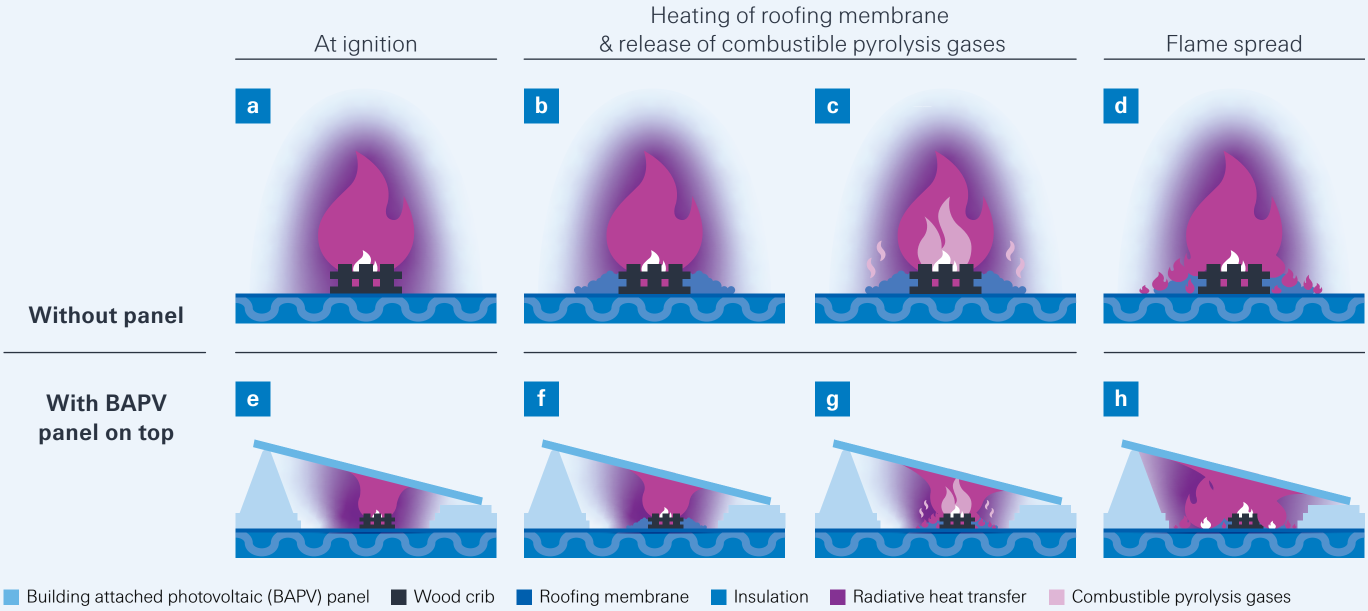
[19] IEC 61730 is an international standard defined by the International Electrotechnical Commission that specifies the fundamental construction requirements for photovoltaic (PV) modules to provide safe electrical and mechanical operation in including testing requirements.

[20] *How Are PV Modules Tested for Fire Resistance?*, RenewSys, 2023.

[21] Kristensen, J.S., *Fire risk associated with photovoltaic installations on flat roof constructions – Experimental analysis of fire spread in semi-enclosures*, University of Edinburgh, 2022.

[22] Gap height can be defined as the vertical distance between the roof and the lowest edge of the PV module. A critical gap height can be broadly defined as the minimum gap height not causing self-sustained 'flame spread' within the semi-enclosure. The flame spread rate (FSR) could remain constant or accelerate if the gap height is below or above the critical gap height determined for the setup.

Figure 4
Ignition process of roof construction



*Note: Figures (a), (b), (c) and (d) illustrate the sketched ignition process of roof construction without a BAPV module. a) Radiative heat transfer from ignited wood crib, b) Heating of nearby roofing membrane, c) Release of combustible pyrolysis gases, d) Ignition of pyrolysis gases, additional radiative heat transfer, but no self-sustained flame spread. Figures (e), (f), (g) and (h) illustrate the sketched ignition process of roof construction with a BAPV module. e) Radiative heat transfer from deflected flame, f) Heating of nearby roofing membrane, g) Release of combustible pyrolysis gases and initial ignition, h) High heat release rate due to higher concentration of pyrolysis gases, heating of nearby materials and self-sustained flame spread
Source: Steemann Kristensen, Jens. (2022)[15]

Yet, existing roof testing standards do not consider the inclination of the panels hosted on the roof, ie, whether horizontal, inclined or vertical panels. Likewise, while fire resistant PV modules may withstand fires, they cannot prevent smoke and heat accumulation. Moreover, the critical gap height and inclination requirements are not yet standardized as these could vary with each system setup. Therefore, testing of systems 'as built' is recommended with a view to how PV panels on rooftops could change fire dynamics.

On the prevention side

Strategies to minimize losses from PV fires should address causes of ignition, such as product and component failures. Proper installation, monitoring and maintenance of components are important aspects of minimizing ignition frequency. The Clean Energy Associates (CEA), based on its recent survey of 600 sites, indicated that 97% of installations had safety concerns.[24] Common safety issues included damaged modules and related equipment, hotspots and improper assembly, all of which could cause fires.

Replacing electric equipment in a timely manner is a significant factor in avoiding electric fires. PV modules, with an average lifespan of 25–30 years, often outlive electric equipment. The Building Research Establishment (BRE) National Solar Centre estimates that direct current (DC) isolators caused 26–28% of fire incidents in 2018.[25] Degraded or poorly installed connectors, cables, invertors and combiner boxes are also catalysts of fires. Panels also require maintenance to manage hotspots caused by microcracks and organic matter. Further, proper design, installation, maintenance and monitoring requires skilled personnel with specific training in handling equipment.

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[23] Kristensen, J.S., *Fire risk associated with photovoltaic installations on flat roof constructions – Experimental analysis of fire spread in semi-enclosures*, University of Edinburgh, 2022.
[24] *PV Rooftop Safety: Top 10 Safety Concerns*, Clean Energy Associates, 2023.
[25] *Fire and Solar PV Systems – Investigations and Evidence*, Building Research Establishment National Solar Centre, 2018.

Increasing sensitivity to hailstorms fueled by recurring and larger hailstones

Hail is a low-frequency, geographically confined but high severity peril. In recent years, hail has accounted for less than 2% of solar project insurance claims volume — but over 50% of total solar losses.[26] Setting up rooftop solar PV in hail exposed regions is increasingly challenging. Furthermore, hail losses are growing around the world. In 2023, severe convective storm insured losses were around USD 64 billion, a new high. Most of the losses (85%) last year originated in the US, but losses are currently growing fastest in Europe, where they have exceeded USD 5 billion in each of the last three years, with hail as the main driver.[27] Italian hailstones broke the European size record twice in July 2023, with a diameter of 16 cm, then with a diameter of 19 cm. [28] In the US, 6 962 hail events were reported in 2023 compared to 4 436 in 2022.[29] The year 2023 was the third largest hail season recorded in Europe in terms of hail size and number of hail days. However, year-to-year fluctuations are significant, and improvements in hail observational systems and more efficient collection of hail reports may contribute to increases.

Different views on growing losses

Growing losses and increased exposure are perceived differently by primary insurers and reinsurers. Primary insurers typically absorb the smaller, higher frequency losses. These may still accumulate to a significant loss burden, especially as retentions have increased in recent years. Hence, primary insurers are more sensitive to changes in exposure. For reinsurers, larger losses are primarily driven by socioeconomic factors such as economic growth, urbanization and inflation. Regardless, understanding the hazard, ie, the alteration in the frequency and severity or the spatial extent of hail events, is crucial for both industries to accurately model hailstorms.

Hailstorms and severe convective storms

Hailstorms are associated with convective systems. Storm updrafts and downdrafts initially carry small water droplets to higher altitudes above freezing level, forming small ice crystals. These ice crystals grow larger as they accumulate additional water and other ice crystals through turbulent wind movements, often resulting in an onion-like structure in the cross-section. Hailstorms frequently occur alongside tornadic and straight-line winds, lightning and extreme precipitation. In insurance terminology, hailstorms compounded with other hazards fall under the umbrella term of severe convective storms (SCS).

Trends and challenges

While climate change has contributed to the increased frequency and intensity of many weather-related perils, its impact on SCS is harder to ascertain. This is primarily due to the lack of comprehensive observational data on hail events, particularly regarding hail size and spatial occurrence. Hail events are often localized and short-lived, making them challenging to capture. Additionally, historical time series of hail events are limited, and hail frequencies vary significantly from year to year. Furthermore, observations are subject to two types of biases: (i) an artificial increase in observed events over time due to improved observation systems, particularly radars; and (ii) event distribution is influenced by population density, as hail events are more likely to be observed in populated areas. For instance, Figure 5 depicts hail reports and size in Europe 2023; and Figure 6 shows hail trends over the last 20-years. However, there is a potential observational bias due to lack of reliable historical data that makes modelling and forecasting hail challenging.

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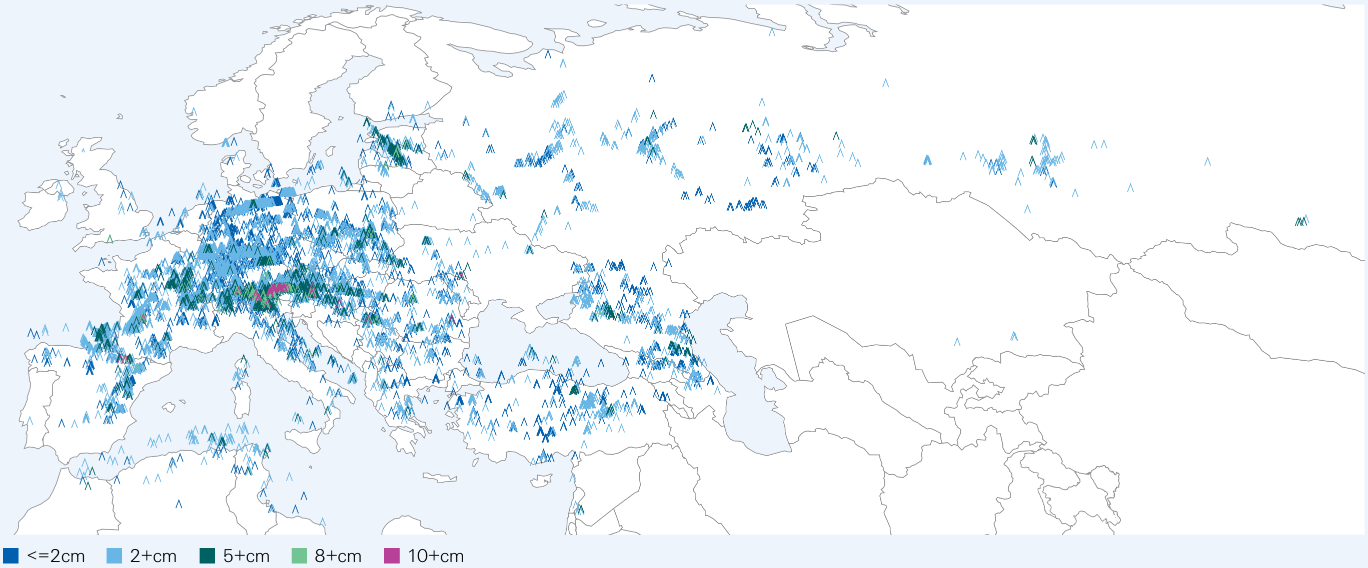
[26] *Hail risk mitigation strategies for solar assets and investment portfolios*, VDE, 2024.

[27] *sigma 1/2024: Natural catastrophes in 2023: gearing up for today's and tomorrow's weather risks*, Swiss Re Institute, 2024.

[28] Pucik,T., *Hailstorms of 2023*, European Severe Storms Laboratory, 2024.

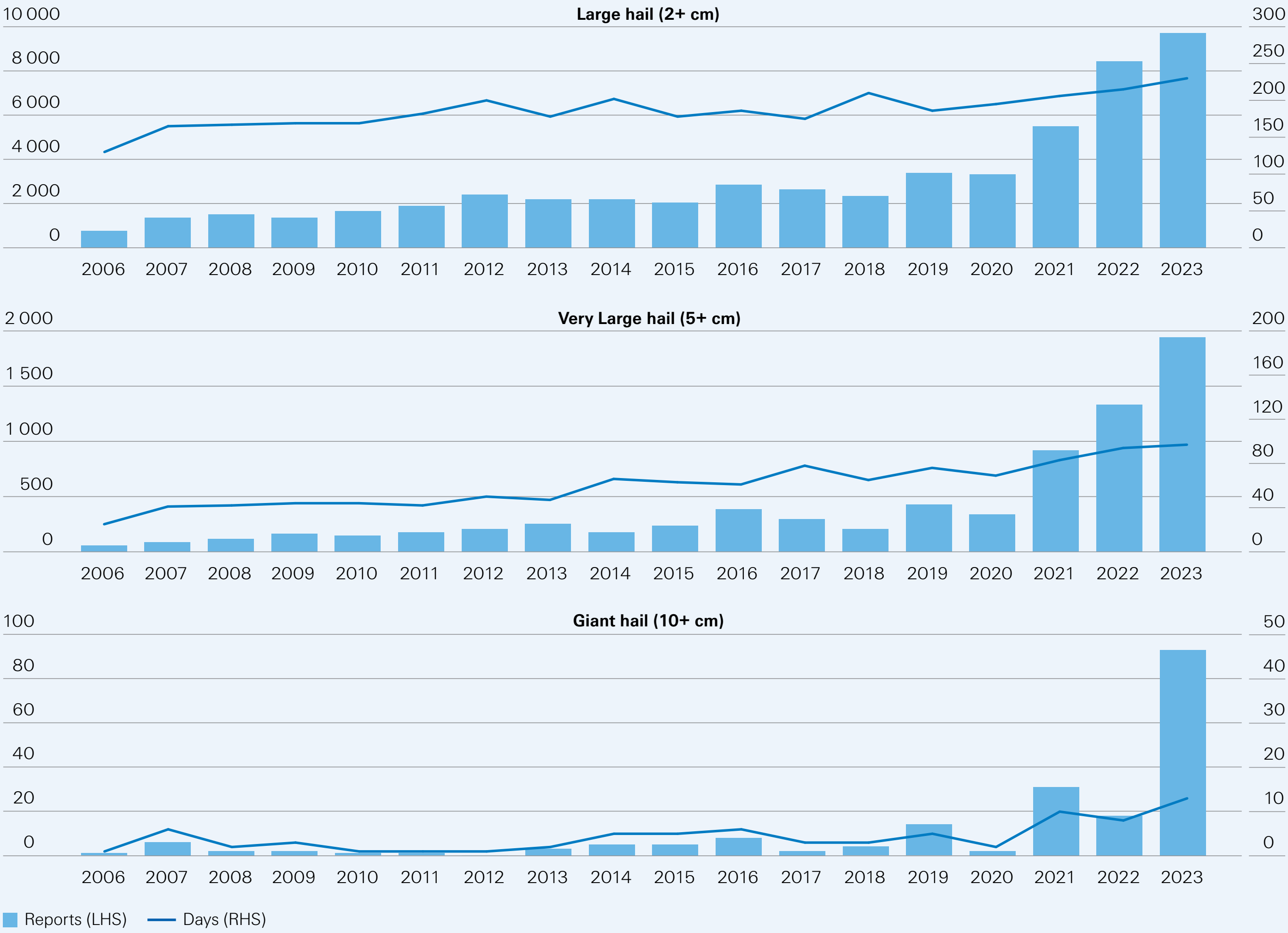
[29] *Facts + Statistics: Hail*, Insurance Information Institute, 2023.

Figure 5
Number of hail reports including their size in Europe in 2023



Source: European Severe Storms Laboratory, Swiss Re Institute[22]

Figure 6
Time series of hail reports and days (2006–2023) in Europe



Source: European Severe Storms Laboratory, Swiss Re Institute[23]

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[30] Pucik, T., *Hailstorms of 2023*, European Severe Storms Laboratory, 2024.
[31] Accessed from *European Severe Weather Database*, 2024.

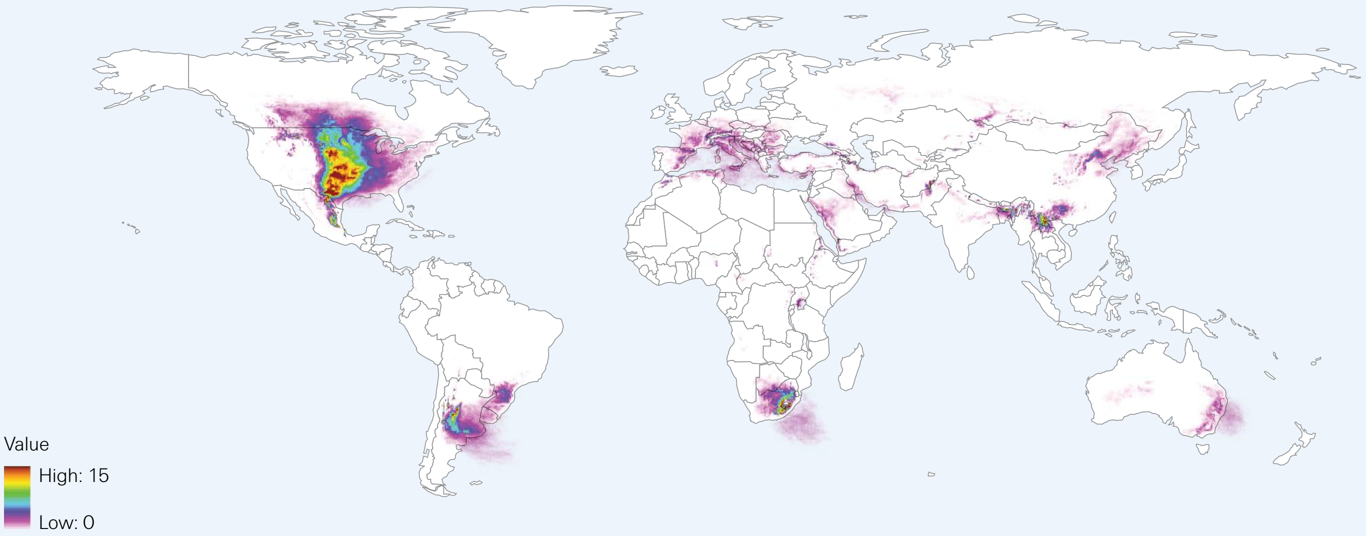
Research collaboration on hail modeling to overcome data limitations

To address the limitations in observational data, environmental proxies can be utilized. These proxies use indirect indicators and methods to infer hail activity and characteristics, helping to fill gaps in observational data, improving the accuracy of hail risk assessments and enhancing risk modelling. Commonly used predictors include atmospheric instability, freezing level height and wind shear. These proxies are used to develop algorithms that estimate the probability of hail occurrence, both spatially and temporally. However, these approaches are not a silver bullet, as an environment with a high hail probability does not always result in hail. Nonetheless, synthetic data can provide valuable insights, especially understanding the spatial extent of hailstorms.

To further advance research, Swiss Re Institute initiated a project with ETH Zurich and the NSF National Center for Atmospheric Research (NCAR) to create a global hail probability dataset based on observations and environmental predictors. The project innovates and adds value by offering (i) over 60 years (1959–2022) of global daily hail probabilities; (ii) globally and regionally (US, Europe and Australia) trained hail models; (iii) machine learning-trained hail models that assess 11 different environmental predictors based on hail observations from the US, Europe and Australia; and (iv) complementary data to other datasets and observations. The modeled global hail probabilities between 1959–2022 are presented in Figure 7.

Figure 7

Average modeled number of hail events per year per grid cell (hailstones >2.5 cm) where the probability of hail is ≥ 50%) for the period 1959–2022



Source: ETH Zurich, NSF National Center for Atmospheric Research (NCAR) in Blanc et al. 2024 (under review)

Future climate change

Current understanding is that more moisture and warmth at a low-level atmosphere will reduce air stability and increase the likelihood of thunderstorm formation. In combination with a rising melt height,[32] this may decrease the frequency of small hail events, while making severe hail events more likely, though regional variability could be high.[33] Changes in the seasonality of hailstorm activity could also be expected.[34] However, the impact of climate change on the frequency and severity of hail and SCS is not yet fully understood and remains an area of intense research. Consequently, trend analysis in observational data and climate change projections contain large uncertainties.

[32] As the atmosphere warms, the 0°C isothermal is higher. This means that falling hail stones start to melt "earlier". Smaller hailstones are more likely to melt before reaching the ground, hence decreasing the frequency of small hail events.

[33] Raupauch, T. H. et. al., *The effects of climate change on hailstorms*, Nature Reviews Earth & Environment, vol. 2, 2021.

[34] Pucik,T., *Hailstorms of 2023*, European Severe Storms Laboratory, 23 January 2024.

Hailstorm impacts on solar PV

Potential for microcracks: Hail stones can range from 0.5 cm to 15 cm in diameter (see Figure 6) or even higher in some exceptional cases. Research suggests that hail stones as small as 3 cm in diameter can damage panels by creating undetectable micro cracks deep inside the panel.[35] These micro fractures in the silicon wafer could result in gradual degradation in the panel's performance as the micro fractures propagate over time. Left unchecked, microcracks can lead to the development of hotspots which can further aggravate cell damage and may lead to short circuits and eventually even fires. For instance, when the cracks prevent more than 8% of the cell from functioning, it may lead to a hotspot.[36,37]

Tests may fall short in real world conditions: Existing industry standards for hail resistance might not be adequate to ensure long term performance under extreme weather conditions. The National Renewable Energy Laboratory (NREL) studied real world performance of modules certified by the International Electrotechnical Commission (IEC) 61215, which tests for resistance to impact by 2.5 cm diameter hail. The NREL studies found that in natural settings, modules had higher performance loss rates when exposed to similar hail sizes as in test settings.[38] Moreover, the trend towards larger modules and thinner front glass make panels more susceptible to damage (see Figure 8 and Figure 9).

Figure 8
Projected market share of (2024–2034) ground-mounted module size (sq.m)

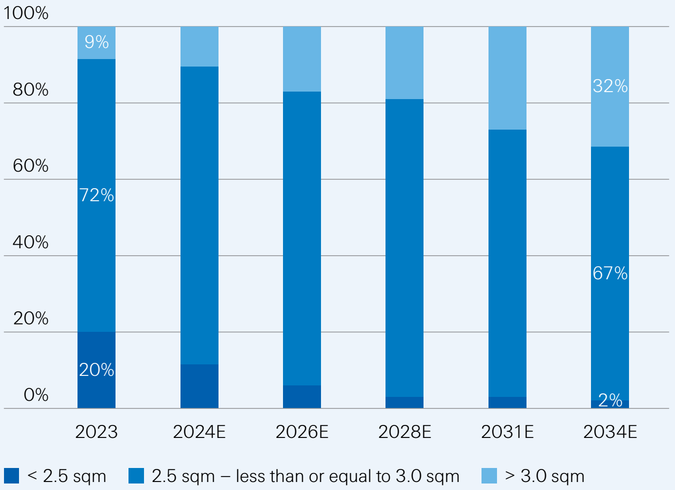
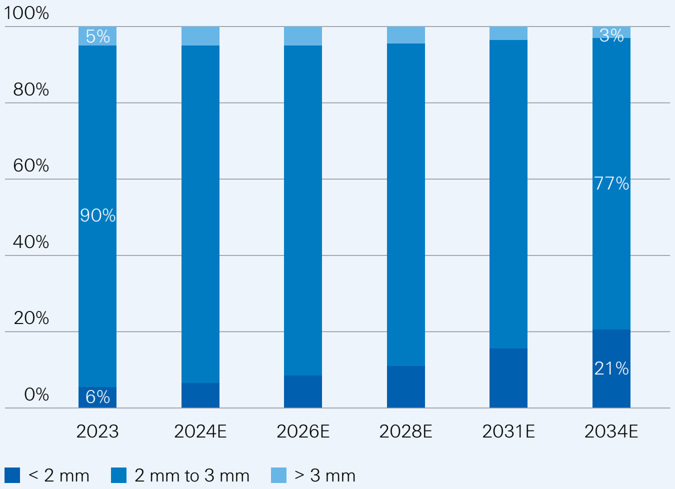


Figure 9
Projected front glass thickness (mm)



Source: International Technology Roadmap for Photovoltaic (ITRPV), VDMA, Swiss Re Institute

Mitigating factors include trackers and monitoring systems: Panels would also require consistent monitoring as damage from micro cracks often go undetected. Technologies such as electroluminescence (EL) testing can detect defects in solar cells and modules that cannot be seen with the naked eye. In addition to using panels with appropriate hail rating, damages can be controlled using panel face protectors/covers or wire mesh/protective netting. The roof orientation and angle of panels can also affect the level of impact from hailstorm depending on its direction (along with prevailing winds). Low-angle panels on flat roofs are more prone to damage than high angle panels on pitched roofs.[40]

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[35] Teule, T. et. al., *The vulnerability of solar panels to hail*, Vrije Universiteit Amsterdam, 2019.
[36] *Review of Failures of Photovoltaic Modules*, International Energy Agency, March 2014.
[37] Dhimish, M., *Micro cracks distribution and power degradation of polycrystalline solar cells wafer*, Renewable Energy, vol. 145, 2020.
[38] Jordan, D.C., et. al., *Extreme Weather and PV Performance*, IEEE Journal of Photovoltaics, 2023.
[39] *Photovoltaic Reliability Workshop*, ITRPV data 2023.
[40] Teule, T. et. al., *The vulnerability of solar panels to hail*, Vrije Universiteit Amsterdam, 2019.

Current hail testing standards for PV modules are mostly pass/fail in nature. The modest kinetic energies used in current test standards are insufficient to characterize resilience to severe hail. Hence, hail testing that goes beyond minimum certification standards and that can replicate real-world hail impacts will play a pivotal role in ensuring resilience of solar assets in hail prone regions.

Strong winds and storms could cause damage, performance loss and water ingression

Though not as hazardous as hail or fire, strong winds and storms increase the risk of performance loss in the case of solar PV. Exposure to winds greater than 90km/hour (56 miles/hour) could lead to notable performance losses, according to NREL.[41] Damage from windstorms could cause dislodgement and breakage. Broken panels or roof aggregates could become windborne debris that damage other panels and roof coverings.[42] In the case of PV systems with penetrative mechanical fixing, if not properly secured, dislodged equipment when exposed to rain could lead to water ingression, damaging building interiors and contents.

Unlike other environmental loads which are pointed downwards, wind uplift load tends to pull the panel/roof upwards.[43] The severity of the suction pressure could depend on numerous factors including wind speed, building/roof/panel geometry and height, overall terrain and geometry of structures upwind.[44,45,46] In the case of roofs, wind uplift load could also vary between the perimeters, corners, ridges and interior zones of the roof. In the case of PV systems, the angle of panel inclination, the distances between the solar PV modules and the roof surface, as well as the proximity of the solar modules to the roof edges are critical in determining resistance to wind load. The geometry, elevation and proximity to other structures of the host building will all affect the intensity of wind load.

Figure 10
Wind uplift pressure on low sloped roof

Source: Adapted, Swiss Re Institute

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[41] Jordan, D.C., et. al., *Extreme Weather and PV Performance*, IEEE Journal of Photovoltaics, 2023.
[42] *DS 1-15 Roof Mounted Solar Photovoltaic Panels*, FM Global, accessed June 2024.
[43] Obina, U., *How to Apply Wind Load on Roofs of Buildings*, Structville, 2022.
[44] Mendis, P., et. al., *Wind Loading on Tall Buildings*, Electronic Journal of Structural Engineering, vol. 7, 2007.
[45] *ANSI/SPRI Wind Design Standard Practice for Roofing Assemblies*, Approved American National Standard and Single Ply Roofing Industry, July 2012.
[46] Schmid, L., *Design and Engineering Considerations for Avoiding Wind Uplift*, Roofing Elements, 2023.

PV panels are susceptible to damage in extreme wind events such as hurricanes, especially when installed on the rooftop of low-rise buildings.[47] Such damage conditions could be aggravated if the damage of peak wind loads supporting structures (including dynamic components) are underestimated.[48] While wind resistance standards (eg, ASCE 7-16, Minimum Design Loads for Buildings and Other Structures, and the National Building Code of Canada 2015) exist for rooftops and panels, there are no standardized test methods that determine the collective performance of the Photovoltaic Roof Assembly (PVRA).[49] For instance, dynamic wind loads during SCSs can exceed wind loads up to five times compared to monodirectional wind loads. While static analysis of standard wind tunnel tests is important, the dynamic effects of wind on PV system parts, such as motorised PV sun-tilting trackers – is also critical as it could lead to potential catastrophic failures.[50]

Nonetheless, the intensity of the wind load impact can be regulated to an extent by:

- Protective measures such as wind deflectors
- Use of rigid PV solar panels and roof assemblies that are approved together in accordance with Approval Standard 4478, where available[51]
- Selection of an appropriate roofing system assembly by comparing the tested wind uplift resistance capacity to the calculated design loads[52]
- Ensuring proper anchoring of panels and related equipment
- Stricter requirements for equipment in roof corners or perimeter
- Avoiding wind exposed roofs with aggregate, pea gravel or other ballast

Existing standards, such as the UL 2703 (for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Flat-Plate Photovoltaic Modules and Panels covers mounting systems) and IEC 61215 (for the design qualification of terrestrial photovoltaic modules), only allow for testing with a uniform test load applied to the entire panel. A failure to include provisions allowing for unbalanced test load might result in failure of modules at loads, which if averaged, are below the rated capacity of the module.[53] Moreover, larger module areas and longer module lengths exacerbate the impact of unbalanced loading. Unbalanced wind pressure is more likely to exceed module capacity, which in turn has implications on wind resiliency of panels.

Snow loading

Snow depths greater than one meter resulted in annual performance losses in PV systems.[54] Roof design should consider the roof's capacity to handle additional snow (and water load in case of heavy rain) in addition to weight of the panels. In the case of flat roofs especially, snow retention could add to the weight of the PV system. Localized snow loads between PV panels are likely, as snow could slide off and melt. Proper roof drainage should also be considered when designing the roof.[55] The weight of snow, combined with wind and cold loading, can physically damage modules and cells. Not only are load stresses in winter poorly understood but almost nothing is known about the robustness of different module technologies exposed to those stresses.[56]

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[47] Peng, H.Y., et. al., *Investigation of wind loading characteristics of roof-mounted solar panels on tall buildings*, Sustainable Energy and Technologies Assessments, 2022.

[48] Estephan, J.et. al., *A new experimental-numerical approach to estimate peak wind loads on roof-mounted photovoltaic systems by incorporating inflow turbulence and dynamic effects*, Engineering Structures, 2022.

[49] Molleti, S., et. Al., *Development of a New Dynamic Test Method to Determine the Wind Pressure Resistance of Photovoltaic Roof Assembly, Journal of Testing and Evaluation*, 2022.

[50] Roedel, A., Upfill-Brown, S., *Using dynamic wind analysis and protective stow strategies to lower solar tracker lifetime costs*, Nextracker, 2018.

[51] *DS 1-15 Roof Mounted Solar Photovoltaic Panels*, FM Global, accessed June 2024.

[52] *Wind Design Standard*, ANSI/SPRI, 2012.

[53] *Photovoltaic Reliability Workshop* , ITRPV data 2023.

[54] *How Extreme Weather and System Aging Affect the US Photovoltaic Fleet*, NREL, 24 January 2024.

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[56] Burnham, L., et al., *Module Reliability in Winter: Field Analysis of Deflection and Cell Cracking Across Multiple Module Architectures*, IEEE, 2023.

Lightning

With increased humidity and more frequent lighting storms predicted with climate change, exposed metallic framed PV systems are vulnerable to lightning strikes.[57] Lightning protection is important as lightning damage could translate into high replacement/repair costs or even failures.

Earthquake

Though a risk primarily for ground systems, earthquakes could cause significant damage if the building is not designed to withstand earthquakes. Recent earthquakes in Chile, Turkey and Syria witnessed significant economic losses, largely due to the vulnerability of existing building stock. The common approach is to address seismic and energy performance with separate interventions. However, to achieve better cost-effectiveness, safety and efficiency, a novel holistic approach combining seismic and energy retrofitting of buildings is needed in renovation of buildings.[58] Though it does not affect the structural integrity of the building, seismic performance of non-structural components, such as rooftop PV sytems, is critical in limiting losses should an earthquake incident occur.[59] Seismic activity can damage panels through lateral or vertical movement. This can cause broken glass, damaged electrical components and an increased ignition potential.[60]

Data centric approach to risk management

It can, however, be hard to identify the cause or trigger of damage incidents to solar PV installations. This uncertainty can result in data gaps in estimating likelihood of loss events. Nevertheless, we can progress towards proactive de-risking by leveraging data and analytics. Defining and tracking important risk indicators can further help identify risks which are currently not transferable or uninsurable.

The resultant risk framework can be defined by risk indicators based on:

- Automated and live risk data from weather stations, sensors, and satellites
- Static risk data from project risk registers and manufacturer's operating manuals

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[57] *RC62: Recommendations for fire safety with PV panel installations*, Fire Protection Association, 2023.

[58] Pohoryles, D.A., et. Al., *Integrated seismic and energy retrofitting of existing buildings: A state-of-the-art review*, Journal of Building Engineering, 2022.

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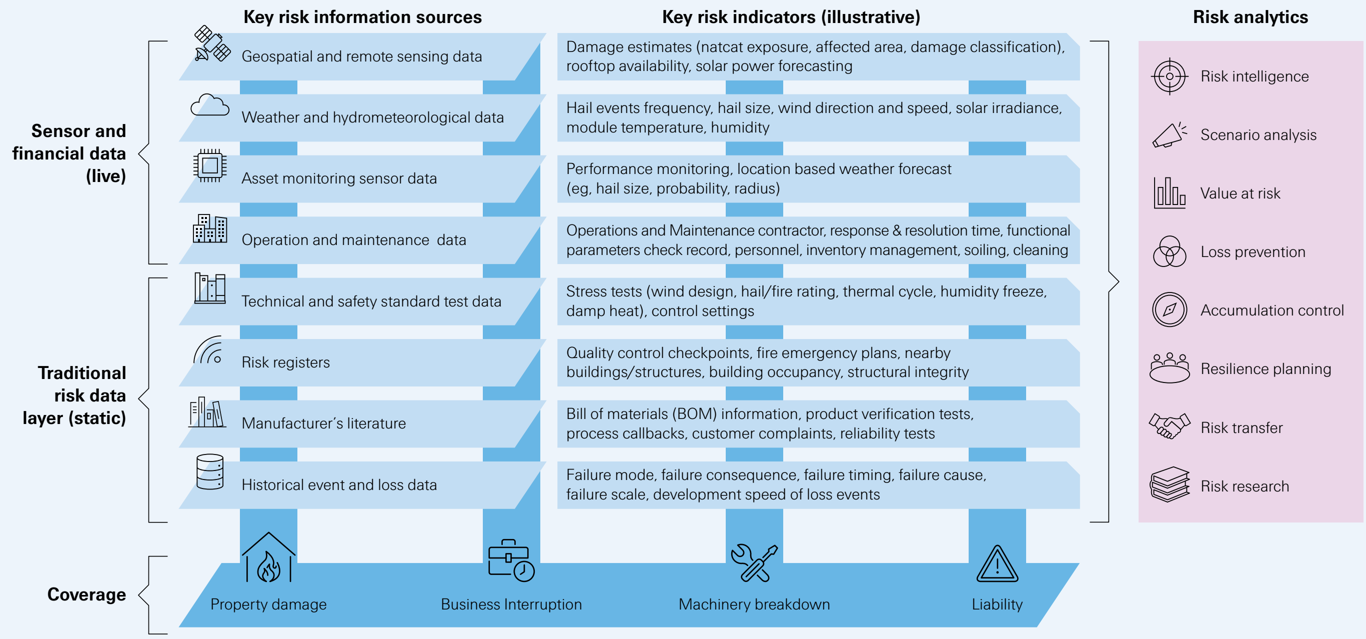
[60] FM Global Property Loss Prevention Data Sheets 1-15, July 2014.

Figure 11
Risk data ecosystem(illustrative)



Source: Swiss Re Institute

Automated and live risk data from weather stations, sensors, and satellites

1. **Geospatial and remote sensing data:** Geospatial and earth observation data is widely utilized to develop solar irradiance models using clear sky irradiance and cloud index data.[61] Geographic Information Systems (GIS) and Remote Sensing (RS) data can be used to delineate appropriate locations for deploying solar PV panels, such as rooftops. Multi-functional Transport Satellite (MTSAT) and Unmanned Aerial Vehicle (UAV) images can also be utilized in conjunction with deep learning to estimate the technical potential of PV.[62,63] Satellite-based irradiance models also facilitate solar radiation levels (historic, recent and future levels) estimation without depending on-field ground sensors.[64,65] In addition to location optimization, geospatial data is also increasingly being used for panel monitoring and damage assessment through visual identification, video monitoring, signature identification and machine learning techniques.[66]

2. **Weather and tracker data:** In addition to GIS and RS data, specialized meteorological stations can also be leveraged to access additional environmental parameters that could optimize risk management. Assessing exposure to extreme weather events, particularly severe storms (wind or hail), for instance, could be critical in feasibility assessment and commissioning of PV installations. Furthermore, real-time response to extreme weather events can be facilitated through the use of automated tracker devices on panels.

3. **Operation and maintenance data:** Continuous monitoring and maintenance of PV infrastructure and associated components is crucial in identifying faults and avoiding loss incidents (see 'Need for resilience as upscaling impacts risk profile'). Timely monitoring, access to information on operations and maintenance (O&M), including the response and resolution time, can supplement a potential risk assessment.

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[61] *Solar radiation modeling*, Solargis, accessed June 2024.
[62] Huo Jiang et. al., *Geospatial assessment of rooftop solar photovoltaic potential using multi-source remote sensing data*, Energy and AI, 2022.
[63] Man Sing Wong et. al., *Estimation of Hong Kong's solar energy potential using GIS and remote sensing technologies*, Renewable Energy, 2016.
[64] *Solar radiation modeling*, Solargis, accessed June 2024.
[65] *PVGIS data sources & calculation methods*, Europe Commission, accessed June 2024.
[66] Haba Cristian Gozo, *The Use of Machine Learning Techniques for Monitoring of Photovoltaic Panel Functionality*, Internet of Energy for Smart Cities, 2021.

Static risk data from project risk registers and manufacturer's literature

4. **Technical and safety standards:** It is important to ensure detailed guidance on property loss prevention related to fire and natural hazards for the design, installation, and maintenance is available and addresses PV infrastructure, roof, building and personnel requirements.[67] Records of stress test results and technical measurements can also be included in the risk register maintained by the insurer.

5. **Risk registers:** Localized on-site data can be collected manually through risk registers, a collection of pre-identified risks graded by experts across cause, probability, severity and impact for PV installations. Qualitative in-situ risk data collected through risk registers can supplement automated risk data. Insights from experiences across countries can also be compiled and refined to develop best practices for local risk register formats.[68]

6. **Manufacturer's literature:** Having access to and the capability to review the materials used for manufacturing PV panels and associated components is essential in assessing PV reliability risk. Information on materials that go into the PV panels – including name, supplier and technical specifications – should be made available to ensure maximum mitigation potential. The information requirement is also prescribed by IEC 61730, which is a pre-requisite for the standard IEC 61215 qualification certificate. Providing insurers with this information should require no extra effort on the part of the manufacturer. Furthermore, information on process callback and customer complaint handling procedures, product verification test results, quality inspection records and performance measurement data from the manufacturer can contribute to technical reliability assessments.[69]

7. **Historical data:** Historical loss data on failure modes (how panels have failed in the past), consequence, failure cause (root cause of failure) and response time can form the foundational layer for quantifying baseline risk.[70]

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[67] *FM approved voltaic modules*, FM Approvals, accessed June 2024.
[68] *Infrastructure resilience De-risking transport infrastructure projects in India*, Swiss Re, 2023.
[69] *Solar Panel Code of Practice,* Swiss Re, 2019.
[70] *Solar Panel Code of Practice,* Swiss Re, 2019.

Conclusion: Risk management

Proper installation and maintenance by qualified personnel

Proper design, installation, inspection and maintenance can serve as both an effective mitigation and preventive measure in the case of Photovoltaic Roof Assemblies (PVRA). Proper installation, however, is dependent on availability of accurate information (natural hazard exposure and change management) and qualified persons who can manage installation, monitoring and maintenance for the specific equipment.

Early involvement of risk engineers

Involvement of risk engineers right from the planning stages will ensure access to proper guidance on quality, design, installation, inspection and maintenance. This would also mean informed decision making with regard to selection of location, roof design, panel equipment, installation and installers. Further, as third-party installation schemes are increasingly being utilized, adequate guidance is necessary for proper risk assessments.

Involvement and skill building of emergency response teams

In addition to risk engineers, active involvement of emergency response teams is necessary, as large fires on rooftops often require involvement of fire brigades. Active involvement from planning stages could, not just ensure the safety of the emergency team but also aid in efficient and effective fire suppression. This will also encourage rooftop design to allow easier and faster access. Emergency teams would also know where BESS (if applicable) can be found; and how to shut down and disconnect the particular PV panels.

Natural hazard mitigation

The natural hazard mitigation strategy should leverage data and analytics capabilities considering the growing uncertainty with regard to extreme weather events. In addition to historical data, real-time weather and tracker data utilizing GIS based models could effectively inform location optimization, panel monitoring, damage assessment and timely response to extreme weather events, thereby optimizing risk management.

Regulations to catch up with technology

As rooftop PV technology is evolving in response to growing demand for clean energy, regulations are trailing the pace of innovation. While standards and certifications exist for rooftops, panels, related components and buildings, a standardized approach to collectively assess PVRA is yet to be developed.

Industry collaboration

With falling costs, growing adoption and changing risk profiles, the insurance industry can play a crucial role in improving risk management and facilitating growth. Swiss Re's Centre of Competence for Renewable Energy, for instance, leverages its in-house expertise contributing to industry best practices such as the Solar Code of Practice. The dedicated team of specialists closely collaborate with insurers and clients in setting out guidance on renewable energy risk management of offshore, onshore and solar risks.[71] As improved insurability translates into better risk assessment and management, insurers can recommend required standards and practices throughout the panel lifecycle. The insurance industry could be a catalyst for cross sector collaboration between regulators, industry players and other stakeholders to define best practices in planning, designing, installation, maintenance and disposal stages of the rooftop solar PV systems.

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[71] *Renewable Energy Risks,* Swiss Re, accessed July 2024.

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