IIGCC

PCRAM case study

Solar plants portfolio analysis: Europe

octopus energy generation

HOWDEN

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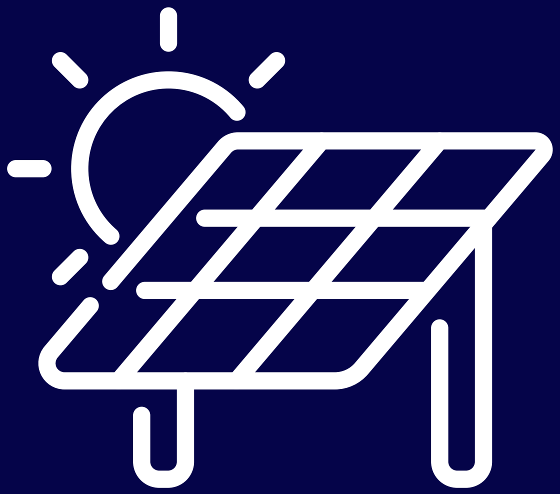
Status: This analysis was undertaken as a pilot to test and explore the methodology. The outputs are illustrative only and derived from simplified financial modelling based on a number of high-level assumptions; they have not been audited, assured, or independently verified, and do not constitute a full risk assessment. The purpose of this work is to support methodological development and to prompt discussion, rather than to provide definitive financial or risk analysis.

Investment overview



Impact fund focused on providing investors with long-term returns from a diversified portfolio of over 40 renewable energy assets. The case study assesses a portfolio of operational ground mounted solar assets across central and southern Europe, with a total capacity of over 100MW. To align with the investment objective, the assets' availability and lifetimes should be maximised, as such retrofitting is favoured.

Asset objectives

- 27 years average lifetime remaining
- c.170 GWh/year potential annual energy generation.

Estimated project impact

- 20.7k carbon emissions avoided
- 29.2k equivalent homes powered

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

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 adaptation 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	Adaptation 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 adaptation 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 & b) Project initiation and definition

This case study applies to a solar portfolio owned by an investment fund. The fund's investment objective is to provide investors with an attractive and sustainable level of income returns through investing in a diversified portfolio of renewable energy assets in Europe. At present, the portfolio comprises over 40 assets with a total capacity of over 800MW across several European countries. Technologies include onshore and offshore wind, ground mounted solar, and battery storage.

The solar portfolio that is the focus of this case study comprises several operational ground mount solar projects in central and southern Europe, with capacities ranging from 5-12MW, and a total combined capacity of over 100MW. The first project became operational in 2013 and the average remaining lifetime for the projects is 27 years. The fund acquired 100% interest in the portfolio when it was already operational.

Step 1 c) Data gathering

In preparation for the data gathering exercise, two specialised sub-groups were formed.

The engineering and climate science group were established to undertake an initial climate study assessment. The ESG, financial risk, and valuation group aimed to define the financial materiality of how asset-level impacts could scale up to portfolio-level financial risks, including implications for revenue, debt servicing, and investor returns.

A review of key performance indicators (KPIs) across construction, operational, financial and commercial dimensions was undertaken to establish a baseline for the portfolio. This baseline reflected the current asset conditions and served as the reference point for further risk and impact analysis.

The preliminary climate risk assessment identified both acute and chronic risk exposure:

- **Acute:** Severe convective storms (specifically hail and wind damage).
- **Chronic:** Heat-related risks driven by increased temperature (affecting asset operation, energy yield and asset structure cabling).

Decision Gate A

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

The scoping process aligns with the fund's strategy of maximising operational yield and long-term asset value.

Sufficient technical, operational, and financial data were available from post-acquisition due diligence to define a current baseline and support climate risk analysis. While construction-stage documentation was limited due to the fund acquiring the assets when they were already operational, this was not deemed material to the physical risk pathways being assessed. This finding showed that the stage of the investment process influences the kind of information that can be accessed and used for appraisal.

To streamline data gathering process, a data tracker is recommended, outlining priority data points, owners and source documents based on investment phase (see lessons learnt section for an open-source data request tracker).

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Step 2: Materiality assessment

The materiality assessment was conducted at portfolio level, evaluating whether asset-level damage thresholds and projected financial impacts from physical climate risks could lead to breaching of the financial materiality thresholds when aggregated across the portfolio level.

Two climate risks were deemed to be the most material and assessed in detail:

- Severe Convective Storm (SCS), with a focus on hail damage
- Heat stress

Step 2a) Hazard scenarios

Table 1: Table of climate hazards screened according to the EU Taxonomy – with a justification for selection

	Temperature-related	Wind-related	Water-related	Solid mass-related
Chronic	**Heat stress** – robust increase in hazard			
	Solar variability – no robust climate trend		**Precipitation** – low vulnerability profile, no robust hazard trend	
Acute		**Severe Convective Storm (SCS)** – robust increase in hazard, to include in future appraisal	**Severe Convective Storm (SCS)** – robust increase in hazard	
	Cold wave / freeze-thaw cycle – reducing risk	**Extratropical storm** – no robust climate trend	**Heavy precipitation** – increase in extremes likely, but low vulnerability	**Landslide** – literature review, requires detailed analytical assessment
	Wildfire – low risk at asset sites	**SCS tornado** – limited data/ robust model. No viable resilience measure	**Flood (fluvial, pluvial)** – others not of relevance	

Based on the EU Taxonomy, the table above shows which climate hazards were selected for hazard scenario modelling (orange), and those deemed non-material (green).

Precipitation stress (chronic): No robust trend was found in precipitation stress from changes in the frequency and/or changes to variability in precipitation (CMIP5/CORDEX) in southern Europe. However, **heavy precipitation (acute)** is likely to increase in line with large hail. Water ingress can degrade the solar power output through delamination and corrosion.

Drought (chronic): Drought in contrast is expected to see a robust increase in severity toward the end of the 21st century (in almost all climate projection models). While there are limited direct impacts to solar PV modules, indirect effects may include dislodgement of support structures and local soil instability exposing the installation 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 studied, and are on a downward climate trend, however acute events from changing regional circulation patterns cannot be ruled out in some more extreme climate scenarios. The overall risk posed to solar assets is generally expected to decrease.

Heat wave (acute): In terms of workforce-related heat wave events (acute heat stress), we used a reference 90th centile for the period 1981 - 2010. The number of these hot days is likely to increase from 14 days (near-term) to 27 days (mid-century) in the moderate emissions scenario, representing a 2.8 to 5.4-fold increase. For the high emissions scenario this increased to around 15 days (near-term) and 38 days (mid-century), 3 to 7.8 times more likely.

Wildfire (acute): The 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 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 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 was considered to be of low material impact assuming regular maintenance and cleaning.

Storm (acute): Storm was classified into two main types. Extratropical storm events show no robust trend across southern Europe (historical trend analysis and CMIP models), the European Severe Weather Database shows a notable increase in the intensity of meso-scale storms linked to hail damage reports. Increasing hailstorm risk in southern Europe is supported by climate models.

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).

Step 2b) Impact thresholds for assets

The following physical risks were selected to be modelled for impact thresholds due to their hazard exposure and financial vulnerability impact:

Hail: Estimated increase in extreme hail frequencies (>5 cm) range from -15 to 61%, representing a mid-term return period of 14 to 20 years (13 to 18 years by late century). For large hail (2 to 5 cm) which can result in degradation to performance from panel micro-cracks and fractures, likelihoods are expected to increase by up to 12.5% (19 to 55%), with a return period of 2 to 4 years in the near-term climate. This represents a material risk, with evidence of a marked increase in hailstorm frequency. Extreme hail events are likely to increase by around 17% by mid-century. Furthermore, for the high-emissions scenario the risk is typically 8 to 15% higher than for the moderate emissions scenarios by late century.

Wind: Extreme winds associated with severe convective storms have potential to cause structural damage to the solar module glass through flexing, leading to cracks or failure. Debris and high winds could also dislodge mountings. SCS wind events coincide with damage from extreme hail, a consideration for implementing adaptation options such as hail nets. We found that extreme wind speeds associated with these localised storm events are likely to occur typically once every 14 years, with the return period increasing to 12 years in the near-term period and 8 to 12 years by late century. SCS wind is expected to cause material increases in asset losses.

Heat stress: Asset heat stress (where solar PV module temperatures exceed 25°C) are currently 132 to 145 days annually. This heat hazard is expected to increase 4 to 11% across 9 models in a high emissions scenario in the near-term. Cloud cover variability accounts for much of this uncertainty, with robust air temperature increases. Asset heat stress risk linked to reduced solar performance is expected to undergo further increases of up to 20% by the mid-term. Frequency of heat stress in the moderate and high emissions scenarios are comparable for the near-term, but vary considerably by mid-century.

Solar assets were considered most vulnerable to the impacts of hail and heat stress; with wind damage reviewed post-analysis as a secondary climate hazard of interest.

Due to the high impact threshold for wind damage to solar in southern Europe, extreme gusts are more likely to result from SCS events that pose a modelling challenge. Mitigation measures for wind include the installation of tracking systems to dynamically stow. Other hazards were deemed out of scope for this case study either because they were considered low risk, or involved more extensive modelling approaches.

Step 2c) Hazard scenarios

Two future climate scenarios were considered for the analysis. These were SSP2-4.5 and SSP5-8.5, mapping with the investment cycle, the asset lifespan and the physical risk long term estimates.

The most up-to-date climate models from CMIP6 were used where available, otherwise CMIP5.

Historic data was also considered to understand how future risk may evolve. 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 depending on the hazard.

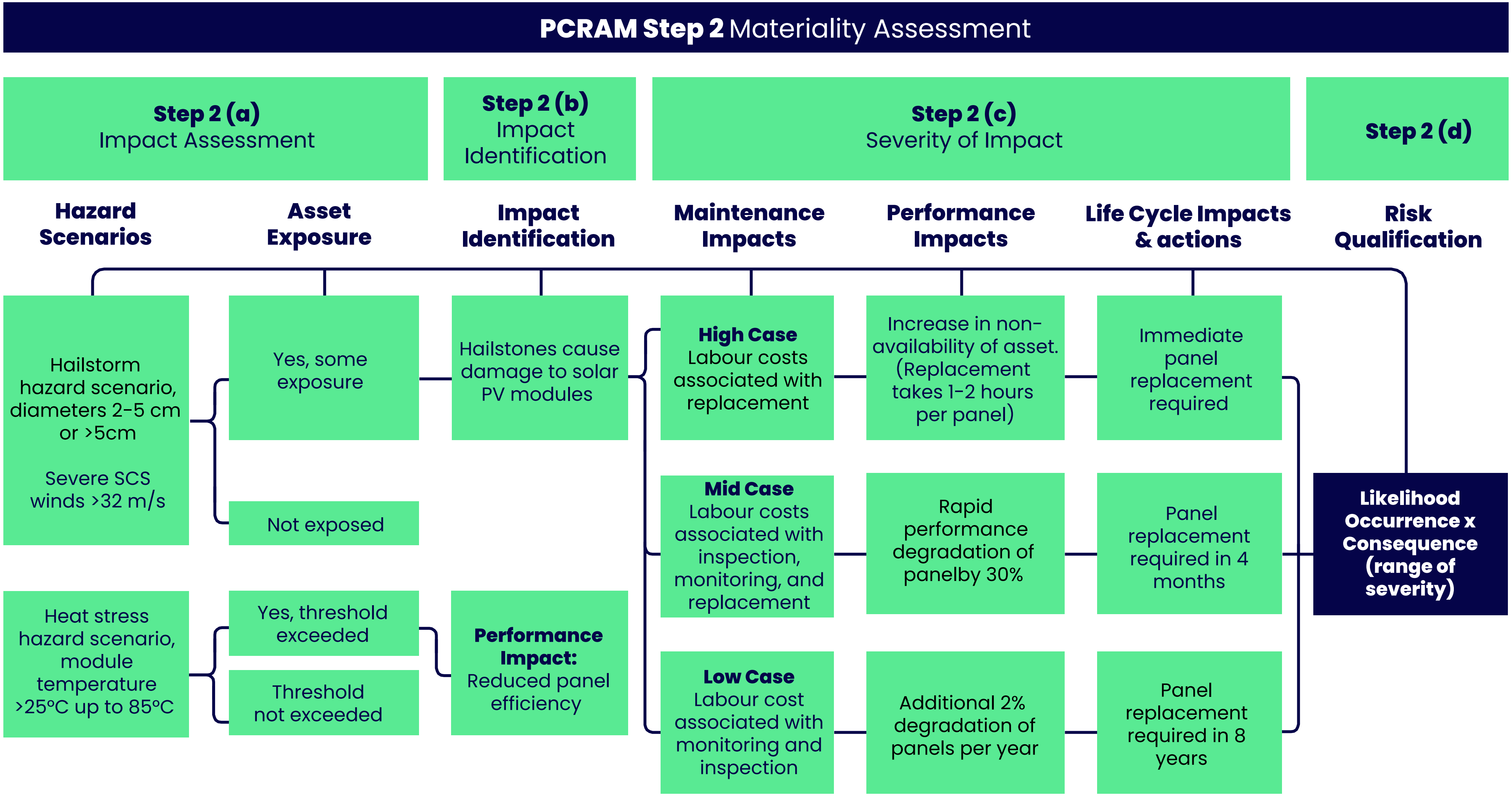
The daily and highest resolution inputs available were used: 50 km (for SCS hail and wind) and 25 km (heat stress).

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 guarantees over the modules' lifespan. When performance drops below 80% it triggers the replacement of the module.

Figure 1: Summary of analysis undertaken



Financial stakeholder considerations in materiality assessment

- In practice, when a climate-induced physical risk materialises, causing damage to the plant(s), thecourse of action is determined based on multiple factors and stakeholders. Typically, most acute events will be covered by the insurance policy of the plant, 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 addressed.
- 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 warranty applies, this also leads to an 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 either by the warranty or the insurance (e.g., below the deductible or outside of the warranty period), are tackled in coordination with the Operations & Maintenance (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 an important stakeholder 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 may be materiality thresholds 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.

Step 2d) Quantify impacts on KPIs

Financial materiality and stress testing:

To quantify the financial implications of this risk at the asset level, it is essential to contextualise the findings at the portfolio level.

Physical climate risks could be material if costs incurred from damage or performance impacts significantly hamper the ability of the fund to generate revenue or service its debt obligations. The investor's long-term infrastructure fund is comprised principally of renewable energy investments located throughout western and northern Europe. Around 15% of this fund is invested in a portfolio of solar assets in Europe.

In order to understand the relevance of a climate-related hazard to the investment, the following must be assessed: the maximum possible impact of the occurrence of a severe weather event at a single site and the possible influence of that event on the cash flows available for debt service (CFADS), as well as the impact of reduced performance of the sites, individually and in aggregate, on CFADS and on its ability to provide sufficient distributions to equity holders.

Debt sensitivities

Funding for the portfolio of solar projects is aggregated under a single senior loan, with repayments drawn from the collective income of all sites. Impacts to operating income at each site come in the form of reduced revenues or increased maintenance and repair expenses. This affects available cash flows to be contributed to service the holding company's debt. This debt has a covenant linked to a CFADs level over a rolling 12-month period. A reduction in CFADs below the covenant triggers an equity lockup, during which the portfolio would be unable to designate any of its profits for payments to its investors.

The risk of operating income shortfalls is reduced over time because debt payments for this portfolio are structured to decrease through the term of the loan. This lowers the pressure of the debt service cover ratio (DSCR) as the materiality of climate risks is projected to increase. Over 2024, a relatively low 12-months revenue shortfall of €669k would have triggered the debt covenant. However, by 2029, the required annual shortfall to trigger the covenant will Increase to €2.90 M.

Return sensitivities

The aggregated construction of the solar portfolio dilutes the effects from single site impacts on returns, as measured by the internal rate of return (or IRR). One specific site had an estimated value of €17.9M in 2024, and a capacity of 10.4 MW, making up 8.7% of the overall solar portfolio. A complete shutdown of the site would result in an average CFADS reduction of €229k annually. This maximum impact would not result in triggering the debt covenant in any of the operational periods. However, it would result in less free cash flow after debt service that is available to distribute to shareholders. On average, this reduction would result in an overall IRR decrease of 1.31% for the portfolio. Typically, a severe weather event at one site would have a smaller impact to overall investment performance, especially for the aggregated portfolio, but a regional, severe weather event or a season with multiple severe events could impact several sites within the solar portfolio and lead to a higher risk of underperformance.

Decision Gate B

Are physical climate risks material for the assets? Reviewing asset KPIs, what factors influence the materiality?

The material physical climate risks selected for assessment were hail (severe convective storm) - acute risk and heat stress - chronic risk.

The case study team identified the cost drivers (sensitivities) based on the identified impact pathways. By running financial sensitivities, we track the transmission channels back through the fund structure and identify what level of impact becomes material to the investment for each hazard. From the various projects in the solar portfolio, one specific site was selected to analyse for resilience building based on its location, relative size and track record of reliability.

	1	2	3	4
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Step 3: Resilience building

Step 3a) Identify adaptation options

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 2).

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 2 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, thisnecessitates 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 inbuilding 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, particularly in agricultural settings, by allowing for dual-use of the land for both energy production and agricultural activities.

Table 2: Adaptation options identified for hail and heat stress

Adaption options	Cost	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
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
3 Panel angle adjustment with / without tracking system	N/A	Monitoring and controlling systems track hail motion and rotate and tilt panels away from incoming hail to reduce impact.	▪ Reduction in downtime ▪ Reduction in O&M costs ▪ Decrease likelihood of incurring replacement costs
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)

Decision Gate C

What are the most effective resilience options for this asset?

Adaptation options were identified; however, further consideration of market maturity conditions at a utility scale for solar panels is required, i.e. large-scale projects, typically in the energy sector, designed to generate significant amounts of electricity (megawatts or gigawatts) for distribution to the wider electrical grid, serving entire communities or regions.

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Step 4: Value enhancement assessment

Modelled financial impacts:

The investor's modelled projections were integrated into a consolidated statement project finance view which models climate and resilience modifications to cash flows and capital investment using standard accounting principles. Opex and revenue impacts modify operating income directly. This, in turn, affects available free cash flows which are consolidated at the holding company level for use toward debt service and shareholder repayments and distributions.

Unexpected capital investment requirements or resilience measure costs are assumed to be funded by shareholder loan drawdown.

Hail: The financial repercussions of hail events include a combination of impacts across maintenance, performance, and asset life-cycle expectations. These categorical effects are linked to increased Opex, decreased revenue, and unexpected Capex, respectively. Analysed hail events ranged in severity and coverage across the site, impacting between 24.8k–33.1k PV modules (60%-80% of total panels on the site), and requiring immediate or eventual replacement over an 8-year period. The effects of an individual event will likely result in limited investment performance impacts or valuation reductions.

Figure 2:

Modelled hail events			
Severity case; Units impacted	Mid Coverage Mid Severity 24,797 units	High Coverage Mid Severity 33,062 units	Mid Coverage High Severity 24,797 units
Capex	€ 1,314,241	€ 1,752,286	€ 1,314,241
Opex	€ 413,718	€ 546,651	€ 652,317
Lost revenue (% annual revenue)	9.49%	12.15%	4.67%
Occurrence Pd.	**Impact (SSP 585) to 2025 valuation**		
Q2 2026	- € 1.78 M	- € 2.19 M	- € 1.77 M
Q2 3032	- € 0.97 M	- € 1.58 M	- € 1.27 M
Q2 2040	- € 0.94 M	- € 1.08 M	- € 0.94 M

Mitigation of these impacts through adaptation optionsresults in a redistribution of damage levels and/or a reduction in the number of affected PV modules across the site in the occurrence of an extreme hail event. However, the occurrence of extreme hail events is not correlated with investment into adaptation options, so the resulting loss mitigation is measured with a comparison of scenarios with, and without, extreme hail events. As seen in Figure 2, investment into adaptation options necessarily incurs a reduction to the investment performance, but in the case that a severe climate event does occur, these installations create significant savings over the non-resilient case.

Heat stress: Over the operational life of the solar asset, the prevalence and materiality of heat stress is predicted to rise in the location of this solar site, with increases in high temperatures resulting in an average decrease in power generation of 0.9% (SSP 585). Efficiency losses directly impact revenue potential for this site, and similar effects are expected to the other portfolio sites. A reduction of income potential at this site results in an average modelled valuation drop of ~€170k (SSP585). Across the solar portfolio, a similar severity to the analysed site would result in an average annual reduction in CFADs of €0.14 M for the holding company. This will not create significant pressure on the current debt covenant expectations but would greatly increase the risk of material financial impacts from any compounding climate event.

Figure 3: 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)

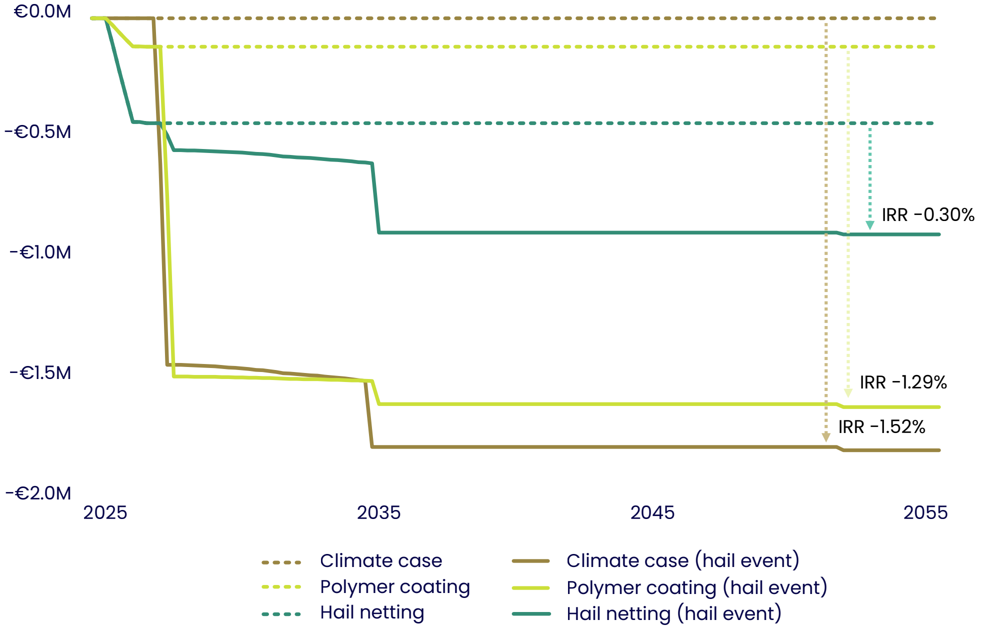
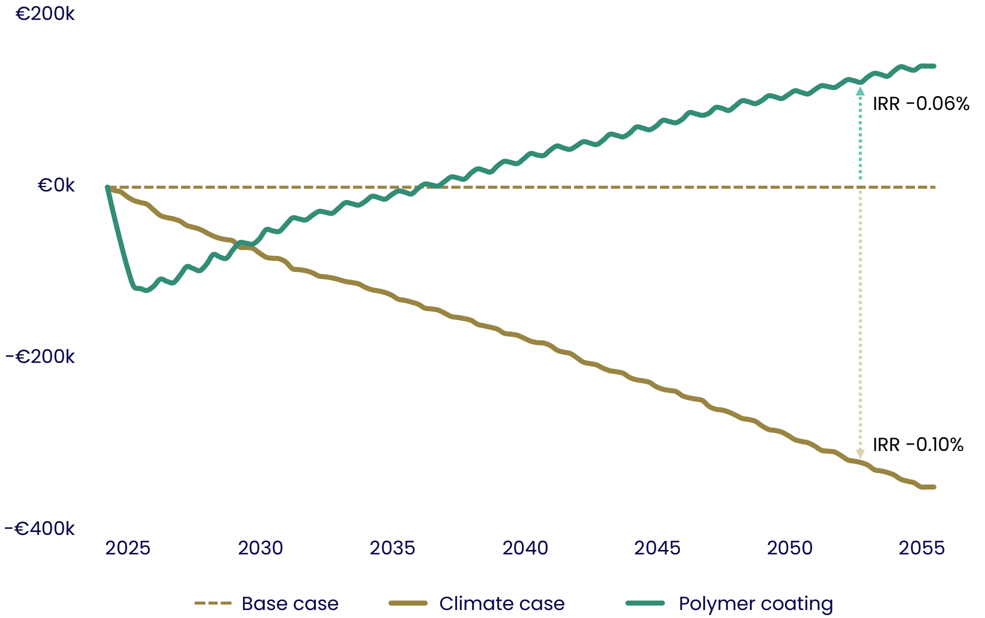


Figure 4: Resilience investment increases performance and preserves value against heat stress
Deviation from expected accumulated revenue over time under climate scenario SSP 2-45 (€ k)



The recommended adaptation options are designed to reduce the vulnerability of the asset, thereby lowering its overall risk profile. By implementing the adaptation options, the asset becomes more robust, and the financial implications of insuring it become more manageable. This reduction in risk can have implications on the cost and availability of insurance.

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.

Additionally, parametric insurance products, which use 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 adaptation options such as panel tilt angles.

Table 3:

Investment scenario		Impacts	Description	IRR* Modelled range	NPV* @5.0%
Base case					
Investor projections *30-yr expected operational life.*		N/A	Investors to hold solar site in perpetual renewables fund, generating revenue into 2055	5.80%	€ 1.43 M
Climate Case					
1 Chronic heat stress	**SSP 2-45**	↓ Reduced revenue profile	Chronic performance degradation	5.67% – 5.72%	€ 1.25 M
2 Chronic heat stress	**SSP 5-85**			5.65% – 5.73%	€ 1.24 M
Resilience Case					
1 Misting system	**SSP 2-45**	↑ 7% PV efficiency ↓ 5-7% Capex, 1% Opex	Resilience measures reduce solar panel surface temperatures, improving performance Modelled investment via shareholder loan	5.45% - 5.67%	€ 1.39 M – € 1.63 M
	SSP 5-85			5.44% - 5.68%	€ 1.35 M – € 1.65 M
2 Polymer Coating	**SSP 2-45**	↑ 3% PV efficiency ↓ 1-2% Capex		5.67% - 5.81%	€ 1.36 M – € 1.54 M
	SSP 5-85			5.65% - 5.82%	€ 1.33 M – € 1.55 M

*projected IRR, NPV calculated using adjusted revenues including investment and operational impacts.

Decision Gate D

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

This case study hopes to contribute to establishing a foundational framework for choosing resilience options based on the optimum threshold of residual risk transfer to insurance. Presenting PCRAM results to an investment committee sparks a crucial conversation on how best to manage and share the risk and rewards of physical climate risks and resilience investment, which benefits investors, insurers and lenders.

	1	2	3	4
Steps	**Scoping and data gathering**	**Materiality assessment**	**Resilience building**	**Value enhancement**
Objective	Determine data sufficiency	Assessing asset vulnerability	Identifying adaptation 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	Adaptation 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 adaptation 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?

Lessons learned

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

- Data collection: during the scoping phase can be time-consuming and involve multiple stakeholders. To streamline this process, a data collection tracker should be used to identify the necessary data points by stage of analysis. Categorizing data points by relevance and importance to the PCRAM stages allows project teams to prioritise the most critical information and maintain clear visibility on data readiness.
- Project team structure is crucial for smooth implementation. 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 the project lifecycle.
- The hazard screening process identified hazards and climate-linked weather patterns which could present material risk to the investment but were not included in the assessment due to a lack of climate modelling availability. For example, solar irradiance directly impacts solar generation but modelling advances are needed to generate credible investment impact results.
- Complex financing structures at the senior debt level can obscure the financial materiality of climate risks. Financially material risks often manifest through potential defaults or the triggering of debt covenants. The extent of this exposure depends on how much of the overall loan is linked to the specific asset under appraisal.

Limitations and caveats

Climate modelling assumptions

Trends in hail risk carry large uncertainties, especially given limited direct measurements of hail. 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.

Changes in solar radiation from decreases in cloud cover over Northern Italy may be offset 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 dependant on the storm's size and the area occupied by the asset.

The overall percentage of the asset impacted by a hailstorm is also dependant 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 modeling 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 adaptation options for hail and heat stress on solar panels was the difficulty in obtaining reliable cost estimates. This is due to their limited maturity and adoption of implementation. Another limitation was 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[1]).
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.
CMIP	Coupled Model Intercomparison Project. A collaborative effort within the World Climate Research Programme (WCRP) aimed at advancing our understanding of climate change.
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.
GWh/year	Gigawatt hours per year (a measure of power).
SCS	Severe convective storms characterised by significant weather hazards such as heavy precipitation, strong (gusty) winds, lightning, large hail, and potentially tornadoes.
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.
Shared socioeconomic pathways (SSPs)	These scenarios were developed to complement the RCPs by varying socio-economic challenges to adaptation and mitigation (Kriegler et al., 2012; O'Neill et al., 2014). Based on five narratives, the SSPs describe alternative socio-economic futures in the absence of climate policy intervention, comprising sustainable development (SSP1), regional rivalry (SSP3), inequality (SSP4), fossil-fueled development (SSP5) and middle-of-the-road development (SSP2) (O'Neill et al., 2017; Riahi, Vuuren, et al., 2017). The combination of SSP-based socio-economic scenarios and Representative Concentration Pathway (RCP)-based climate projections provide an integrative frame for climate impact and policy analysis.

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

IIGCC

77 Kingsway
London
WC2B 6SR

info@iigcc.org

www.iigcc.org

octopus energy generation

HOWDEN