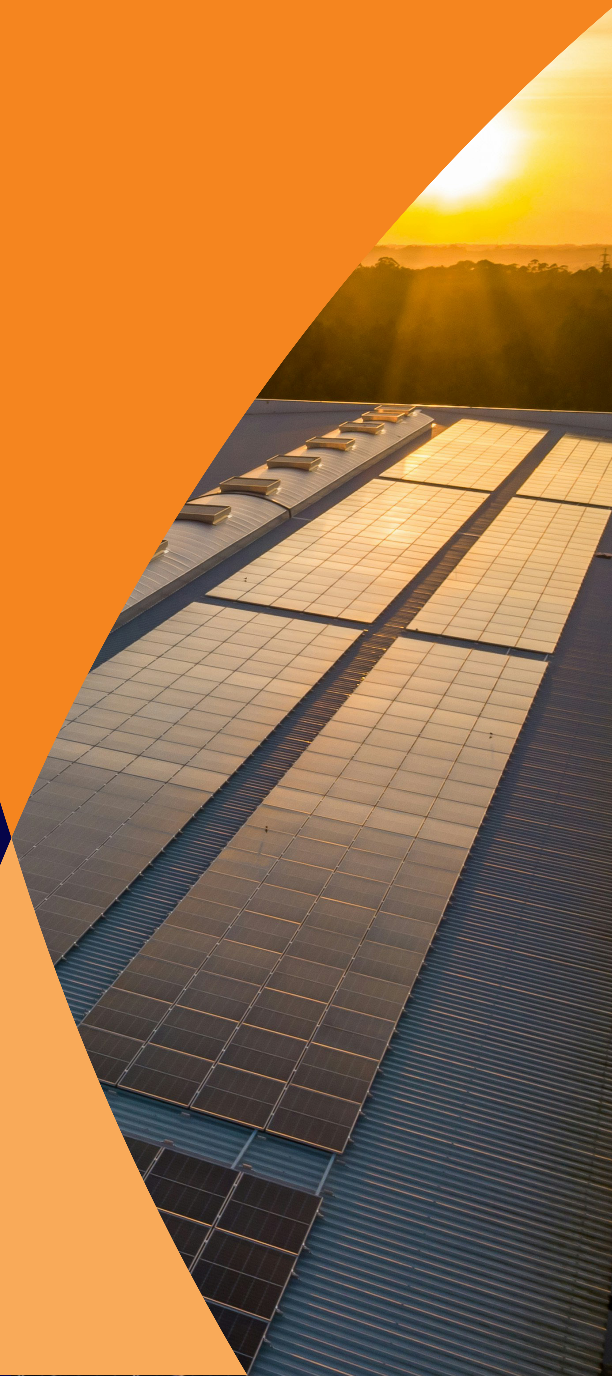
IIGCC

PCRAM case study

Solar and mini hydro portfolio analysis in Italy



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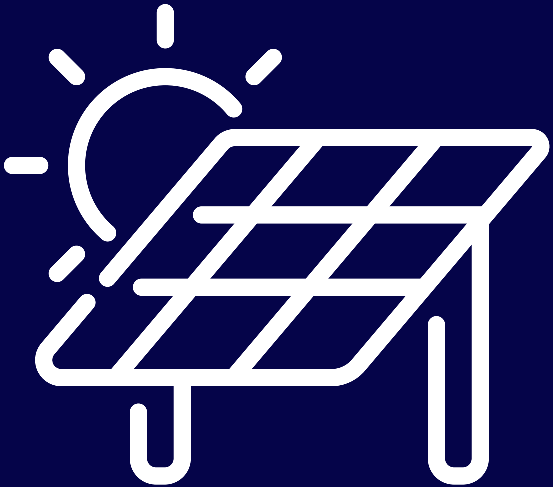
Investment overview



Equity investments in two leveraged investment platforms, one of which includes three operational solar assets across Italy with capacities ranging from 994 kW to 7966 kW, the other a mini hydro power plant.

Asset objectives

- Lifetime of +25 years
- Aggregated average annual energy generation of 24 GWh/year

Estimated project impact

- With this generation, the projects are able to avoid emissions of 5,389 tCO_2e[1]
- The projects' generation is providing electricity to the equivalent of 6,727 households[2]

Sector

- **Power generation (renewable)**
- Power generation (other)
- Power transmission
- Other energy infrastructure
- Maritime Transport
- Rail
- Water resources/network
- Airport
- Highway
- Telecommunications
- Data centres

Asset lifecycle

- Development
- Construction
- **Operational**
- Decommission

Investment Stage

- Pre investment
- **Holding**
- Exited

Finance type

- Blended finance facility
- **Private sector funding**
- Government funding
- DFI funding

Hazards screened (EU Taxonomy)

- Acute – Storm, Heavy Precipitation, Flood, Heat Wave, Cold Wave, Wildfire, Landslide
- Chronic – Precipitation, Heat Stress, Solar variability

Hazards analysed

- Heavy Precipitation (Severe Convective Storms – Hail)
- Storm (Severe Convective Storms – Wind)
- Heat wave
- Heat stress

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1 Assuming 223gCO_2e/kWh as Italy carbon intensity, EEA

2 Assuming 3.57MWh/household/year, EU data 2022 from Eurostat

Figure 1: The PCRAM Process

	1	2	3	4
Steps	**Scoping and data gathering**	**Materiality assessment**	**Resilience building**	**Value enhancement**
Objective	Determine data sufficiency	Assessing asset vulnerability	Identifying adaption options	Optimised resilience with residual risk transfer
Sub-tasks	→ Project initiation → Project definition → Data gathering and sufficiency	→ Hazard scenarios → Impact pathways → Financial sensitivities (return & debt) → Distinguish acute damage vs. chronic performance efficiency	Adaption options, costs and availability: → Hard (Structural/Capex) → Soft (Operational/Systems)	→ Identify resilience metrics → IRR comparisons → Insurability and credit quality
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Decision gates	**Gate A** What are the scope boundaries and data sufficiency according to the investment strategy?	**Gate B** Are PCRs material for the asset(s)? Reviewing asset KPIs, what factors influence the materiality?	**Gate C** What are the most effective adaption options for this asset, the optimal timing for their implementation, and the responsible parties for funding and execution?	**Gate D** How can resilience investment be optimised and incentivised, while ensuring equitable risk-reward distribution across the value chain actors?

Step 1: Scoping and data gathering

Step 1a) Project Initiation

PCRAM case study group: Two sub-groups were formed ahead of the materiality assessment. The first focused on engineering and physical climate risks to determine asset-level thresholds and losses. The second group focused on sustainability, financial risk and valuation, to review the financial materiality thresholds, aggregating from asset to portfolio level.

Step 1b) Project definition

Investment structure and KPIs: Theia, through investment received from two different Stafford secondaries funds, acquires and manages renewable energy assets – among which there are the four assets discussed in this report. The portfolio assets are held through a combination of special purpose vehicles (SPVs) owned by holding companies (HoldCos). The debt financing is raised at the HoldCo level.

Preliminary climate risk assessment determined exposure to convective storms (hail and storm damage) and landslides for acute and heat risks driven by drought for the chronic risks affecting asset operation, energy yield and asset structure cabling.

Step 1c) Data availability

The hydroelectric plants managed by Theia had lower-quality technical and structural data compared to the photovoltaic ones. This is largely due to the fact that they were acquired further into the asset's operational life (i.e. later after the end of construction), and the necessary documentation for a full physical risk assessment was not available from the previous owner at the time of acquisition. Inputs to PCRAM include detailed technical specifications for assets.

For older acquisitions, as with the hydropower plants, Theia's due diligence process prioritises reliable production data and ensuring that all technical and legal requirements are met. A full technical assessment would have required additional time and third-party involvement and was deemed unnecessary given the extensive access to satisfactory historical operational data.

Data on acquired photovoltaic systems are more complete, as most of these plants have been acquired at an earlier stage in their operational life or, in some cases, plants were built directly by Theia.

Decision Gate A

What are the scope boundaries and data sufficiency according to the investment strategy?

Data quality was good & deemed sufficient to carry out the appraisal for the three solar assets, but the mini-hydro data was not as readily available, the appraisal scope was thus focused on the three solar assets.

To streamline data gathering, see the Lessons learnt section for an open-source data request tracker outlining data points, data owners and best documents per investment stage.

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Step 2: Materiality assessment

The highest exposed and most vulnerable asset within the portfolio was identified, and a detailed financial materiality assessment of the maintenance, performance and life cycle impacts was performed.

Step 2a) Hazard scenarios

Mapping climate scenarios to investment lifecycle: A detailed assessment of the climate hazards and their impacts for the portfolio was performed. Two future climate hazard data horizons were considered for severe climate scenarios (RCP 4.5/intermediate, and RCP 8.5/high emissions) to understand the potential risks and vulnerabilities. These were mapped to the investment cycle, the asset lifespan and the physical risk long-term estimates. For acute impacts to solar panels from high solar PV module temperatures, SSP2-4.5 and SSP5-8.5 were used as suitable equivalents. Present-day risk assessments were based on 30-year histories to account for inter-annual variability. Climate histories were dependent on the most recent 30 years of data availability between 1971 and 2015 depending on the hazard. Most up-to-date climate models from CMIP6 were used were available; otherwise, CMIP5. Daily and the highest resolution inputs available were used: 50 km (for SCS hail and wind) and 25 km (heat stress).

Climate hazard screening: Qualitative analysis was undertaken for precipitation stress, heat stress, storm (hail, lightning, tornado) – specifically related to severe thunderstorm activity referred to as SCS, chronic solar radiation variability (aerosol/dust, cloud cover), wildfire, large-scale storm, flood, freeze-thaw events, and a landslide literature review. 'Derecho' wind events linked to severe convective storms were not directly considered in the screening process, but were considered in SCS as a multi-hazard event.

Precipitation stress (chronic): Associated with changes in the frequency and/or variability in rainfall events are most likely across Northern Italy (CMIP5), largely during the winter season. No robust climate trend was observed in **heavy precipitation (acute)** for either extreme wet days (>20 mm) or 5-day consecutive rainfall accumulations (>50 mm). Water ingress can degrade the solar power output through delamination and corrosion.

Drought (chronic): Intensification is very likely by the end of the 21st century (almost all climate scenarios). While there are limited direct impacts to solar PV modules, indirect effects may include dislodgement of support structures and local soil instability, potentially exposing the assets to landslide/pluvial flood risk. Wind-blown dust may also increase the deposits on the panels, increasing the need for maintenance.

Cold wave (acute): Freeze-thaw events associated with deterioration of panels were reviewed, but are considered a decreasing risk, however, acute events from changing regional circulation patterns cannot be ruled out during the higher altitude locations in Northern Italy. Overall, climate change is likely to reduce the number of freeze-thaw events by around a third compared to the most recent 30-year period.

Heat wave (acute): Events days, defined by the present-day 90th centile, pose an increasing risk to the health and safety of workers. These are likely to increase by up to 3-fold over the next 30 years, and by 511% to 822% over the next 60 years.

Wildfire (acute): Solar PV units are generally located in low wildfire hazard zones, where the likelihood of damage is not material. Fire damage to assets is more likely to occur from an electrical malfunction, which is exacerbated by heat stress.

Flood (acute): No robust change in precipitation was noted from climate models in this region. While solar assets are not directly vulnerable to hydrological events, debris from pluvial flood may cause damage to the panels or their mounting. Exposure to water can also cause malfunctions, corrosion, or electrical shorts to inverters. Fluvial (river) flood and coastal flood were considered very low to negligible for these asset locations.

Landslide (acute): This was considered to be out of scope, since no robust model was available. There is a moderate baseline climate hazard for both of the asset locations reviewed; therefore, further analysis work should be considered. Changes in precipitation patterns (frequency, severity and duration) combined with periods of drought may increase this climate hazard. Vegetation cover, water-course and local land management can mitigate landslide risk to solar assets.

Solar (chronic): No significant trend in solar radiation was observed in climate model projections. Variability in cloud cover is the main driver of solar PV output, and wildfire smoke and/or aerosol dust were considered to be of low material impact, assuming regular maintenance and cleaning.

Storm (acute): Storms were classified into two main types. Extratropical storm events show no robust trend across Italy, with a mixed climate signal in the Northern provinces. The European Severe Weather Database shows a notable increase in the intensity of meso-scale storms linked to hail damage reports. Increasing hailstorm risk across all Northern Italy sites is robustly supported by climate models.

Step 2b) Identify Impacts on Assets

Severe convective storm, wind and heat stress were determined to be more material, and impact thresholds were identified for those climate hazards (see Step 2b).

Acute risks damage thresholds: Extreme and large hail return periods present considerable inter-annual and decadal variability across Northern Italy and between climate emissions scenarios. Climate models (CMIP5 CORDEX) and observational data (ESWD) indicate a stark increase in this hazard. The estimated 10-year average return periods range from 22 to 43 years (3 to 6 years) for extreme (and large hail), respectively. Extreme hail frequencies are expected to increase by an estimated 17% by the end of the century. Strong winds, associated with severe hailstorm events, can cause structural damage. This is also expected to increase, from a return period of 15 to 21 years to 13 to 17 years by 2100.

For heat wave impacts, we considered a nominal impact threshold at the 99th percentile (52°C), representative of typical daily maximum panel temperature in a present-day climate, in the reasonable worst case, 24% of the operational period may be impacted by the mid-century period.

Chronic risk performance efficiency: For chronic heat stress, a more complete climate model assessment was also performed using 9 models selected as suitable for European assessment. We found that solar PV panel temperatures above a 25°C damage threshold are expected to robustly increase (-2% to +12%) from their historical values over the near-term, and by mid-century, -2% to +16% in an intermediate emissions scenario. For the high emissions scenario, increases are more robust at +5 to +20%, with a climate model average of 7%. This translates to a decrease in solar power generation of 1.3% (0.6% to 2.8%) in the SSP5-8.5 emissions scenarios, and 1.0% (0.5 to 2.6%) in SSP245. Considering the most relevant peak summer-time period, decreases are 1.7% (0.4% to 2.5%) in SSP5-8.5, and 1.3% (0.3% to 2.0%). Several resilience measures can be implemented to substantially offset these efficiency losses.

Step 2c) Impact Pathways

The engineering properties of the solar assets are assessed to build a view of how vulnerable the asset is to both acute and chronic physical risks. This involves identifying the various components and systems of the asset, along with their associated value and exposure to the physical risks. For example, the properties of the solar PV module are analysed to determine the minimum energy required to break the glass due to hailstones to create damage thresholds. Whereas, for heat stress, instead of defining a damage threshold, an operational threshold is identified to develop a performance curve to assess how heat impacts the asset output and reduces efficiency.

Based on the damage threshold from the hail modelling, three impact pathways – high, mid, and low case – are defined across three interconnected categories: maintenance, performance, and life cycle. The lifecycle impact influences maintenance schedules, while performance dictates the timing of the lifecycle. An operational threshold of 80% relative performance to the nominal power output was set, in line with the manufacturer's guarantees over the modules' lifespan. When performance drops below 80% it triggers the replacement of the module.

Step 2d) Quantify Impacts on KPIs

Financial materiality and stress testing

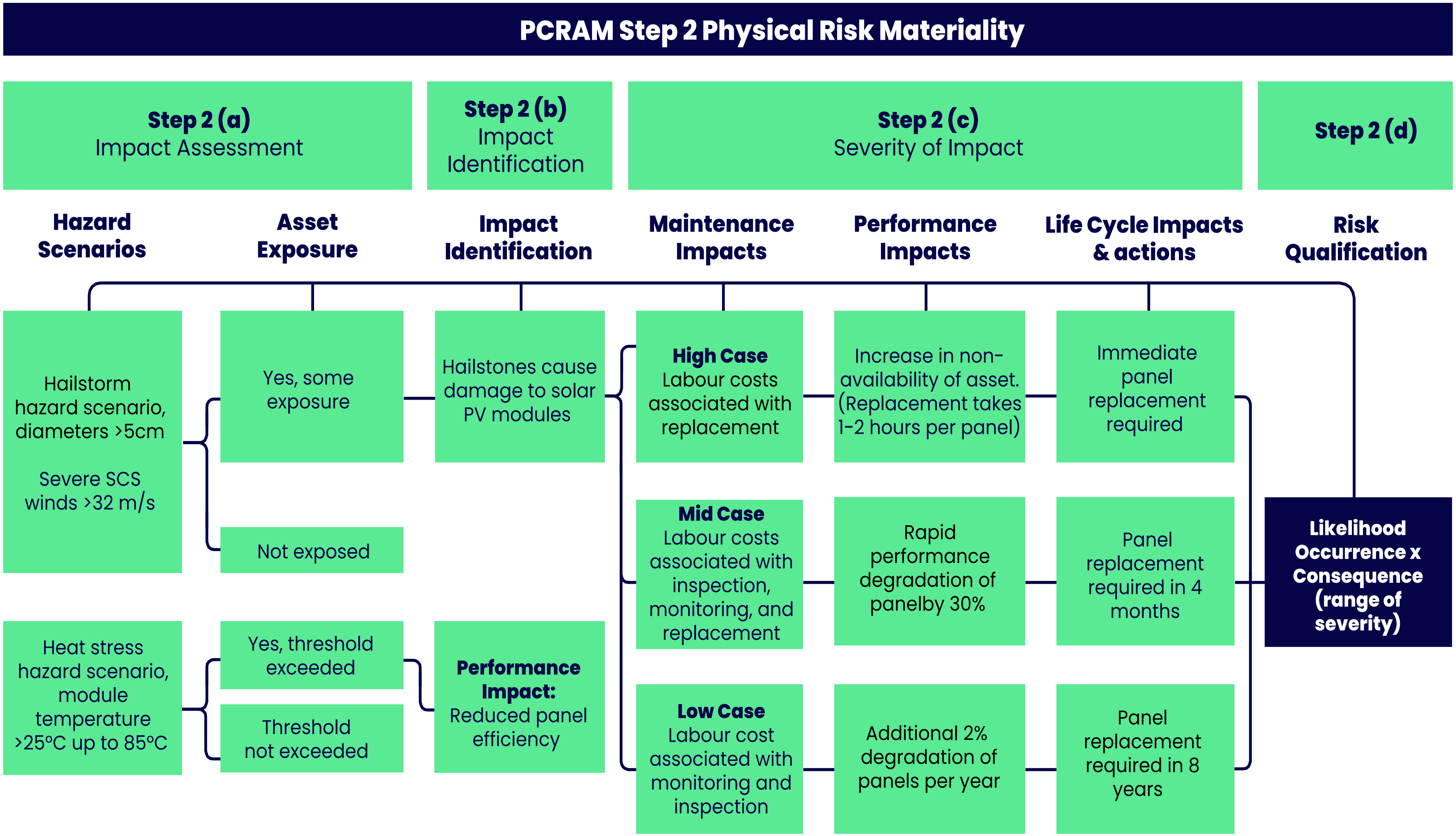
The investment fund manager presented multiple solar projects that are integrated into an investment platform with a defined divestment horizon. Financial performance could be sensitive to the occurrence of physical climate risks if incurred damages are extreme enough to reduce revenue potential or increase operational and capital expenses to a point that the fund is no longer able to comfortably service its debt, as reflected in periodic cash flows available for debt service (CFADS) or provide sufficient distributions to its equity holders.

Debt sensitivities: The sensitivity of the fund to the performance of each asset is closely linked to the debt expenses and CFADS as modelled by the investment management team, but the responsibility to service debt and retain earnings for distributions to shareholders is often distributed among multiple assets within a fund under aggregated loans. This allows funds to be resilient and flexible against sudden shocks from acute risks to a particular investment. The operating income of the assets presented in this case study contributed between 5 and 29% of the overall CFADS for their respective loans.

With this leverage across loans, a physical climate event or events must incur extra costs, or loss of revenue to the investment of at least 50% of annual CFADS in order to trigger the debt lock-up covenant, meaning that the project(s) will be temporarily restricted from making equity distributions to investors, impacting fund returns. Losses from climate-related events over a single year, totalling 78% annual CFADS, can result in cash flows falling below the level of debt payments entirely and triggering an emergency loan from a Debt Service Reserve Facility to prevent defaulting on the debt.

Return sensitivities: In addition to loan considerations, climate risk impacts can reduce the return profile of the investment project, limiting the amount of cash available to return to shareholders in the form of regular distributions. This will result in reductions to the internal rate of return (IRR), a key metric for all investors interested in gauging the appeal of projects for similar funds. In the materiality assessment, impacts to IRR are measured; however, this measurement traditionally underrepresents (or discounts) the increasing prevalence of climate risks over the coming decades. Thus, the results of the materiality assessment are used to illustrate additional measurements for the performance and resilience of these assets.

Figure 2: Impact Pathway with example for solar PV heat stress and hailstorm hazard



Financial Stakeholder Considerations in Materiality Assessment

In practice, when a climate-induced physical risk materialises causing damages to the plants, the course of action is determined based on multiple factors and stakeholders:

- Typically, most acute events will be covered by the insurance policy of the plants, leading to a solution being put in place immediately in consultation with the insurer and the operational contractor. In any case, any acute event (covered or not by the insurance) that has a material impact on the production level will be fixed immediately.
- For chronic events (e.g., overheating), the course of action will depend on the event in question and the condition of the warranties of the damaged components. If the warranty applies, this also leads to immediate action in coordination with the original provider. Similarly, if the event poses a risk of materially harming the production, it should be addressed immediately.
- Smaller events that have limited or no impact on the production level, and that are not covered by either the warranty or the insurance (e.g., below the deductible or outside of the warranty period), are tackled in coordination with the O&M contractor in order to make the solution more efficient (e.g., coordinating the replacement/the reparation at the same time as an ordinary maintenance visit).
- It is worth noting that lenders are also important stakeholders to consider in this situation. In general, they are not directly involved in the process of fixing the issue, but they will be made aware through the maintenance reports that are being made available to them. There will also be some materiality threshold above which they will need to be made aware ex-ante and potentially confirm the resolution process. The level of these materiality thresholds will depend on the lender's sophistication for the specific technology.

Decision Gate B

Are PCRs material for the asset(s)? Reviewing asset KPIs, what factors influence materiality?

The Climate Case cashflow forecast was created from the financial sensitivities for acute hail and chronic heat stress risks. The case study team decided to focus resilience building on Emerald snake.

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Step 3: Resilience building

Step 3a) Identify Adaptation Options & Step 3b) Cost Benefit Analysis

Following the identification of hail and heat stress as material physical climate risks, a range of adaptation options for the selected site were assessed. These include both hard (structural /CAPEX) and soft (operational / OPEX) interventions. Each measure was evaluated for its cost and effectiveness in enabling quicker recovery from reduced downtime and maintenance costs from increased hail events and heat stress (see Table 1).

Heat stress is a chronic hazard, primarily impacting the performance of the asset rather than its lifecycle. The financial benefit of resilience is largely observed in the mitigation of power output reduction and maintaining efficiencies in line with the operational expectations of the solar panels.

The measures noted in Table 1 show varying degrees of effectiveness and price implications. Cheaper measures, such as coatings, present significant cost benefits, but may not be as effective at reducing the vulnerability of the asset and the financial impacts. Other measures may have limitations in their applicability. The protective coating against hail is a new technology, and its efficacy in reducing the vulnerability of PV panels is not well studied, making it difficult to model its financial impact. Additionally, the lasting impact of hail netting options needs further review, given that extreme wind gusts and hail typically coincide. Fixings for nets would need to withstand wind gusts of at least 100 mph.

Structural changes such as adjusting the tilt angle of solar panels or the installation of tracking systems could reduce the likelihood of hail damage (a 60-degree tilt can deflect the kinetic energy of hail). However, this necessitates a complete overhaul of the mounting structure, which is costly, and fixing the panels at such a steep angle would significantly reduce their power output. A mounting structure with trackers, which allows for dynamic adjustment of the tilt angle, is more beneficial but would require significant investment for retrofitting. Such structural changes are generally only recommended during the asset's development stage.

Nature-based solutions are important to consider in building resilience, to enhance natural systems whilst providing climate risk mitigation factors at financially viable costs. The incorporation of vegetation around solar panels offers several benefits, including a reduction in ambient temperature that helps mitigate efficiency loss, ensuring that the solar panels operate more effectively. Additionally, integrating vegetation can enhance land-use efficiency and the impact force of falling hailstones. A 60-degree tilt can deflect the kinetic energy of hail; but for the reasons just outlined, a mounting structure with trackers, which allows for dynamic adjustment of the tilt angle, is more beneficial but would require significantly higher costs for retrofitting.

Step 3c) Reassess Materiality with Adaptation Options

The adaptation options were presented, and the case study team factored these measures into the materiality assessment. This results in the Resilience Case cashflow forecast, which can be compared to the Base Case from step 1 and Climate Case from step 2 (see table on page 8).

Table 1: Selected resilience measures for solar investment risks from heat stress and hailstorms

Resilience measures	Estimated Costs	Benefits	Financial benefit to quantify
Hail			
1 PMMA coating A polymer spray applied to solar panels to enhance their impact resistance against hail.	1-2% CAPEX	Increased impact resistance to hail as well as enhanced protection against moisture ingress.	▪ Reduction in downtime ▪ Reduction in O&M costs ▪ Lower risk perception
2 Leno woven hail netting A netting system designed to catch and reduce the impact of larger hailstones.	5–6% CAPEX	Prevents damage from large hailstones with mesh sizes as small as 2mm to 8mm. Transparent colouring results in minimal effect to the performance ratio of the modules. This reduces the impact pathways to the low case with a lower likelihood.	▪ Reduction in downtime ▪ Reduction in O&M costs ▪ Decrease likelihood of incurring replacement costs ▪ Lower risk perception
Heat stress			
1 Polymer reflective coating A coating applied to the frames and backsheet of solar panels.	1-2% CAPEX	Reduces the panel temperature by up to 7˚C and increases performance efficiency by 3%.	▪ Reduction in O&M costs ▪ Reduction in efficiency loss
2 Misting system An automated system that sprays water onto the solar panels to cool them down.	5-7% CAPEX + <1% OPEX	Reduces the panel temperature by up to 20°C and increases performance efficiency by 7%.	▪ Reduction in efficiency loss
3 Vegetation An agri-solar measure where crops or vegetation are planted around the solar panels.	N/A	Reduces the panel temperature by up to 8°C and increases performance efficiency by 3%.	▪ Reduction in efficiency loss ▪ Increasing land-use efficiency (in the case of agricultural production) ▪ Public sector grants to reduce the CAPEX of some measures e.g. BNG

Decision Gate C

What are the most effective adaptation options for this asset, the optimal timing for their implementation, and the responsible parties for funding and execution?

The adaptation options were presented, and the case study team was set up for factoring these measures into the materiality assessment. This results in the Resilience Case cashflow forecast, which can be compared to the Base Case from step 1 and Climate Case from step 2.

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Step 4: Value enhancement assessment

Step 4a) Risk Transfer: Enhancing Resilience and Insurability

Resilience measures effectiveness and insurability: The effectiveness of hail netting options needs to be reviewed, given that extreme wind gusts and hail typically coincide. Fixings for nets would need to withstand a minimum 100 mph wind gust.

The recommended resilience measures are designed to reduce the vulnerability of the asset, thereby lowering its overall risk profile. By implementing the resilience measures, the asset becomes more robust, and the financial implications of insuring it can become more manageable. **This effective management of the risk could have implications on the cost and availability of insurance.**

Heat extremes may lead to additional economic impacts. These could include a surge in demand-side energy requirements from widespread deployment of air-conditioning. Solar modules are likely to be affected by reductions in efficiency and potentially component failure at the same time. Workers may not be able to safely travel and undertake essential maintenance.

Insurance plays a crucial role in continuing to manage the risks from extreme events. This is particularly important when the optimum threshold of residual risk transfer to insurance is being considered. Reviewing the change in insurance metrics for pricing across different time horizons due to altering physical climate risks helps inform decisions around resilient investments and risk transfer strategies. By understanding these dynamics, risk management for climate-related risks can be optimised. Regulatory considerations for resilience in Italy might evolve in the context of a new public-private reinsurance entity guaranteeing insurance availability and affordability.

Additionally, parametric insurance products, which can utilise advanced technology to track and monitor events, play a significant role in this context. These products rely on predefined triggers, such as specific weather conditions or natural disaster parameters, to automatically initiate claims payouts. This approach ensures faster resolution and transparency, as claims are processed based on real-time data and predefined criteria, without the need for lengthy assessments. By integrating parametric insurance, solar farms and other assets can benefit from immediate financial support following an extreme event, further enhancing their resilience and financial stability.

For future panel installations, insurability may depend on high-quality data collection and management. Weather stations and sensor networks, such as hail pads and anemometers to measure wind speeds, should be considered. This data would help verify claims, while real-time monitoring combined with early-warning systems from weather suppliers would help manage extreme weather events and implement resilience measures such as panel tilt angles.

Step 4b) Making the Investment Case for Resilience: Key Considerations

Investment exit strategy: The solar investment is part of a closed renewables fund, which has been invested in a variety of energy projects and is scheduled for divestment over the coming decade. The solar project analysed for this study has a projected operational lifetime extending past 2050, long after the anticipated divestment of the project from the fund. The fund is targeting an overall annualised return to its investors of 10%.

The most recent financial forecasts for the solar project anticipate a lifetime return (IRR) of 7.9%, but a return over the fund life of 10.8% assuming a favourable sale at divestment. This will depend heavily on the production and climate risk outlook at the site in proceeding decades.

The ability for the solar project to meet its return targets depends on near-term distributions to its shareholders in addition to a positive forward outlook when sold. Heat stress and extreme hailstorms present the project with differing risks to manage when projecting overall returns.

The chronic impacts of rising temperatures directly impact the revenue profile for solar projects, with expected average efficiency reductions ranging from 0.6% to 1.6% in both the SSP 245 and SSP 585 scenarios. Over the investment timeline, the revenue losses, ranging from €260k-730k, will not create shortfalls to trigger debt covenant terms, but the reduction in cash flows available for equity could create project IRR impacts between -0.1 and -0.3%, or up to a 2.4% reduction in sell-on value.

Table 2:

Investment scenario	Impacts	Description	Avg. Investor IRR (assuming 2033 exit) [Min/Max]	Avg. Lifetime IRR [Min/Max]
Base case				
Investor projections *28 years expected operational life with planned exit in 2033.*	NA	Sell on for yield-based returns to institutional investor with desired IRR of 5.5%	10.77% TV: €10.1 Mn	7.85%
Climate Case				
1 SSP 245 – Chronic heat stress	↓ Revenue Span: operational life	Chronic efficiency loss *Average impact: -0.8%* *Max impact period: -2.2%*	10.48% [10.37% / 10.59%]	7.71% [7.66% / 7.77%]
2 SSP 585 – Chronic heat stress	↓ Revenue Span: operational life	Chronic efficiency loss *Average impact: -0.9%* *Max impact period: -3.3%*	10.43% [10.30% / 10.60%]	7.69% [7.62% / 7.77%]
3 Severe hail event in H1 2026 *(5cm+ hailstones)*	↓ Revenue ↑ Opex, Capex Span: 8 years	Recovery investment - New debt funding (CoC = 5%) *No recovery*	8.44% *-0.56%*	6.64% *2.56%*
Resilience Case				
1 Misting system + SSP 585 *+ SSP 245*	↑ 7% PV efficiency ↑ 5-7% Capex, 1% Opex	Investment funded at 5% Cost of Capital	10.68% [10.47% / 10.91%] *10.72%* *[10.54% / 10.91%]*	7.77% [7.66% / 7.89%] *7.79%* *[7.69% / 7.89%]*
2 Polymer Coating + SSP 585 *+ SSP 245*	↑ 3% PV efficiency ↑ 1-2% Capex	Investment funded at 5% Cost of Capital	10.80% [10.60% / 11.04%] *10.76%* *[10.60% / 10.96%]*	7.86% [7.76% / 7.99%] *7.84%* *[7.76% / 7.95%]*
3 PMMA coating	↓ 18% Impacted units ↑ 1-2% Capex	Severe hail event in H1 2026 + Debt financed recovery	8.43-8.45%	6.64-6.65%
4 Leno woven hail netting	↓ 82% Impacted units ↑ 5-6% Capex	Severe hail event in H1 2026 + Debt financed recovery	9.91-9.98%	7.39-7.43%

Figure 3: Resilience investment mitigates heat stress effects and increases performance
Deviation from expected equity distributions over time under climate scenario SSP 5-85 (€ k)

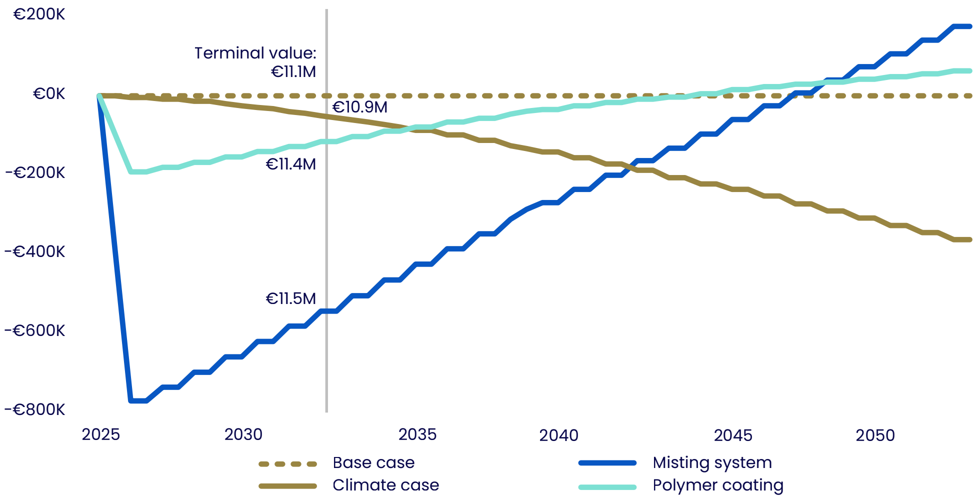
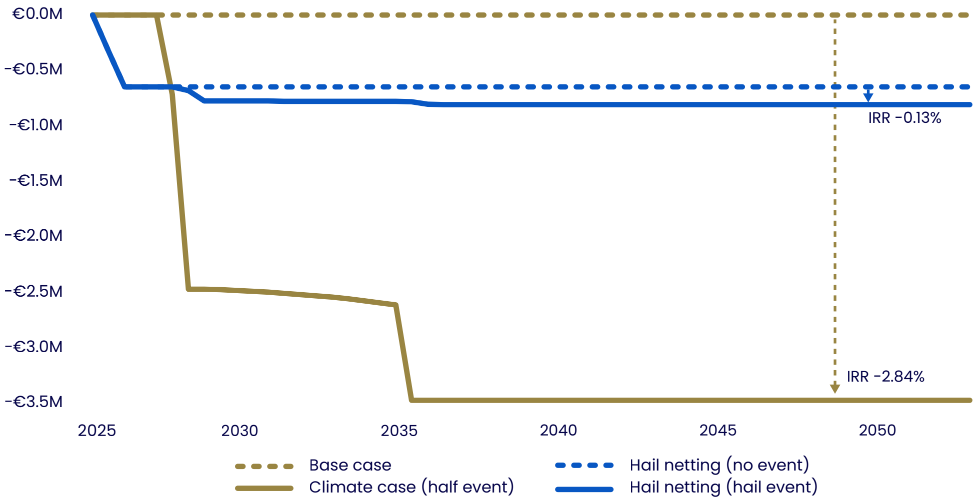


Figure 4: Resilience investment reduces the downside impact to IRR from severe hail storms
Deviation from expected equity distributions for a hail storm occuring in 2028 (€ Mn)



Decision Gate D

How can resilience investment be optimised and incentivised, while ensuring equitable risk-reward distribution across the value chain?

Steps	1 Scoping and data gathering	2 Materiality assessment	3 Resilience building	4 Value enhancement
Objective	Determine data sufficiency	Assessing asset vulnerability	Identifying adaption options	Optimised resilience with residual risk transfer
Sub-tasks	→ Project initiation → Project definition → Data gathering and sufficiency	→ Hazard scenarios → Impact pathways → Financial sensitivities (return & debt) → Distinguish acute damage vs. chronic performance efficiency	Adaption options, costs and availability: → Hard (Structural/Capex) → Soft (Operational/ Systems)	→ Identify resilience metrics → IRR comparisons → Insurability and credit quality
Outputs	→ Initial climate study → Critical asset and system components → KPI selection, risk appetite → Base Case cashflow forecast	→ Detailed climate study → Quantified list of impacts and severity by component → Climate Case(s) cashflow forecast	→ Repeat materiality assessment → Cost/benefit for suitable measures → Adaptive pathways → Resilience Case(s) cashflow forecast	→ Investment case narrative → Value implications across investment value chain actors e.g. investors, lenders, insurers
Decision gates	**Gate A** What are the scope boundaries and data sufficiency according to the investment strategy?	**Gate B** Are PCRs material for the asset(s)? Reviewing asset KPIs, what factors influence the materiality?	**Gate C** What are the most effective adaption options for this asset, the optimal timing for their implementation, and the responsible parties for funding and execution?	**Gate D** How can resilience investment be optimised and incentivised, while ensuring equitable risk-reward distribution across the value chain actors?

Value implications: The analysis presented above shows that resilience measures will add value to the projects (by enhancing the cash flow profile) in comparison with the "Climate Case" (i.e. the case where additional climate risk materialises). However, in the case of an investor that has an investment period that is shorter than the operational life of the asset, for added value to be fully recognised, the investor needs to be able to exit the asset at the end of its own investment period to a buyer that would recognise this value added.

If the buyer looks at the "Climate Case", the value of the resilience measure should be recognised, however, given the resilience measures don't always add value compared to the "Business As Usual Case" (i.e. case where additional extreme climate event triggered by climate change are not considered), then, with a buyer that looks exclusively at the "Business As Usual Case", the value-added of these mitigation measures may not be recognised, and therefore, the exit price may not be enhanced by the implementation of these resilience measures.

In such a scenario, for the investor to consider the resilience measures, the value added needs to compensate the cost of the measure over the course of its investment period (i.e. short to medium term), which is unlikely, given these measures are generally put in place for events happening over the medium to long term. Therefore, it means that it is important that a wide range of investors recognise the value of such measures, i.e. considering the "Climate Case" and the "Resilience Case". This value recognition can be boosted if the resilience measure triggers additional benefits for the project, which are widely recognised as value added (e.g., the project could become easier to insure, and at better terms, or lenders could recognise the resilience of the project by offering more favourable lending terms).

Resilience measures may imply a reduction of the originally expected return: In most cases, the resilience case generates a lower return than the original case. This may lead the investor deciding not to implement the risk resilience measures, unless this reduction in the return is compensated for by the projects being exposed to a lower risk. For example, many renewable energy investors decide to enter into a fixed price PPA that offers a lower price than the market, but in exchange, reduces the volatility of the revenue. For the effective management of climate risk, investors should therefore see this "cost" in economic returns as a way to reduce their climate risk exposure. However, this means that, the **investors need to consider climate risk as part of their risk assessment.**

Adjusting discount rates is about reflecting the risk - resilience metrics and the cost of capital: Investors can accept lower returns on the basis of many factors. Typically, if the project becomes more robust to stress and sensitivity tests than another project, it is legitimate for the former to generate a lower return than the latter. Similarly, the cost of capital allocated to a specific project can be lowered if the risk perceived by the investor is lower – for example, if the project becomes more resilient to severe hail events.

Therefore, **a metric that should be highlighted is the risk-adjusted return rather than the return in absolute terms.** The risk-adjusted returns would show if the short-term harm made to the return by the resilience measure in question is sufficiently compensated through a reduction of the climate risk. This would typically be reflected in the Net Asset Value ("NAV") calculated by the investor. Indeed, **if the investor can allocate a lower cost of capital to a resilient project, this would imply it could use a lower discount rate to calculate the NAV, and therefore, the project post-implementation of the resilience measure should recognise a NAV gain, which should at least compensate for the costs of the implemented measure.** If this is the case, then the risk-adjusted return of the resilient project can be considered better than the non-resilient project.

It is worth nuancing this approach by stressing that **most investors still don't have the tools to assess the reduction in cost of equity (and, as a consequence, the magnitude of the reduction of the NAV discount rate) that can be expected for a given resilience measure.**

Therefore, it makes the assessment of the risk-adjusted return more complicated. Also, some investors may not be allocating any weight to the extra climate risk induced by climate change; therefore, these investors will not recognise any value to the resilience measures, because the risk these measures are reducing is not part of their risk assessment.

Avoiding double counting: Adjusting the cost of equity with a premium reflecting the climate risk is a way to recognise this risk as part of the valuation process of an investment. However, another strategy consists of applying a discount to the expected future cash flows to reflect the impact of a climate risk-induced event (i.e. the Climate Case described above). If the climate risk is embedded in the future cash flows, then it should not represent any risk, in the assessment of the cost of equity.

To illustrate this, if a project assumes a P99 production profile, the meteorological risk posed by lower irradiance or wind should not be factored anymore in the cost of equity. However, the impact on future cash flows of acute events can't be assessed (other than in a stress test case).

Therefore, acute climate risk should remain accounted for in the cost of equity. The chronic risk, on the other hand, can either be reflected in the cash flow profile, or in the cost of equity – as the cash flow profile can more easily reflect the impact of chronic risk (e.g., lower estimated production). Therefore, chronic risk poses the risk of double-counting, if included in both the cost of equity and the cash flow profile estimate.

This double-counting risk should be kept in mind when incorporating climate risk into a risk assessment, as it poses the threat of overestimating the risk represented by chronic climatic events, or the positive impact of a resilience measure.

Lessons learned

In applying the PCRAM to this case study, the following lessons have been learned:

- The data collection process during the scoping phase of PCRAM can be time-consuming and involve multiple stakeholders. To streamline this process, a data collection tracker could be used to identify the necessary data points based on their respective stages of analysis. By categorising these data points according to their relevance and importance for the PCRAM stages, project teams can prioritise gathering the most critical information first, ensuring full transparency on the readiness of each data point.
- Project team structure is crucial for the smooth implementation of the PCRAM. Identifying the roles and stakeholders across the teams and organisations is key to establishing clear lines of communication and responsibility. This collaboration ensures that the climate science, risk engineering and finance workstreams are aligned, enabling efficient data collection, analysis and decision-making throughout the project lifecycle.
- The hazard assessment process identified hazards and climate-linked weather patterns that could present material risk to the investment but were not included in the assessment due to a lack of climate modelling availability. Solar irradiance directly impacts solar generation, but modelling advances are needed to generate credible investment impact results.
- Renewable assets may be funded by complex structures at the senior debt level, and the risk of default or triggering debt covenants depends on the exposure of the overall loan to the assessed investment.
- Integrating investor-side debt & return sensitivity tests into the scoping or materiality phase allows hazard screening processes to accurately account for necessary levels of loss to create material impacts to an investment.
- The decision for resilience building is assuming that future buyers will recognise the value.
- Regulatory considerations for resilience in Italy might evolve in the context of a new public-private reinsurance entity guaranteeing insurability.

Limitations and caveats

Climate modelling assumptions

Extreme hail hazard is modelled as a static hazard over 30-year intervals, with 2051 – 2070 not available from our data source. Hail is modelled as a function of multiple climate variables; therefore, trends in hail risk carry large uncertainties, especially given limited direct measurements of hail.

Changes in solar radiation from decreases in cloud cover over Northern Italy may offset these changes in many climate scenarios, with a projected increase in solar irradiance of 6%. Due to the large interannual variability in cloud cover effects, solar power efficiency change is based largely on robust temperature increases.

The overall percentage of the asset impacted by a hailstorm is also dependent on the storm's size and the area occupied by the asset. The most extreme hailstorm events are generally associated with larger damage footprints.

Engineering assumptions

The impact of physical climate risk on the asset is assessed through a combination of theoretical modelling and validation with real-world data. The theoretical approach is taken where parameters cannot be accounted for. For example, the varying tensile strength of the solar panel glass and previous imperfections could not be modelled. This led to making informed assumptions to obtain damage thresholds.

The main limitation in identifying resilience measures for hail and heat stress on solar panels was the difficulty in obtaining reliable cost estimates due to the limited maturity and adoption of their implementation and assessing their actual real-world impact on reducing damage and/or vulnerability thresholds.

Financial assumptions

Quantifying the financial cost-benefits of implementing vegetation as a nature-based resilience measure is challenging because the effectiveness of vegetation in mitigating climate-related risks can vary based on location, plant species, and environmental conditions. This variability makes it difficult to create a standardised financial model.

Glossary

Climate projection	The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases (GHGs) and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, e.g. future socioeconomic and technological developments that may or may not be realised (IPCC 2018[3]).
CMIP	CMIP aims to improve understanding of the Earth's climate system, including processes like atmospheric interactions, ocean dynamics, land surface, cryosphere, and biosphere. The resulting data is crucial for the Intergovernmental Panel on Climate Change (IPCC) and other climate assessments, informing policy and mitigation strategies.
CORDEX	Coordinated Regional climate Downscaling Experiment. A framework under the World Climate Research Programme (WCRP) of the World Meteorological Organization (WMO) that coordinates activities for regional climate model downscaling.
Climate base cases	Base case evaluations are a part of scenario analysis, which helps decision-makers visualise and compare the most realistic outcomes for a business. With foresight into all possible outcomes, an organisation can greatly improve its financial planning and modelling, allowing management to make decisions with confidence.
GWh/year	Gigawatt hours per year (a measure of power).
Internal Rate of Return (IRR)	A metric used in financial analysis to estimate the profitability of potential investments. Annual return that makes the net present value (NPV) equal to zero or is the annual rate of growth that an investment is expected to generate.
Resilience measures	Physical or hard modifications in order to alleviate the impacts of climate change.
SCS	Severe convective storms characterised by significant weather hazards such as heavy precipitation, strong (gusty) winds, lightning, large hail, and potentially tornadoes.

3 IPCC (2018). Annex I: Glossary. In: Global Warming of 1.5°C. Available at: https://www.ipcc.ch/sr15/chapter/glossary/

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