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INSURANCE FOR A BETTER WORLD

BRINGING CLIMATE TECH TO MARKET:

The powerful role of insurance

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The Geneva Association

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ABBREVIATIONS

ARL	Adoption Readiness Level
BCP	Business Continuity Plan
BI	Business Interruption
CBAM	Carbon Border Adjustment Mechanism
CCM	Compliance Carbon Market
CCUS	Carbon Capture, Utilisation & Storage
CDR	Carbon Dioxide Removal
D&O	Directors & Officers
DAC	Direct Air Capture
DACS	Direct Air Capture and Storage
DoE	Department of Energy
DSU	Delay in Start Up
EAR	Erection All Risk
EPC	Engineering, Procurement & Construction
ESG	Environmental, Social &Governance
FID	Final Investment Decision
FOAK	First-of-a-Kind
GA	The Geneva Association
GHG	Greenhouse Gas
HAZOP	Hazard & Operability
IE	Independent Engineering
IRF	Insurability Readiness Framework
LD	Liquidated Damage
LDES	Long Duration Energy Storage
MGA	Managing General Agent
MPL	Maximum Possible Loss
MRV	Measurement, Reporting & Verification
Mt p.a.	Million Tonnes Per Annum
Nat Cat	Natural Catastrophe
NOAK	Nth-of-a-Kind
O&M	Operation & Maintenance
OAR	Operation All Risk
OEM	Original Equipment Manufacturer
P&C	Property & Casualty
PAC	Provisional Acceptance Certification
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
QA	Quality Assurance
QC	Quality Control
SAF	Sustainable Aviation Fuel
SMR	Small Modular Reactor
TRL	Technology Readiness Level
VCM	Voluntary Carbon Market

Executive summary

Innovative risk management measures and insurance solutions will be key to unlocking the potential of climate technologies.

Accelerating the commercialisation of climate technologies to decarbonise industries over the next decade will require new ways of doing business. Demonstrating and deploying these emerging technologies at scale is capital intensive and comes with many challenges and risks. Strong cross-sectoral collaboration will be required to develop innovative risk management measures to improve insurability, design appropriate insurance solutions and unlock the needed capital. The task will be complex and will necessitate changes to traditional commercialisation pathways and financing frameworks.

To explore the role re/insurers can play, The Geneva Association launched a two-part research series on climate tech and insurance. The first report in the series describes the climate tech commercialisation landscape and related challenges. It also offers perspectives from key stakeholders and insurance C-level executives on the benefits of and difficulties with engaging re/insurers in climate tech commercialisation. A lack of mechanisms to bring re/insurers and other key stakeholders together, profitability concerns and the limited number of projects available were found to hinder their early engagement in projects.

This second report examines the changes that need to be made to traditional approaches to developing and financing emerging technologies for climate tech and focuses on the importance of insurability and the development of affordable insurance solutions for market readiness. It makes clear the benefits of engaging P&C re/insures from the pre-commercialisation stages of projects to frame risks and develop risk management strategies. The report also offers a novel 'Insurability Readiness Framework' to help climate tech stakeholders pinpoint specific areas of projects that pose problems from an insurance perspective.

Key findings

1. **Efforts are underway to modify the traditional framework for technology development and financing to expedite the deployment of climate technologies.** The Technology Readiness Level (TRL) framework, which has been used since the late 1980s to assess a technology's maturity, does not capture many risks that hinder market readiness.

   - Project finance is increasingly being used instead of traditional technology financing mechanisms (e.g. growth venture capital funding) to address project complexities and large capital requirements, even for first-of-a-kind pilots in the demonstration and early deployment stages.

   - Using the U.S. Department of Energy's Adoption Readiness Level (ARL) framework, which identifies 17 risks that hinder the market readiness of climate technologies, alongside the TRL framework from the pre-commercialisation stages could help with the wide-scale deployment of climate tech.

2. **Affordable insurance solutions are essential for getting climate technologies market ready, securing financing and managing project liabilities.** Assessing the insurability conditions and developing insurance solutions for new climate technologies is complex and time consuming due to the myriad new risks involved and the lack of historical data. Greater risk sharing among stakeholders in the early stages could lead to the development of structured risk management solutions and better risk allocation among parties based on risk appetite and ability to bear risk, thereby attracting more capital and ensuring optimal risk financing. As the technology matures and deployment increases, more data on the performance and efficacy of risk management strategies becomes available, standards are developed for project replication, and the technology becomes more insurable. This allows insurers to take a greater share of the overall risk pool.

3. **Insurability challenges exist but, in general, can be overcome.** While there are issues associated with the common insurability criteria for emerging climate technologies, they can generally be addressed. Specific risks may not be insurable through the commercial insurance market and may instead require other interventions. If not solved, such risks could hold back the scaling of the technology indefinitely, as has been the case for carbon management technologies.

4. **Early engagement of re/insurers at the industry level from the demonstration and early deployment stages of technology development would offer a number of benefits,** including increased transparency and enhanced knowledge about the untested risks; convergence on data needs and monitoring requirements to initiate the development of databases for risk assessment in the industry; strengthened collaboration among stakeholders to develop risk management strategies for different aspects of the technology (e.g. equipment design); creation of 'pools of projects' to spread risks; and identification of unique insurance needs on a tech-by-tech basis to motivate insurance product innovation. This would also expedite the co-development of risk management standards, guidelines and codes of practice as projects reach the desired commercial scale, which is fundamental for project replication for wide-scale deployment.

5. **At the project level, very early engagement re/insurers (irrespective of the stage of technology development), would ensure that risks are considered, assessed and managed more holistically to enhance the insurability and potentially shorten the due diligence period for obtaining insurance, with subsequent impacts on financing and execution.** Traditionally, re/insurers are contacted after the project has been fully designed for development at an approved site, to arrange for insurance needs to secure financing and for execution. By engaging early, e.g. from the project feasibility phase when the site is selected and approved, re/insurers can provide important feedback on critical decisions, such as where and how to build facilities to maximise their insurability against extreme weather events over the project's life cycle.

6. **The novel 'Insurability Readiness Framework' (IRF) presented in this report allows climate tech risks to be viewed through an insurance lens.** The IRF translates the risks in the ARL framework into seven categories: 1) technology risk; 2) project information and organisation risk; 3) legal, finance and compliance risk; 4) physical risk at project location; 5) business interruption and supply chain risk; 6) long-term risk; and 7) environmental, social and governance risk. The framework enables more informed conversations among climate tech stakeholders and re/insurers for framing risks, identifying data needs, exploring insurability conditions, and considering risk management strategies. It also brings focus to the most challenging risks from an insurability perspective. We demonstrate its use in the report by applying it to two emerging technologies: green hydrogen and carbon management.

The report offers recommendations for stakeholders including insurers, investors, climate tech associations and developers, and governments on how they can leverage these findings to help expedite the commercialisation and at-scale deployment of climate technologies.

1 Introduction

Introduction

Huge funding gaps, challenges with scaling and scarcity of data on the risks posed hinder the commercialisation of climate tech.

The 28th United Nations Conference of Parties (COP28), held in Dubai in December 2023, stressed again that limiting global warming to 1.5ºC requires reducing greenhouse gas (GHG) emissions by 43% by 2030 and 60% by 2035 – relative to 2019 levels – with the goal of reaching net zero by 2050.[1] The conference ended with the release of a climate deal, referred to as 'The UAE Consensus', which explicitly calls for transitioning away from fossil fuels, tripling renewable energy capacity globally and accelerating zero- and low-emission technologies for the decarbonisation of industrial sectors with heavy GHG emissions by 2030.[2] Decarbonisation is highly capital intensive, with an estimated USD 7–9.2 trillion annual investment gap between now and 2050.[3]

In 2022, The Geneva Association (GA) launched a multi-stakeholder, two-part research project, *Accelerating Climate Technologies for Industrial Decarbonisation and the Insurance Industry,* to explore how re/insurers can help accelerate the deployment of new climate technologies for adoption by 'hard-to-abate' sectors – the steel, cement, aluminium, chemicals, aviation, trucking and shipping industries – which account for over 30% of global GHG emissions.[4,5]

The first report examines the climate tech commercialisation landscape and traditional approaches to developing new technologies based on the Technology Readiness Level (TRL) framework (Figure 1)[6]. It highlights major barriers to expediting climate tech commercialisation – including huge funding gaps, technical challenges with scaling and market readiness, and scarcity of data on the risks – and presented perspectives of C-level insurance executives on the topic.[7] It stressed that new ways of doing business will be needed to expedite climate tech financing and market readiness, which will require stronger cross-sectoral collaboration among stakeholders in the climate tech ecosystem. The report concludes that re/insurers can play a pivotal role in their capacity as risk engineers and underwriters, but that they need to get involved in projects from much earlier stages. Currently, however, mechanisms to bring this about do not exist. Further, there is a lack of awareness among climate tech stakeholders of what re/insurers can offer and how insurance solutions could help unlock financing for projects and impact market readiness.

This second report:

- Explores why insurability and the development of affordable insurance solutions are critical to expediting climate tech market readiness.
- Explains why existing frameworks need to be enhanced to allow climate tech stakeholders to better leverage re/insurers' expertise, especially from the pre-commercialisation stages.
- Showcases examples of the benefits of early engagement between re/insurers and climate tech stakeholders.

1 Paragraph 28 of the official UN document on the Outcome of the First Global Stocktake. United Nations Framework Convention on Climate Change (UNFCCC) 2023.
2 Ibid.
3 Bloomberg NEF 2022; McKinsey 2022.
4 For example: for the steel industry, expanding from one demonstration plant today to nearly 70 zero-emission steel plants delivering 170 Mt of near-zero-emission primary steel in 2030; for concrete: expanding from zero operational plants today to 20+ commercial-scale carbon capture, usage and storage plants to deliver 160 Mm^3 concrete in 2030.
5 The Geneva Association 2024. Authors: Maryam Golnaraghi and Ignacio Belanche-Guadas.
6 Ibid.
7 A survey of 88 C-level executives (Chief Executive Officers, Chief Investment Officers, Chief Underwriting Officers and Heads of Risk Engineering) from 26 re/insurers was conducted for the report. A number of consultations and workshops were also held with project developers; government representatives; engineering, procurement and construction (EPC) firms; investors; and the scientific community.

- Presents an 'Insurability Readiness Framework' (IRF), which allows the risks identified by existing frameworks to be viewed through an insurance lens.

- Applies the IRF to two technologies: green hydrogen and carbon management.

Section 2 takes a deeper look at existing frameworks and how they may be modified to gain a more holistic view of the risks associated with climate technologies, as well as the implications for insurability and the development of insurance solutions. Section 3 examines the insurability issues associated with new climate technologies. Section 4 highlights the benefits of engaging re/insurers in climate tech projects from the pre-commercialisation (demonstration and early deployment stages) phases. The IRF is presented in section 5 along with the results of its application to two technologies. Section 6 offers concluding remarks, highlights remaining issues and suggests recommendations for the way forward.

2 Frameworks for climate tech development and market readiness

Frameworks for climate tech development and market readiness

Various factors that could hinder market readiness are not captured in existing frameworks used to assess the maturity of new technologies.

A significant portion of the estimated USD 7–9.2 trillion annual investment gap to fund the transition of the global economy by 2050 needs to be mobilised towards the development, demonstration and at-scale commercial deployment of emerging climate technologies.[8] Massive amounts of public and private capital will need to be raised through financial institutions, but institutional investors and banks are reluctant to fund these technologies.[9] Reasons for this include the complex risk profile of projects; low risk appetite from investors due to their limited resources and expertise in this area; financial regulatory constraints, such as high cost of capital for investing in risky projects; an inconducive public policy and regulatory environment; limited accessibility to investable-grade projects; and investors' commitment to fiduciary responsibility.[10]

Cross-sectoral collaboration to identify, understand and manage the risks will be central to mobilising capital and expediting climate tech market readiness. These solutions could also have a material impact on the cost of capital for borrowers and enhance risk-adjusted returns for investors. This section will take a deeper look at frameworks that are currently used for the development of new climate technologies and examine the collaborations needed to develop proactive risk management solutions.

Cross-sectoral collaboration is required to manage the risks associated with climate technologies.

2.1 The Technology Readiness Level framework

The TRL framework (Figure 1) has been used as the main framework for assessing the evolution of the maturity of a new technology from laboratory research (TRL 1) to wide-scale commercial deployment (TRL 9).[11] It has helped to align discussions between innovators, entrepreneurs, project developers and investors on issues such as technological performance and safety risks, which need to be addressed through pilots and scaled projects before operational deployment.

However, the TRL framework does not address a number of factors that contribute to a technology's market readiness; for example, market demand, equipment manufacturing and supply chain issues, availability of a sufficiently skilled workforce, or the public policy and regulatory environment. These factors, if not dealt with from the pre-commercialisation stages, could significantly delay or compromise the at-scale commercial deployment of climate technologies. Solar and wind power (onshore and offshore) technologies, for example, took over four decades to commercialise[12] but have still not realised their full market potential due to manufacturing and supply chain issues, project developers' or offtakers' credit risk, and long permitting processes.

8 BloombergNEF 2022; McKinsey 2022.
9 BloombergNEF 2023.
10 The Geneva Association 2024.
11 The traditional TRL framework has nine stages. However, different sectors have adopted variations tailored to their specific needs and applications. For example, the International Energy Agency (IEA) and the American Petroleum Institute (API) have developed their own TRL scales based on NASA's original framework.
12 The Geneva Association 2024.

FIGURE 1: TECHNOLOGY READINESS LEVEL FRAMEWORK

Technology stage	Technology Readiness Level (TRL)		
At-scale commercial deployment	9	Wide-scale commercial deployment	Focus of this report
	8	Early commercial deployment	
Demonstration and early deployment	7	Complete system demonstration in an operational environment	
	6	Early field demonstration and system refinement completed	
	5	Early system validation demonstrated in a laboratory or limited field application	
	4	Subsystem or component validation in a laboraory environment to simulate service conditions	
Research and development	3	Proof-of-concept validation	
	2	Technology concepts and/or application formulated	
	1	Exploratory research transitioning basic science into laboratory applications	

Source: NASA[13]

Furthermore, first-of-a-kind (FOAK)[14] pilots and early commercialisation projects are capital intensive, complex and involve many stakeholders, such as project owners and developers, Engineering, Procurement and Construction Companies (EPCs), suppliers, contractors and offtakers.[15] Traditional growth venture capital financing is no longer sufficient for funding and scaling these new technologies. Project finance is increasingly being utilised for the development and deployment of newer climate technologies. While more prominently used in TRL 8 (early commercial-scale projects) to TRL 9 (wide-scale commercial deployment projects), it is occasionally being used for FOAK to nth-of-a-kind (NOAK) pilot projects in TRL 7.[16]

Project finance is increasingly being utilised for the development and deployment of newer climate technologies.

The emergence of project finance in this space is helping to facilitate discussions among key stakeholders and opening up further channels for financing these projects.[17]

2.2 The Adoption Readiness Level framework

The Adoption Readiness Level (ARL) framework (Table 1, risks 1–17) was developed to complement the TRL framework, to allow climate tech stakeholders to assess the market readiness of emerging climate technologies. It was released by the U.S. Department of Energy (DoE) in 2023 for consultations and introduced 17 risk types under the following four categories:

1. *Value proposition* covers risks associated with delivered costs, functional performance and ease of use/operational complexity (risks 1–3).

2. *Market acceptance* encompasses risks associated with demand maturity, market openness, barriers to entry, market size and development of the downstream value chain for getting the product from producers to customers (risks 4–6).

3. *Resource maturity* for market adoption and large-scale commercial deployment includes risks associated with capital flow and availability; project development, integration and management; underpinning infrastructure (digital and physical); manufacturing and supply chains; access to critical materials required for the technology; and the availability of a trained workforce (risks 7–11).

13 The TRL was originally developed by the U.S. National Aeronautics and Space Administration (NASA) in 1974 and was formally defined in 1989.
14 FOAK is a term used in engineering economics where the first item or generation of items using a new technology or design can cost significantly more than later items or generations, which are called nth of a kind (NOAK). FOAK or even NOAK projects have significant inherent uncertainty related to untested risks and project returns. Innovative climate tech companies are often embarking on FOAK projects as transforming industrial processes requires them to prove new tech at legacy scale for financing.
15 New Energy Risk (2021) offers a comprehensive overview of industry and energy technology project finance to provide startups and developers with guidelines for scaling and commercial success.
16 Expediting new climate technologies requires the deployment of FOAK pilots, which are difficult and capital intensive. Climate Tech VC 2023, 2024.
17 Ibid.

4. *Licence to operate* includes risks associated with the regulatory and public policy environment; permitting and siting processes; environmental and safety issues; and community perception (risks 13–17).

Consideration of the risks defined in the TRL and ARL frameworks from the pre-commercialisation stages is critical to accelerating the commercial deployment of climate technologies. A complex ecosystem of stakeholders – including manufacturers and suppliers, infrastructure owners and regulators – is engaged in addressing market readiness factors. They need to align priorities, engage proactively and work together in a more concerted and interactive fashion (Figure 2).

Risks defined in the TRL and ARL frameworks must be considered from pre-commercialisation stages to accelerate the commercial deployment of climate technologies.

TABLE 1: ADOPTION READINESS LEVEL FRAMEWORK WITH INSURANCE INCLUDED AS A KEY ELEMENT FOR MARKET READINESS

Value proposition	Market acceptance
1. Delivered cost Risks associated with achieving delivered cost competitiveness when produced at full scale, including amortisation of incurred development and capital costs, and accounting for switching costs (if any). **2. Functional performance** Risks associated with the ability of the technology solution to meet or exceed the performance and feature-set of incumbent solutions or create new end-use markets. **3. Ease of use/complexity** Risks associated with operational switching costs; the ability of a new user (individual, company, system integrator) to adopt and operationalise the technology solution with limited training, few new requirements, or special resources (e.g. tools, workforce, contract structures).	**4. Demand maturity/market openness** Risks associated with demand certainty and access to standardised sales & contracting mechanisms (if required), as well as with natural (e.g. network effects, first-mover-advantages) and/or structural (e.g. existing monopolies/oligopolies) barriers to entry in the market(s) to which the technology solution can be applied. **5. Market size** Risks associated with the overall size of the market that can be served by the technology, and the level of uncertainty with which it will materialise. **6. Downstream value chain** Risks associated with the projected path to get the product from a producer to a customer along the value chain (e.g. considering split incentives, technology acceptance, business model changes).

Source: Modified from U.S. DoE1[18]

18 U.S. DoE 2023a

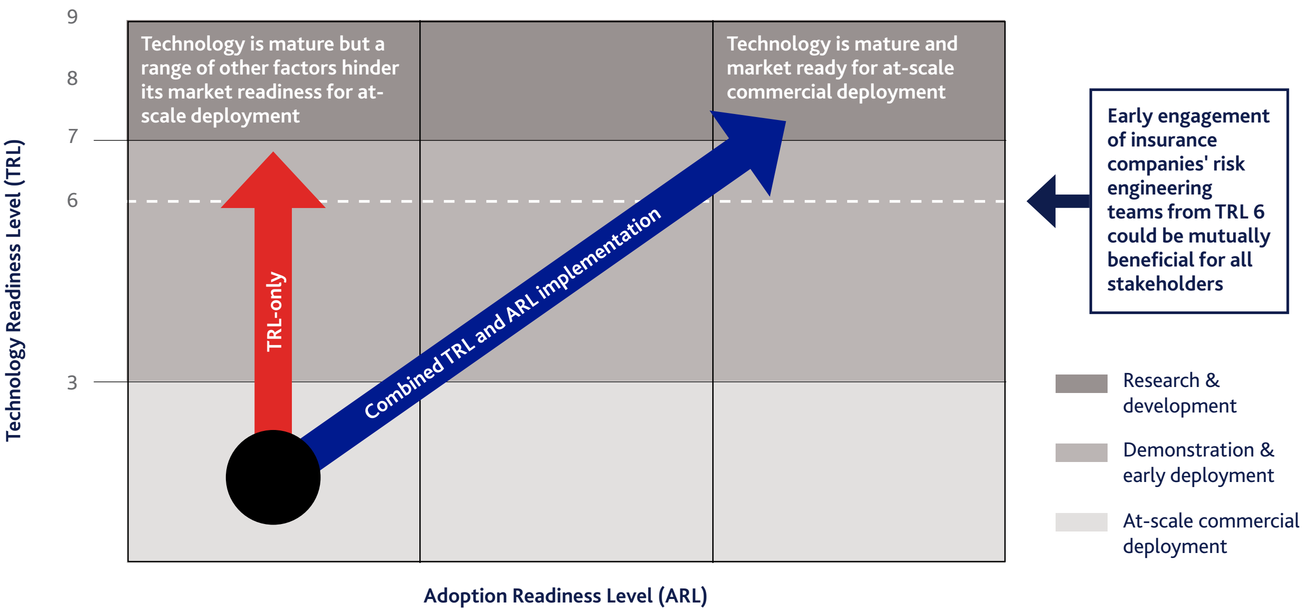
As new climate technologies are demonstrated and scaled from TRL 7 to 9, feedback based on lessons learned could help address market readiness factors. Mechanisms are needed to harness the knowledge and experience gained from project execution, for example on the performance and resilience of equipment, gaps and challenges in the value chain and special requirements for training the workforce.

The development of climate-tech-specific hubs, which aim to bring together technology developers and customers to leverage existing infrastructure systems, create a business marketplace and develop safety standards to expedite scaled deployment, are a step in the right direction.[19]

Resource maturity	Licence to operate
7. Capital flow & availability Risks associated with the availability of capital needed to move the technology solution from its current state to production at scale, including total investment required, availability of willing investors, availability of associated financial & insurance products, and the speed of capital flow. **8. Project development, integration & management** Risks associated with the existence of processes and capabilities to successfully and repeatably execute projects using the technology solution. **9. Infrastructure** Risks associated with the physical and digital large-scale systems that need to be in place to support, enable, or facilitate deployment at full scale (e.g. pipelines, transmission lines, roads and bridges). **10. Manufacturing & supply chain** Risks associated with all the entities and processes that will produce the end product, including integrators, component and sub-component manufacturers and providers. **11. Materials sourcing** Risks associated with the availability of critical materials required by the technology (e.g. rare earth and other limited availability materials). **12. Workforce** Risks associated with the human capital and capabilities required to design, produce, install, maintain and operate the technology solution at scale.	**13. Regulatory environment** Risks associated with local, state and federal regulations or other requirements/standards that must be met to deploy the technology at scale. **14. Policy environment** Risks associated with local, state and federal government policy actions that support or hinder the adoption of the technology at scale. **15. Permitting & siting** Risks associated with the process to secure approval to site and build equipment and infrastructure associated with deploying the technology at scale. **16. Environmental & safety** Risks associated with the potential for hazardous side effects or adverse events inherent to the production, transport or use of the technology solution or end product in the absence of sufficient controls. **17. Community perception** Risks associated with the general perception by global and local communities of the technology solution and its risks or impact, whether founded or unfounded.
18. Insurability and availability of affordable insurance Risks associated with the lack of data and technical capacity to identify, frame and assess risks of new climate technologies and related insurability conditions; delays with the development of risk management frameworks, standards and codes of practice for project replication; addressing unique insurance needs on a tech-by-tech basis which could delay scaling; and the development and availability of a full range of insurance solutions to meet financing and market needs.	

19 The Geneva Association 2024.

FIGURE 2: EXPEDITING CLIMATE TECH MARKET READINESS UTILISING THE TRL AND ARL FRAMEWORKS



Source: Modified from U.S. DoE[20]

2.3 The importance of insurance for climate tech market readiness

Available and affordable insurance solutions will be essential for getting new climate technologies market ready, securing financing and managing the liabilities associated with the execution of projects. However, assessing insurability conditions and developing such solutions for new climate technologies is complex and time consuming because of the myriad new risks, and lack of historical data and relevant experience. It is important to begin assessing conditions at the pre-commercialisation stages to determine what may be insurable through commercial insurance markets and how to address uninsurable aspects, for example through public-private partnerships (PPPs) or government backstops.

The development and implementation of risk management solutions is fundamental for improving insurability conditions. Beyond risk management efforts at the project level, industry-level efforts are needed to help change the risk profile of climate technologies. Such actions may include building extreme-weather-resilient equipment (e.g. thicker or vertical solar panels for protection against hail) and more resilient infrastructure systems, targeted workforce training (e.g. contractors, operators), and developing public policy and regulatory requirements that mitigate environmental and safety risks.

As understanding of the risks associated with new climate technologies improves and risk management solutions are developed and tested, industry associations and standard-setting and certification bodies will be able to engage and collaborate with insurers to develop risk management frameworks, standards and codes of practice. These in turn will have a significant impact on insurability conditions and the development of affordable insurance solutions.

As such, we propose to include an additional risk, 'Insurability and Availability of Affordable Insurance,' under 'Resource Maturity' in the ARL framework (Table 1, risk 18).

> ***Available and affordable insurance will be essential for getting new climate technologies market ready, securing financing and managing project liabilities.***

20 U.S. DoE 2023a

3 Insurability of climate tech

Insurability of climate tech

Assessing the insurability of climate tech is complex. Conditions will evolve as technologies mature and risk mitigation strategies are developed, allowing insurers to take a greater share of the risk pool.

Assessing the insurability conditions for new technologies is not straightforward and decisions will not be binary ('yes' or 'no'). They will instead fall somewhere on a scale that will evolve as the technology matures and risks are identified, understood and mitigated, or at the very least become more measurable. In the early stages of commercialisation, greater risk sharing among stakeholders, i.e. insurers, project owners, project developers, investors and government agencies, is required. As the technology matures, deployment increases and more data on the performance and efficacy of risk mitigation strategies becomes available, new technologies become more insurable and insurers can take a greater share of the overall risk pool.

Table 2 outlines the fundamental criteria of insurability[21] as well as related issues for emerging climate technologies.[22]

An essential criterion of insurability is the randomness and independence of loss occurrence. For example, insurability is compromised if there is a systemic *foreseeable* risk, such as design flaws, which are only discovered once a technology has been in operation for a period of time. At the time of discovery, multiple units would typically already have been manufactured, delivered and installed. As a result, units may need to be fixed in the field at increased costs. Real-world examples include design flaws of rotor blades and gear boxes in wind turbines.

Re/insurers also need to be able to assess and measure the maximum possible loss (MPL) and average loss per event in monetary terms. For proven technologies, this analysis is carried out using scenarios that are developed based on previous experience. For new technologies, scenarios are developed based on assumptions and thus bear significant uncertainty.

Data transparency and knowledge sharing between project developers and re/insurers is critical for assessing the MPL. It is difficult for re/insurers to gain the same level of insight as project developers, especially in the earlier stages of development (e.g. TRL 7–8), and they may have no or limited access to information on technological risks. Ultimately, the project developer needs to ensure effective communication of complex technical information with the insurer, as project finance relies on convincing investors to assume well-mitigated technology risk.

The number of exposure units is another important consideration. From an insurance perspective, risk should be spread over a sufficiently large number of independent exposure units (i.e. projects) to reduce the variability of the loss experience. As the technology matures and the number of projects expands across different jurisdictions, more favourable conditions are created to form insurance pools. However, if the number of projects is limited – as has been the case for nuclear power, for example – government interventions are needed to cover the liabilities. This is the reality for emerging climate technologies, which are high risk and have a limited number of exposure units.

21 The Geneva Association 2023a. Author: Kai-Uwe Schanz.
22 Berliner 1985.

TABLE 2: CRITERIA OF INSURABILITY AND ISSUES RELATED TO EMERGING CLIMATE TECHNOLOGIES

Criteria of insurability	Issues for emerging climate tech
1. Randomness and independence of loss occurrence Losses should be uncorrelated and the insured should not be able to influence them through their actions. The loss must be uncertain but there should be a chance of occurrence. Insurers only pay out claims for loss events brought about through accidental means to protect against intentional acts of loss.	– Systemic technological risks are foreseeable across projects, e.g. serial defects similar to wind and gas turbines. – Business model risks. Advanced loss control and preventative risk management strategies are essential to enable favourable insurability conditions.
2. Maximum possible loss (MPL) The aggregate maximum loss should be measurable in monetary terms and manageable for the insurer.	– Calculated based on scenarios that rely on assumptions and therefore come with uncertainty. For proven technologies, scenarios are developed based on previous experience, whereas for new technologies, these scenarios rely on assumptions. – Re/insurers require transparency and data sharing to assess risks and the MPL. – Development and adoption of preventive risk management frameworks, standards and codes of practice could reduce the MPL of projects but often do not exist.
3. Average loss per event Should be predictable, measurable and manageable. This allows the insurer to accurately estimate the expected cost of insuring the risk.	– Lack of or insufficient historical data or evidence of loss patterns. Many projects are first of a kind (lack of relevant insurance data sets and distributions). – Learning from projects to development and test out risk management measures through various channels, could lead to the development and adoption of preventive risk management frameworks, standards and codes of practice for industry adoption for project replication could result in reduction of MPL for the projects and technology.
4. Number of exposure units Risk should be spread over a sufficiently large number of independent exposure units (i.e. projects), which can form an insurance pool. This reduces the variability of the loss experience.	– Lack of sufficient number of projects to form a risk pool (minimum size); in other words, a high number of projects with similar comparable risks must exist.
5. Information asymmetries The insurer and insured should have access to the same information about the risk. Information asymmetries lead to inaccurate risk assessment and adverse selection.	– Transparent information is crucial for assessing the risks, developing risk management solutions to enhance insurability conditions and ultimately to expedite the development of innovative risk transfer solutions for the technology, related processes and integration with other technologies in projects. – Achieving the same level of insight as the project developer is challenging for insurers in the earlier development stages.
6. Insurance premiums Should be economically viable and reflect the expected cost of the risk.	– Important to know how the risks evolve and are managed through various channels during the life cycle of the project. Preventative risk management measures could result in more affordable premiums. – Factors such as limited number of exposure units, and a lack of exposure and vulnerability data as well as severity patterns lead to high risk loadings and uncertainty with premium calculations.
7. Cover limits Should be clearly defined at reasonable complexity.	– Lenders' requirements may be misaligned with project developers' expectations and the insurance market's ability to provide coverage. – Early engagement of re/insurers could potentially impact lender's requirements.
8. Public policy Coverage must be in accordance with public policy and societal values (e.g. does not promote criminal behaviour).	– Public policy and societal values vary across jurisdictions and will have different implications for projects. – Clear public policy on emerging climate technologies may be lacking or change over time.
9. Legal and regulatory restrictions Coverage should be in accordance with current and future legal restrictions (e.g. governments might change legal frameworks and make insurance compulsory if the consequences of climate change become too extreme).	– Predicting and assessing future legal restrictions is challenging for emerging climate technologies. – Clear legal and regulatory policies and restrictions are lacking and may change over time.

Source: The Geneva Association

Assessing the 'insurable interest' of the stakeholders involved in climate tech projects is also complex. This refers to the financial interests of each stakeholder and the potential financial losses that each may experience in case of damage or destruction of the insured asset(s) or injury or death of the insured person(s).

- *Project owners* may be individuals, small to medium-sized enterprises, corporations or government entities. They may have insurable interest as they are responsible for the project's operation and maintenance. They may seek to manage and transfer risks associated with equipment failure, property damage or liability claims.

- *Project developers* have significant insurable interest as they have a financial stake in the project's success and may seek to protect their investment against potential risks such as damage to equipment, disasters caused by natural hazards or business interruption.

- *Investors* may include private investors, venture capital firms, banks and institutional investors who provide different types of funding via equity, debt and other capital market tools. They have a vested interest in protecting their investment and ensuring the project's profitability.

- *Suppliers and contractors* include companies involved in the construction, installation or supply of equipment and materials. They may seek insurance to protect against potential losses arising from project delays, equipment failures, liabilities or accidents.

- *Power purchasers or offtakers*[23] are utilities or companies that enter into power purchase agreements or offtake agreements with project owners. They rely on the project's ability to supply and may want to safeguard against any disruptions that may impact power supply.

Though there are insurability issues associated with climate technologies, in general, these are not expected to be unmanageable (as opposed to pandemic business interruption or catastrophic cyber risks, for example). However, there may be tech-specific risks that may not be insurable through the commercial insurance market. These will require other interventions. If not solved, these risks may hold back the scaling of the technology indefinitely (see the case study on carbon management provided in section 5).

23 "Offtaker" is a term used in project financing. This is the party that buys the product being produced or uses the services being sold.

4 Benefits of engaging re/insurers from earlier stages

Benefits of engaging re/insurers from earlier stages

Early involvement of re/insurers in climate tech projects will facilitate the development of risk profiles for specific technologies and help to identify insurance needs.

This section outlines the benefits of engaging re/insurers through their risk engineering services from the early stages of climate tech projects (TRL 6).

4.1 Demonstration and early deployment stages

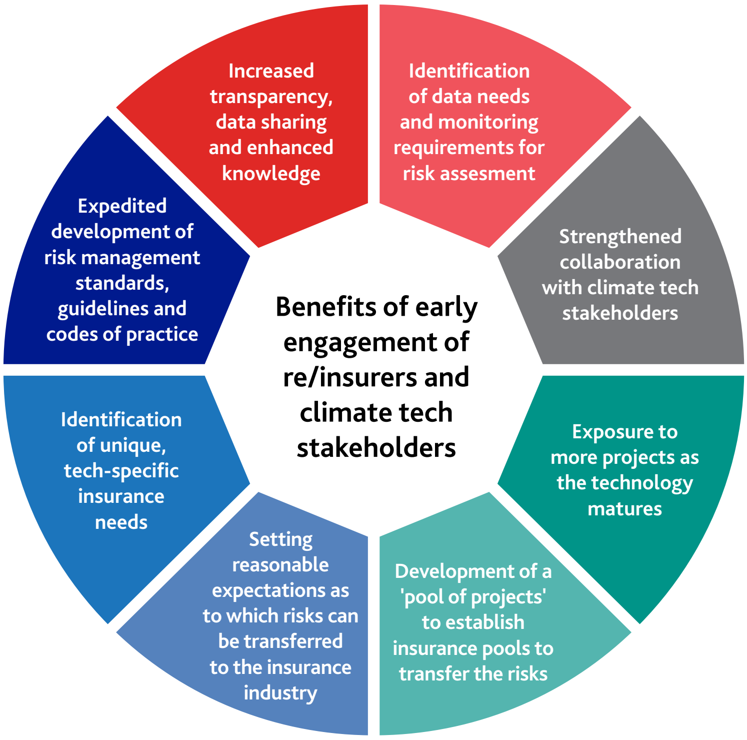
The benefits of involving re/insurers as early as the demonstration and early deployment stages of climate tech projects are manifold (Figure 3):

- *Increased transparency, data sharing and enhanced knowledge* on the risks. This would allow a more holistic approach to developing the risk profile of the technology to assess and fine-tune insurability conditions as it moves through the TRLs.
- *Identification of data needs and monitoring requirements* from early stages. This would facilitate the development of databases for risk assessment and determining insurability conditions.
- *Strengthened collaboration with climate tech stakeholders* (e.g. project developers, policymakers, equipment manufacturers and suppliers, infrastructure operators) to develop risk management strategies.
- *Exposure to more projects* as the TRL of the technology matures, which could lead to faster identification of systemic foreseeable risks and defects that could be mitigated, for example, through rethinking equipment design or government policies and interventions.
- *Development of a 'pool of projects'*, which could lead to the establishment of an insurance pool to spread the risks.
- *Setting reasonable expectations among climate tech stakeholders* as to which risks can be transferred to the insurance industry, and how that risk-sharing balance may evolve over time as the technology matures and more risks become known or measurable.
- *Identification of unique, tech-specific insurance needs*, which may require product innovation in commercial insurance markets, or other interventions such as PPPs and/or government backstops.
- *Expedited development of risk management standards, guidelines and codes of practice*, which is fundamental for project replication and wide-scale deployment.

Appendix 1 offers an overview of the issues that may arise for project developers as emerging climate technologies move from TRL 6 to 9. Project developers need to start thinking about insurance needs as early as TRL 6, as they start planning their FOAK pilot.[24] Insurance-related issues will also change significantly from TRL 6 to 9; for example, the insurable value of assets at TRL 6 is relatively low but risks and insurance needs evolve markedly for projects over TRL 7–9 (see Appendix 1).

24 FOAK to NOAK pilot projects in TRL 7 traditionally aim to assess and improve technological risks, such as technical performance, operational complexities and related safety issues to develop associated economic models.

FIGURE 3: BENEFITS OF ENGAGING RE/INSURERS AND CLIMATE TECH STAKEHOLDERS FROM THE PRE-COMMERCIALISATION STAGES



Source: The Geneva Association

It is important to note that many emerging climate technologies in TRL 6–7 are being developed by small- to medium-sized entrepreneurial technology firms, which often do not have strong balance sheets, risk management expertise, knowledge about insurance requirements or the management skills required to run a successful business in the growth stage.[25] There is a unique opportunity for these project developers to leverage the risk engineering expertise of re/insurers.

4.2 Early in project development

Climate technologies are demonstrated, scaled and implemented in an operational capacity from TRL 7. Given the complexities and large capital requirements of these projects, traditional technology financing mechanisms, such as growth venture capital funding, are not sufficient and project finance is increasingly being utilised. Figure 4 demonstrates the six phases of project development, financing and execution, with related milestones. Decisions that are made during the early development phases have significant implications for the insurability of the project, with subsequent impact on its financing and execution.

Traditionally, re/insurers are contacted after the project has been designed for development at an approved site (red circle in Figure 4). However, this often means that insurance-related considerations may not have been made during project design, potentially leading to unanticipated surprises, both for untested (or not-fully-tested) and known risks that may have been overlooked. Such oversight could result in insurability challenges, delays or compromises in financing and executing the project.

Engaging re/insurers' risk engineering teams early on in project development will help with risk management and enhance insurability.

Engaging re/insurers' risk engineering teams much earlier on would ensure that risks are considered, assessed and managed more holistically, enhancing the insurability of the project and potentially shortening the due diligence period for obtaining insurance. For example, extreme weather events can significantly damage or destroy industrial assets.[26–28] Between 2019 and 2023, wildfires, floods and hailstorms have resulted in major losses for renewable

25 Major energy and tech corporations, such as Siemens Energy or Occidental Petroleum Corporation, are also engaged in developing these technologies from TRL 6. These companies have robust balance sheets, extensive experience in risk management and may even have their own insurance captive to guarantee project financing.
26 Norton Rose Fulbright 2023.
27 Rider 2023.
28 Swiss Re 2023.

energy facilities.[29,30] Rising insurance costs and difficulty finding coverage are starting to limit where such projects can be built, particularly where the risk of weather-related events is above average. With trillions of public- and private-sector funding being mobilised to expedite the commercial deployment of new climate technologies over the coming decades, deciding where and how to build facilities will be critical to keeping them insurable over their life cycle. Specifically:

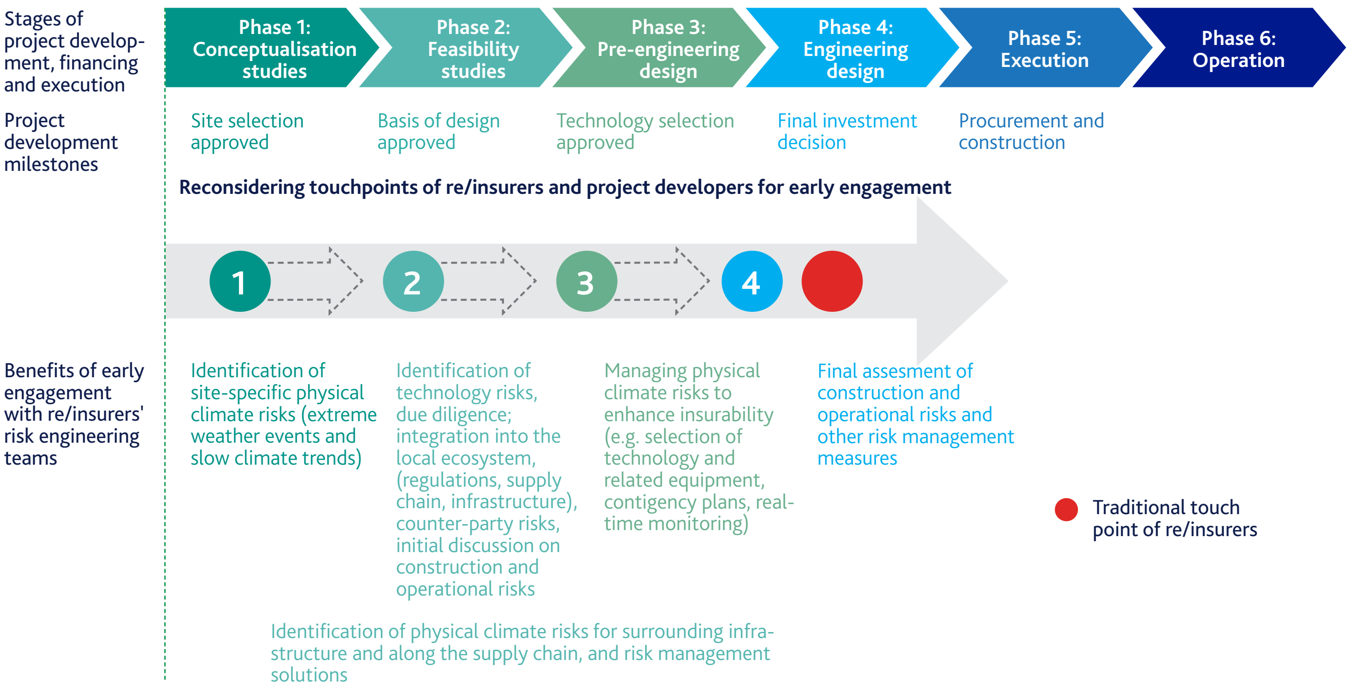
- Involving re/insurers' risk engineers from early project feasibility (phase 1, Figure 4) and pre-site selection approval will help guide these decisions. Traditionally, project site selection involves trade-offs between many different factors such as the cost of land, access to infrastructure and supply chains, as well as consideration of regulatory constraints and requirements. Using forward-looking scenario analysis, re/insurers can help project developers to anticipate current and future physical climate risks at a given site. Based on this, it may not make economic sense to build the project in the chosen location or, if it is decided to proceed with the site, project developers could integrate climate resilience and contingency plans into project conceptual development and design.

- When the design of project feasibility is being conducted (phase 2, Figure 4), re/insurers can help identify risks associated with the performance of the technology and its integration into the local ecosystem. Re/insurers can also work with project developers and their EPC partners to develop risk management strategies, such as contingency plans, advanced control systems and sensors for system-wide monitoring for anticipation of system failures for consideration in the design phase to enable proactive maintenance when the project is implemented.

- There are further opportunities for re/insurers to propose risk mitigation measures in the pre-engineering design phase, before the technology has been selected (phase 3, Figure 4). Re/insurers can propose risk mitigation strategies, through selection of technology and related equipment. For example, the use of thicker glass or vertical solar panels for a solar plant in a zone with high hail risk. Such measures may make a big difference to the insurability of the project. In addition, during phase 3 discussions about re/insurers' requirements for construction and operational risks, regulatory requirements, industry standards (if available) and contract risk allocation among various counterparties can be addressed.

- Finally, re/insurers can help assess construction and operational risks in line with insurance requirements and suggest any additional risk management measures pre-financing (phase 4, Figure 4).

FIGURE 4: ENGAGING RE/INSURERS IN EARLY PROJECT DEVELOPMENT FOR ENHANCED INSURABILITY



Source: The Geneva Association

29 Kaminsky 2023.
30 In 2022, the U.S. renewable energy insurance industry experienced record-breaking losses upward of USD 300–400 million related to hail damages. Aragon 2024.

4.3 Developing industry standards and codes of practice

When risk management standards and codes of practice have been insufficient or non-existent for projects, with implications for insurability, re/insurers have been known to initiate the development of guidelines (Box 1). Early engagement of re/insurers in climate tech projects will improve their expertise in this area, help build relationships with key stakeholders and potentially lead to the development and fine-tuning of insurability requirements, best practices, standards and codes of practice for project replication.

Early engagement will improve re/insurers' expertise and help with the development of standards and codes of practice for project replication.

Box 1: Standards and codes of practice for offshore wind initiated by re/insurers

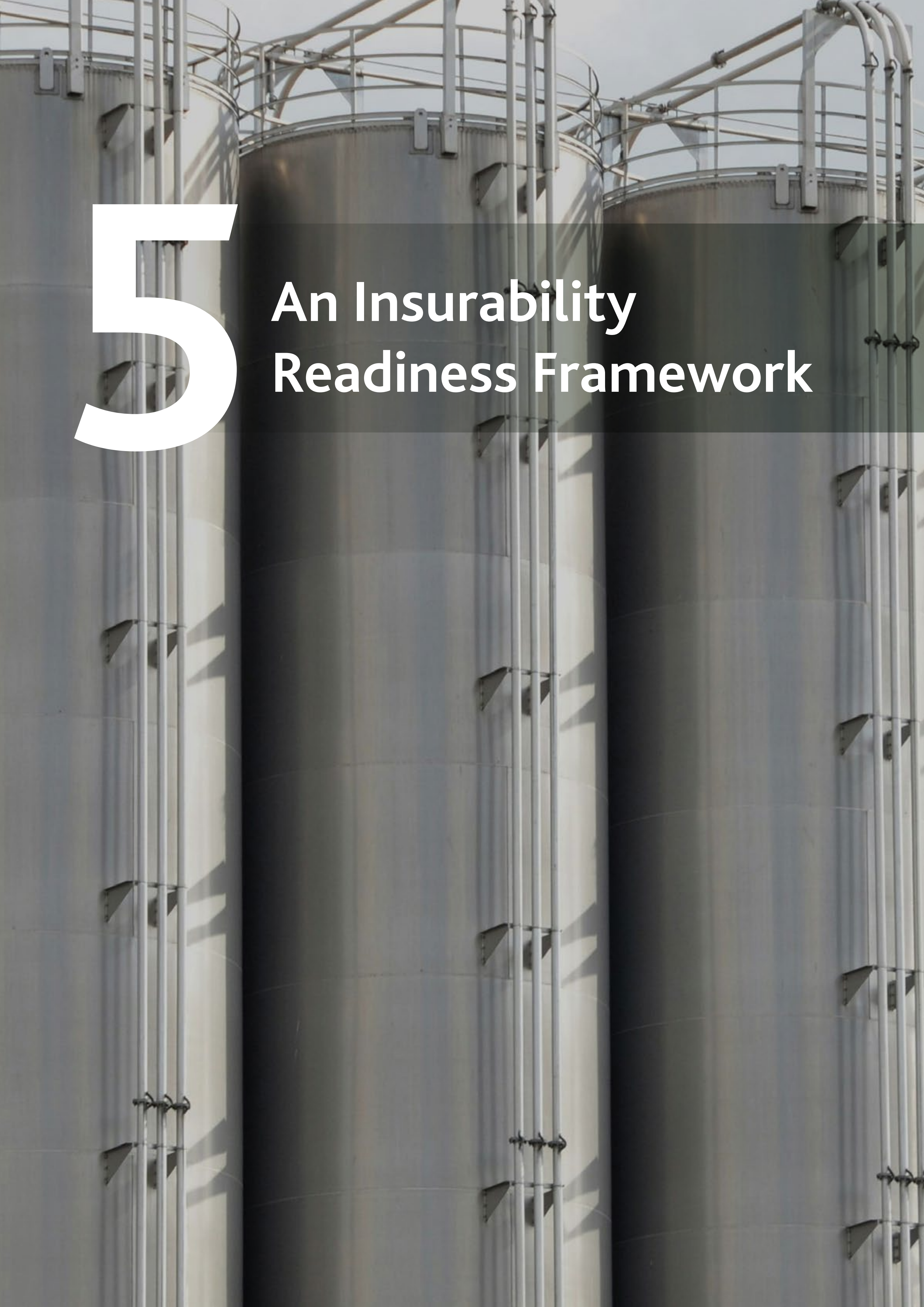
Codes of practice for the offshore wind industry were initiated by insurers, who had limited experience assessing risk and offering solutions for these types of emerging projects, during a meeting of the European Wind Turbine Committee. The focus was on the German market to limit the number of possible participants and keep the process manageable, with the intention of sharing the results with other markets. The German Insurance Association (GDV) and German Offshore Wind Energy Foundation helped organise the meetings, which involved more than 90 representatives from a diverse range of sectors, including re/insurers, brokers, manufacturers, developers and investors. Working with organisations and associations of stakeholders proved successful in engaging these representatives.

The goal was to develop a best-practice paper on state-of-the-art risk management for constructing offshore wind farms. This extensive process included building a virtual offshore wind farm and developing working groups that addressed different aspects. More than 500 risks were identified and categorised as very high, high, medium or low, and risk mitigation measures were described. The guidelines are intended as best practice for industry adoption and project replication.

Similar initiatives may be carried out for emerging decarbonisation technologies, through closer collaboration between standard-setting bodies and re/insurance companies. For example, for the hydrogen industry, the development of standards is recommended, with the U.S. market a potential starting point.

Source: Verband der Sachversicherer (VdS)[31]

31 The Association of Property Insurers, a subsidiary of the GDV. VdS 2014.



5 An Insurability Readiness Framework

An Insurability Readiness Framework

Presenting a novel framework for assessing and mitigating climate tech project risks towards insurability

In this section, we present a novel 'Insurability Readiness Framework' (IRF), which will help climate tech stakeholders to think about risks from an insurance lens. This will enable more informed conversations with re/insurers around framing risks, exploring insurability conditions and considering risk management strategies. Developed by The Geneva Association in collaboration with other stakeholders, it builds on the risks identified in the ARL framework.

The Insurability Readiness Framework helps climate tech stakeholders to think about risks from an insurance lens.

5.1 Viewing the risks of new technologies through an insurance lens

The IRF (Appendix 2) breaks down the risks of new technologies into seven categories relevant to insurance and demonstrates how they relate to risks identified in the ARL framework. Table 3 provides a breakdown.

For each of the insurance-relevant risk categories, the IRF specifies key issues that need to be considered by climate tech stakeholders when framing risks in their dialogue with re/insurers, the information project developers need to compile to share with re/insurers for risk and insurability assessment, and risk mitigation strategies that would help enhance insurability conditions. The full template is provided in Appendix 2.

Table 4 shows the issues specified under 'technology risk'. The types of data and information needed for discussion with re/insurers range from a basic overview of the technology and the scale-up strategy to material selection, proof of performance, quality control and risk management in the development process.

Table 3: Insurance-relevant risks provided in the IRF and their relation to ARL risk types

Insurance-relevant risks	Related ARL risk types
1. Technology risk: Potential risks for applied technologies, such as key components for upscaled features, prototypical designs, integration of technologies and processes, and risks of technology and equipment underperformance or failure.	- Functional performance (no. 2) - Ease of use/complexity (no. 3) - Manufacturing & supply chain (no. 10) - Materials sourcing (no. 11)
2. Project information & organisation risk: Risks associated with the development, organisation and management of the project with a system-based approach.	- Functional performance (no. 2) - Ease of use/complexity (no. 3) - Project development, integration & management (no. 8) - Infrastructure (no. 9) - Manufacturing & supply chain (no. 10) - Materials sourcing (no. 11) - Workforce (no. 12)
3. Legal, financial & compliance risk: Encompasses any legal or contractual aspect of the project and interactions between stakeholders that could halt the project, such as issues with licences, contractual obligations and statuary compliance. It also includes any financial aspects, such as solvency or sanction-related topics. Additionally, it covers issues related to inadequate compliance by stakeholders that could halt the project, such as not adhering to antitrust rules, and potentially lead to financial troubles.	- Delivered cost (no. 1) - Capital flow & availability (no. 7) - Regulatory environment (no. 13) - Policy environment (no. 14) - Permitting & siting (no. 15) - Environmental & safety (no. 16) - Community perception (no. 17)
4. Location-specific physical climate risks (extreme events and slow-changing climatic trends): Extreme events (Nat Cat, e.g. severe storms, floods, wildfires, extreme heat) that may impact the project over its lifetime. Takes into account any risk management measures that are being considered to build resilience.	- Infrastructure (no. 9) - Manufacturing & supply Chain (no. 10) - Workforce (no. 12)
5. Business interruption & supply chain risk: Any aspect that can lead to delays in the project, such as supply chain issues, as well as any aspect that can impact production during operation and impact profitability.	- Downstream value chain (no. 6) - Infrastructure (no. 9) - Manufacturing & supply chain (no. 10) - Materials sourcing (no. 11) - Workforce (no. 12)
6. Long-term risk: Issues that could have a significant impact on the long-term profitability and success of the project.	- Market size (no. 5) - Downstream value chain (no. 6) - Infrastructure (no. 9) - Manufacturing & supply chain (no. 10) - Materials sourcing (no. 11) - Workforce (no. 12) - Regulatory environment (no. 13) - Policy environment (no.14) - Environmental & safety (no. 16) - Community perception (no. 17)
7. Environmental, social and governance: Risks related to factors such as labour practices, human rights, board diversity, community engagement, biodiversity and nature-related management, and transparent reporting.	- Workforce (no. 12) - Permitting & siting (no. 15) - Environmental & safety (no. 16) - Community perception (no. 17)

Source: The Geneva Association

Table 4: Insurance-relevant issues related to technology risk

Technology risk
1.1. Basic technology overview and the scale up strategy, for example: 1.1.1. What manufacturing methods are used in mass production?
1.2. Material selection, for example: 1.2.1. Corrosion and materials of construction study
1.3. Development process, for example: 1.3.1. Development history, including descriptions of previous generations of prototypes or pilots, the performance of each generation, and the changes made between each generation. 1.3.2. Has any third-party certification been carried out on the technology and at project level? 1.3.3. Is an Independent Engineer's (IE) report available on the technical design?
1.4. Technology performance, for example: 1.4.1. Proof of functional performance of components and sub-components, new or prototype and upscaled technology sections 1.4.2. Provision of performance metrics, e.g. lifetime/number of cycles, specific power consumption, turndown flexibility, product quality specifications 1.4.3. Proof of both short-term and long-term reliability and durability, e.g. accelerated stress testing and accelerated lifetime testing 1.4.4. Proof of scale and quantity 1.4.5. Proof of integration with existing systems
1.5. Risk assessment of technology and level of technology maturity, for example: 1.5.1. Are the complete details of the testing and validation process for the technology available? 1.5.2. What level of protection and/or automatic shutdown features does the project have to prevent damage to equipment?
1.6. Due diligence activities and results, for example: 1.6.1. Have all external commercial operating conditions (such as interface risk, power interruption, grid instability, surcharge event etc.) been taken into consideration in the scenario testing?[35]
1.7. Quality assurance and control, for example: 1.7.1. Is there a quality control process in place? 1.7.2. Is there inspection and test plans in place?
1.8. Risk management of the development process, testing and validation in real-world environment, for example: 1.8.1. Proof of performance with real-world feedstock or input 1.8.2. Proof of acceptance of final product with the applicable customer or offtaker 1.8.3. Validation that the extent of piloting or prototyping is commensurate with level of novelty. Should consider scale, level of integration, duration, operating window, etc. 1.8.4. Environmental, health and safety risk evaluation and mitigation plan 1.8.5. How are risks identified through the development process and how are they addressed?
1.9. Regulatory standards, for example: 1.9.1. Is it feasible/possible for the industry to go beyond health and safety standards, to also consider standards to protect insured property from damage?

Source: The Geneva Association

32 Whilst this is a standard process, no operating data is available to support.

As another example, Table 5 shows the 'location-specific physical climate risks' section of the IRF, which provides more clarity on the types of issues that need to be considered for managing these risks.

Table 5: Insurance-relevant issues related to location-specific physical climate risks

Location-specific physical climate risks
4.1. Geographical exposure to extreme events, accumulation of risks for portfolios and mitigation approaches in place, for example: 4.1.1. Description of location- or portfolio-location-specific extreme events (Nat Cat and other perils) – Have the project, processes and equipment been designed to accommodate extreme weather conditions outside the normal expected range (beyond what may be considered typical based on historical records)? – Has this been discussed with all manufacturers, suppliers, operators, etc.? – What mitigation measures have been built into site design as a consequence? – What additional factors are built into the project design to monitor, anticipate and conduct preventive risk management? – Has the impact of extreme weather events on workforce and operational capacity been considered to avoid business interruption? 4.1.2. Description of location- or portfolio-location-specific slow-changing trends (prolonged extreme heat, water scarcity, etc.) outside normal conditions that may lead to recurrent business interruption, damage to equipment, compromised performance of the system.
4.2. Design/resilience of the project, including equipment and processes, supply chain, underlying infrastructure

Source: The Geneva Association

It is important to note that the issues associated with the seven risk categories in the IRF are not meant to be exhaustive. Individual re/insurance companies may add other issues that are relevant to their own assessment processes.

5.2 Benefits of the IRF

Utilising the IRF for enhanced strategic risk conversations at the industry level

At the strategic level, the IRF can be used to identify and frame risks that may be considered uninsurable from a commercial insurance market lens and may require different interventions, such as PPPs or government backstops. Using the IRF in climate tech project development from the demonstration and early deployment stages (TRL 6–7) could help to identify the most challenging risk areas and develop structured risk management solutions. It may also aid in allocating risks among parties based on appetite and ability to bear risk, thereby attracting more capital and ensuring optimal risk financing. As technologies mature and re/insurers become engaged in more projects, they can engage with standard-setting and certification bodies to identify effective risk management strategies to help with the development of risk management standards and codes of practice.

Utilising the IRF at the project level

Transparency around insurance requirements will enable climate tech project developers and their engineering partners to address them in a more targeted way during different phases of project development, with the following benefits:

- Information provided by project developers will be more in line with insurance expectations, which will help to streamline the process.
- Insurance-related risk considerations will be reflected during project design. This could include long-term climate risks being considered during site and equipment selection or the development of mitigation measures to minimise operational risks across the value and supply chains.
- The IRF could help avoid unnecessary iterations during project development due to oversight of insurance-related risks. It may even help expedite the process, given the enhanced risk awareness of project developers.

5.3 Case studies

Through three technical multi-stakeholder workshops,[33] we utilised the IRF to frame and facilitate a dialogue around the range of risks associated with two major emerging technologies: green hydrogen and carbon management (with focus on geological storage technologies and related carbon markets) to identify the risks that pose the most challenges from insurability perspective. A summary of findings is provided in this section.

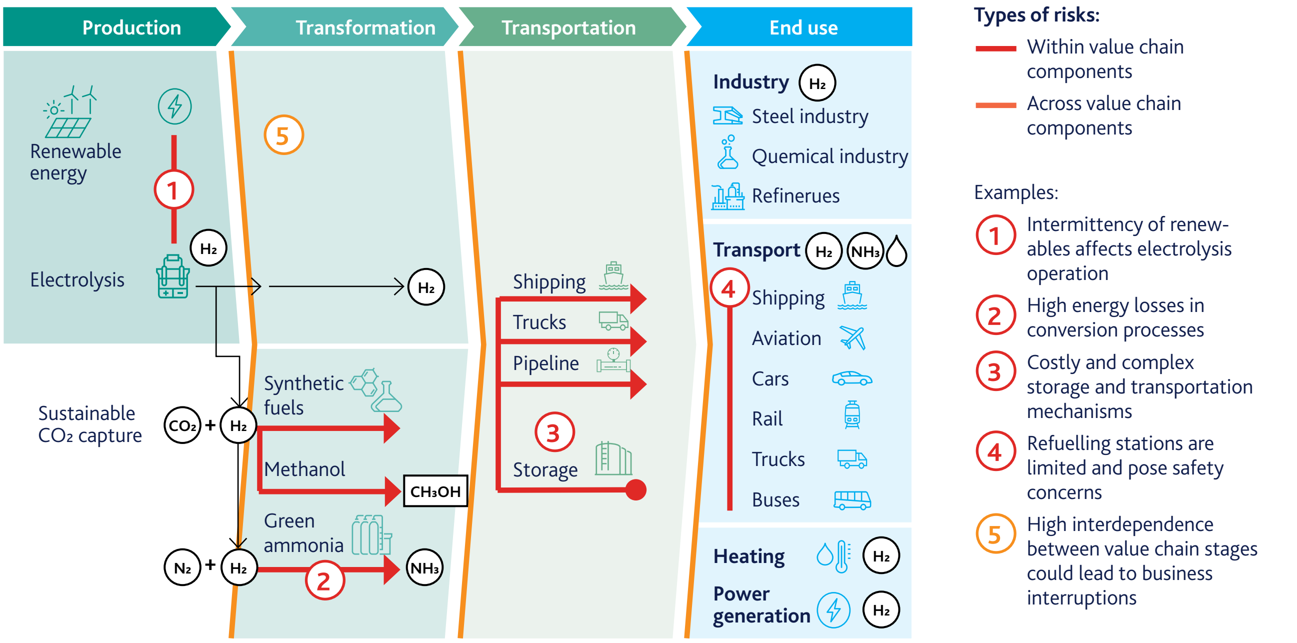
Green hydrogen

The least emissions-intensive pathway to produce hydrogen is referred to as green hydrogen.[34] It is produced through electrolysis using renewable energy as the power source, mainly solar and wind power. As of December 2023, globally announced green hydrogen production capacity is 32 million tons per annum (Mt p.a.) by 2030, with approximately 2 Mt p.a. already having passed the final investment decision.[35]

As of October 2023, the total investment gap for both green and blue[36] hydrogen projects (collectively known as clean hydrogen) is USD 961 billion by 2030,[37] with 50% allocated to hydrogen production and supply, 25% to infrastructure including hydrogen transportation and storage, and the remaining 25% to support end-use applications such as electric power or mobility. While an estimated USD 570 billion in direct investments has been announced, only USD 39 billion has passed the final investment decision. Further development and commitment are required to close the gap.[38] The establishment of hydrogen hubs is playing a crucial role in expediting the market, boosting supply chains and facilitating infrastructure for the commercial-scale deployment of clean hydrogen.[39,40]

This case study considers complex and large-scale green hydrogen projects (Figure 5). The value chain consists of hydrogen production, transformation into transportable products (such as ammonia or methanol), storage and transportation (via ships, pipelines, etc.) to the end user. At the point of end use, there may be a need for final deconversion of the transported product (e.g. ammonia) back to hydrogen. An overview of the major risks as well as the most challenging risk categories from the IRF is provided in Box 2.

FIGURE 5: COMPLEX GREEN HYDROGEN PROJECTS AND RISKS ALONG THE VALUE CHAIN



Source: Modified from IRENA[41]

33 These workshops included representatives from the insurance industry, certification organisations, data developers, project developers, engineering and technology companies, financial institutions and investors, government agencies, hydrogen hubs, law firms, equipment manufacturers, universities and the scientific community, and multi-lateral organisations. The Geneva Association 2023b,d,e.
34 For more information on other production pathways see IEA 2023a.
35 Hydrogen Council and McKinsey 2023.
36 Blue hydrogen is produced through natural gas reforming with an additional carbon capture and storage (CCS) step. As for green hydrogen, blue is considered a clean production pathway due to the inclusion of the CCS step.
37 Hydrogen Council and McKinsey 2023.
38 Ibid.
39 The Geneva Association 2024.
40 Examples of hubs currently under development include the Hellesylt Hydrogen Hub in Norway (expected to start operations in 2024) and the Pacific Northwest Hydrogen Association (PNWH2) Hub in the states of Washington, Oregon and Montana (U.S.).
41 IRENA 2022 (Figure 3.9).

Box 2: The most challenging risks associated with complex green hydrogen projects from an insurance perspective

1. **Within each component of the value chain**
   - Interdependencies between renewable power sources and electrolyser operations; for example, the intermittent nature of renewable power could result in insufficient power supply for electrolysers.
   - Transformation, transportation and storage are complex and costly and require improved technologies, particularly as the projects scale.
   - Long-term availability and quality of feedstocks, such as water and CO_2 (for green fuels), are critical for sustainable production.
   - End-use applications, such as freight transport, long-duration energy storage and refuelling stations, need to be demonstrated on a large scale.
   - Transformation of hydrogen to ammonia as fuel or as a hydrogen carrier requires new infrastructure and safety measures.
   - The massive upscale required across all components presents a number of risks, such as lack of an experienced workforce, supply and replacement of equipment, and the need for new technologies for storage and transformation.

2. **Across value chain components.** A failure in one component can disrupt the entire value chain and affect business continuity. For example, failure to produce sufficient renewable energy would lead to disruptions in transformation, storage, transportation and delivery to the end user, with implications for insurability if not anticipated and mitigated.

The following risks specified in the IRF have been identified as the most challenging:

Technology risk
- Assessing risks, evaluating technology performance and conducting due diligence activities are hindered by a lack of operational experience due to the limited number of projects currently in operation.
- Developing risk-transfer capabilities and allocating risk between project stakeholders may be hampered by inconsistent application of standardised structures and project diversity (size, technology, location, etc.) due to a lack of standards and codes of practice.

Project information and organisation risk
- Carrying out risk assessments and benchmarking practices is difficult due to the number and interconnectivity of value chain components.
- Finding companies that are capable of handling the operational risk is challenging because of the lack of operational and maintenance experience and workforce.

Long-term risk
- Assessing the long-term viability of projects with a full life cycle view is challenging due to climate change and the lack of historical data and analytics.
- The continuous push to improve technology efficiencies and performance could result in cycles of series upgrades and technology obsolescence.

How are public policy and government programmes mitigating risks?

A number of actions are being undertaken through new public policy, regulations and subsidies to mitigate some of the risks associated with hydrogen.

- The U.S. government, through the Bipartisan Infrastructure Law[42] and Infrastructure Reduction Act (IRA),[43] is addressing risks by:
  - Facilitating hydrogen markets and incentivising early offtakers through a Notice of Intent[44] that aims to provide necessary market certainty for producers and end users during the early stages of production.

42 The White House 2021.
43 The White House 2022.
44 U.S. DoE 2023b.

– Establishing seven major hydrogen hubs[45] across the country to address the risks associated with market development and growth, as well as the development of supply chain and infrastructure for the commercial-scale deployment of clean hydrogen.
– The U.K. government, through the Research and Innovation Industrial Decarbonisation Challenge,[46] is supporting the development of underpinning infrastructure systems.
– The launch and establishment of carbon border adjustment mechanisms (CBAM) enforced by a legislative act in the EU and the U.S. promotes greener manufacturing by imposing import fees on foreign products that cause more pollution during manufacturing than similar domestic products. This aims to drive heavy industries to transition to green hydrogen from conventional fossil fuel sources.[47]

Source: The Geneva Association[48]

Carbon management (with focus on carbon storage and carbon markets)

The carbon management value chain includes CO_2 capture, transportation, and utilisation or storage, usually summarised by the term carbon capture utilisation and storage (CCUS). The intended outcome can be to either reduce ongoing emissions at their source, or to undo past emissions independently from their original source (carbon dioxide – or simply carbon – removal). The processes involved in CCUS can be carried out through nature- or technology-based solutions, or a combination of both.[49] In nature-based solutions, the CO_2 capture step is performed in biological systems. Technological solutions capture CO_2 in one of two ways:

- From high-CO_2-emitting point sources, e.g. municipal solid waste incineration plants or steel and cement production facilities, known as point-source capture.

- Through direct air capture methods, which remove CO_2 directly from the atmosphere.

CO_2 can either be directed to dedicated geological storage sites or utilised for other purposes, such as the production of concrete or synfuels. There are two approaches for storing in deep geological formations:

- *Geological storage.* Compressed CO_2 is pumped deep underground into a porous host rock that is concealed by a layer of impermeable caprock (examples of such geological formations are depleted oil and gas fields, or saline aquifers).

- *In-situ mineralisation.* This entails injecting dissolved CO_2 into rock layers where the rock minerals help to fix the CO_2 in the form of solid mineral carbonates (such as limestone).

As of July 2023, there are 41 operational CCUS facilities worldwide, with a collective total CO_2 capture capacity of 49 Mt p.a.[50] Of these facilities, 40 are dedicated to emission reduction through point-source capture. Only one facility is dedicated to carbon removal, namely the Direct Air Capture and Storage (DACS) pilot 'Orca,' located in Iceland.[51] To achieve the decarbonisation of heavy industries, approximately 700 Mt p.a. of CO_2 would need to be captured and stored by 2030.[52] According to the Intergovernmental Panel on Climate Change (IPCC), maintaining global emissions at net-negative levels will be necessary throughout the second half of the current century. Globally, the carbon removal sector would need to achieve around 6 billion tonnes of negative CO_2 emissions annually by 2050[53] to limit global warming below 1.5°C and a cumulative total of up to 1,000 billion tonnes of negative emissions by 2100, depending on how fast and at what scale global emissions are reduced.[54] The carbon removal industry must continue developing at an unprecedented pace to deliver such enormous negative emissions on time.

Increasing the establishment of CCUS networks or clusters (hubs) has been key to bolstering the supply chain, facilitating infrastructure, and bringing together producers and consumers.[55]

45 U.S. DoE 2023c.
46 U.K. Government 2023.
47 Cohen 2023; European Commission 2023.
48 The Geneva Association 2023b.
49 Swiss Re 2021.
50 CCS Institute 2023.
51 The 'Orca' DACS facility has a capacity of 4,000 tonnes p.a. Climeworks 2021.
52 The Geneva Association 2024. Table 1.
53 McKinsey Sustainability 2022.
54 IPCC 2018.
55 Regions such as the Gulf Coast in the U.S., Alberta in Canada and the North Sea in Europe exemplify this trend. These host a number of CCUS facilities that form networks essential for the development and deployment of carbon removal technologies.

Furthermore, the development of robust and trustworthy carbon markets with verifiable carbon credits is important for incentivising carbon management projects. They provide a platform to monetise carbon reduction or removal efforts through the trading of carbon credits. There are two types:[56]

- *Compliance carbon markets* are created and maintained by jurisdictions as part of national, regional and/or international climate policies or conventions.
- *Voluntary carbon markets,* whether national or international, are not a compliance tool and involve the issuance, buying and selling of carbon credits on a voluntary basis.[57]

In recent years there has been increased scrutiny on the integrity of carbon credits, especially for credits from nature-based solutions projects. There is also growing interest in unlocking carbon finance via the sale of credits from technological solutions that involve geological CO_2 storage and in-situ mineralisation. To ensure the credibility of these markets, more robust project methodologies and certification standards need to be developed, including stringent monitoring, reporting and verification practices.[58] Using the IRF in discussions with stakeholders indicated that the scalability of the carbon management industry is heavily reliant on the long-term durability of carbon storage systems, i.e. long-term liabilities associated with potential future storage reversal events (release of CO_2 back into the atmosphere). Carbon markets involving long-term CO_2 storage operations face the same challenges and related uncertainties. Box 3 captures the issues in more depth.

Box 3: The biggest risks related to carbon management scalability from an insurability perspective

Long-term risks associated with the durability of carbon storage are the 'elephant in the room'. If not solved, they could hold back the scaling of the entire carbon management value chain indefinitely. In addition:

- Technological risks such as insufficient or deficient storage site characterisation or abandoned/poorly mapped wells in depleted oil/gas fields targeted for CO_2 storage.
- Legal, finance, compliance and litigation risk such as environmental liabilities associated with ground water contamination linked to CO_2 leakage, and higher risks of induced seismicity and ground movement associated with in-situ mineralisation.
- Insufficient monitoring capabilities or resources that render the assessment of the size of a loss, as well as indemnity and pricing aspects, very difficult.
- For carbon markets, storage reversal would lead to loss of carbon certificates, price risk[59] and/or delivery risk.[60]

PPPs are recommended for the development of insurance solutions, with governments as potential insurers of last resort. Such partnerships are crucial to bridging the insurability gap and enabling innovative risk transfer solutions for technological carbon storage mechanisms. This approach is similar to past situations involving low-frequency/high-risk sectors such as nuclear power and brownfields,[61] where PPPs helped overcome long-term liability issues. Better data availability and analytics, and more robust monitoring, reporting and verification tools are also crucial for assessing, framing and managing the risks associated with storing CO_2.

How are government programmes mitigating risks?

Government programmes have been developed to:

- Encourage the establishment of carbon management hubs and dedicated storage facilities to advance the wide-scale deployment of carbon management technologies, such as the U.S. DoE's Carbon Storage Assurance Facility Enterprise (CarbonSAFE)[62] programme, which funds nine carbon storage projects across the country to develop and increase the number of geologic storage sites progressing toward commercial operations.

56 Carbon Market Watch 2020.
57 United Nations Development Programme (UNDP) 2022.
58 The Geneva Association 2023c.
59 Price risk is the risk that the value of a security or investment will decrease. https://www.investopedia.com/terms/p/pricerisk.asp
60 Delivery risk happens when carbon storage does not meet forecasted expectations due to unreliable measuring methodologies to estimate the number of carbon credits of a certain project, and permanence, validation and usage failures of the storage system.
61 A brownfield site is defined as a real property, the expansion, redevelopment or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutants or contaminants.
62 U.S. DoE 2023d.

- Incentivise carbon markets to address the risks associated with market development, such as the EU Carbon Removal Certification framework[63] and the U.S. DoE's Carbon Dioxide Removal Purchase Pilot Prize.[64] These initiatives aim to build standards for successful and high-quality carbon removal programmes, create a market to encourage technology innovation and foster industry growth.
- Protect subsurface potential drinking water when injecting carbon in underground geological formations for storage, e.g. the Class IV well regulation of the U.S. Environmental Protection Agency's (EPA's) Underground Injection Control programme.[65]
- Expand the market, lower the cost of CCUS and shorten construction timelines, e.g. the set of rules proposed by The Government of Japan and other Asian countries at an Asia Zero Emission Community (AZEC) meeting.[66]

Source: The Geneva Association[67]

63 European Commission 2022.
64 U.S. DoE 2023e.
65 U.S. EPA 2011.
66 AZEC 2023.
67 The Geneva Association 2023d,e.

6 Conclusions and recommendations

Conclusions and recommendations

Implementing climate technologies at the scale needed for industrial decarbonisation over the next decade will require new ways of doing business. Demonstrating and deploying these technologies is capital intensive and comes with many challenges. Available, accessible and affordable insurance solutions will be essential for getting new climate technologies market ready, securing financing and managing the liabilities associated with projects. Assessing insurability conditions for climate tech projects and developing insurance solutions is complex and time consuming due to the myriad risks involved and the lack of historical data and experience.

Most new climate technologies are being developed by small- to medium-sized firms, which may not have a strong balance sheet, sufficient risk management expertise and/or broader knowledge about insurance and related requirements. This report outlines why and how climate tech developers, their partners and other stakeholders could benefit from working with re/insurers, particularly through leveraging their risk engineering expertise.

Collaboration from the very early stages of projects will enable insurability conditions to be determined and insurance tools to be developed on a tech-by-tech basis. Furthermore, the development and implementation of risk mitigation strategies will help to improve insurability conditions. The costs associated with involving re/insurers' risk engineering teams should also be acknowledged and evaluated very early on in the project. The long-term benefits – risk prevention, financial optimisation, commercial opportunities – would potentially outweigh the initial costs.

This report sheds light on issues that need to be considered for assessing and improving the insurability of new climate technologies. The Insurability Readiness Framework (IRF) offers guidance on how to think about risks from an insurance perspective and will enable more informed conversations between re/insurers and climate tech stakeholders.

Recommendations

1. **Entities with access to pipelines of projects, e.g. investor platforms, engineering companies, and climate tech hubs and associations, should collaborate with re/insurers to:**

   - Raise awareness and educate climate tech project developers about:
     - The crucial role of insurance for managing risks, mobilising capital and financing projects.
     - The benefits of early, direct engagement with re/insurers' risk engineering teams.
     - The benefits of using the IRF to consider risks holistically.
   - Utilise the IRF to identify factors that could hinder the insurability and scalability of climate technologies, as demonstrated in this report for carbon management and complex green hydrogen projects. The framework could be applied to other emerging technologies such as long-duration energy storage, sustainable aviation fuel or small modular nuclear reactors, for example.

2. **Climate tech stakeholders should leverage re/insurers' risk engineering expertise and utilise the IRF from the early stages of projects to:**

   - Frame project risks more holistically and evaluate the data needed by re/insurers.
   - Better address insurance requirements by providing information that is in line with insurance expectations and ensuring that adequate risk management measures are considered in project design.

3. **Governments and policymakers should collaborate with re/insurers to:**

- Raise awareness of the importance of insurance for commercialising new climate technologies and obtaining government subsidies.
- Identify risks that are not insurable through commercial insurance markets and may require public-private solutions.
- Support the development of climate-tech-specific databases and analytical tools needed for risk assessment and the development of insurance solutions.
- Identify tech-specific risk management and incorporate these in the development of public policies, regulatory frameworks and government programmes.

4. **Re/insurers should:**

- Invest strategically in building their internal expertise and capacities by expanding their risk engineering services for viable emerging climate technologies.
- Strengthen partnerships with entities that have access to climate tech projects from TRL 6–7, such as EPCs, climate tech hubs, investor platforms and governments. This will help to educate project developers about the benefits of risk engineering services and the key role of insurance, and explore opportunities to develop pools of projects to spread risks.
- Strengthen industry-level collaboration and partnerships to develop innovative risk management solutions to identify the unique insurance needs of different climate technologies, as well as work with standard-setting and certification bodies to converge on best practices for the development of risk management frameworks and standards to enable project replication.
- Strengthen collaboration with governments, the scientific community, climate technologists, and third-party technology verification and testing firms to compile data and analytics that may already be available on emerging climate technologies and translate these for insurance use.

We hope the findings and recommendations presented in this report help advance dialogue and collaboration among climate tech stakeholders and re/insurers. The re/insurance industry has a crucial role to play in supporting the rollout of new climate technologies, but significant progress needs to be made in order to unlock their potential contributions. This includes:

- Developing practical mechanisms for engaging re/insurers' risk engineering teams directly and more efficiently with project developers and other stakeholders from the demonstration and pilot stages and from early phases of project development.
- Exploring how insurance markets could be best leveraged to enable the at-scale deployment of climate tech.
- Better understanding insurance needs for funding climate tech projects through debt and capital market financing.
- Improving understanding of how industrial sectors are adopting these emerging technologies and the implications for their business models.

Appendices

Appendix 1: Factors to consider as climate technologies move from TRL 6 to 9

	TRL	Types of projects	Financing	Insurance-related issues of concern to project developers
Demonstration and early deployment	**TRL 6 – Early field demonstration and system refinements are completed**	- Projects in pre-pilot, demonstration with limited hours under highly controlled conditions.	- Generally a combination of grants, venture and private equity investments, and possibly some development capital.[71]	- While the insurable value of the assets is relatively low at this stage, project developers start thinking about the evaluation of supply chain capabilities, offtake agreements and performance insurance, which are essential to secure non-recourse project financing.[72] - As they prepare to launch FOAK pilots, they need to think about a range of protection, e.g. offtake credit insurance, revenue/price insurance protection, political risk insurance, supply chain insurance.

	TRL 7 – Complete system demonstration in an operational environment	- First-of-a-kind (FOAK) to first-few-of-a-kind pilot-type projects..[73]
		- Main goals:
		  - Assess and improve technological risks, such as performance, operational complexities and related safety issues.
		  - Develop associated economic models for the entire system within an operational environment.
		  - Projects emphasise customer adoption and the value proposition of the technology.
		- There are inherent uncertainties associated with projects' unique technological complexities, the risks associated with planning for project finance and target markets for the technology.
		- The company's new business model and ability to implement it may have inherent uncertainty.
			- Generally include multiple rounds of private equity and development capital to fund preparatory work.
			- Government support plays a major role in the execution of most FOAK projects.
			- At this level, multi-hundred-million-dollar projects or assets can secure non-recourse financing.
			- Coordinated investor platforms such as Breakthrough Energy.[74]
				- Specific terms of EPC agreements, ensuring the creditworthiness of offtake and feedstock (if relevant) with implications for insurance. Insurers may receive specific insurance queries from developers and their insurance intermediaries, e.g.:
				  - Surety[75] and liquidated damages (LDs)[76] for delays in startup – particularly important with EPC agreements and technology vendor agreements and guarantees. In most cases, LDs and performance guarantees from EPCs and technology vendors are inadequate for lenders/bond investors.
				  - Customers seeking equipment finance are also concerned by the lack of adequate warranty support and LDs insurance in the event of failure. This is because the original equipment manufacturers are often new and not creditworthy, even if the technology is leading in the market.

Source: The Geneva Association, based on deliberations with re/insurers, MGAs EPCs and investors.

68 Development capital is a form of business funding which helps established businesses to grow. It is typically provided by an investor in exchange for an equity stake in the business. Development capital can enable mature businesses to scale up, increase their revenues and build up their customer base.
69 Non-recourse project financing refers to a type of commercial lending that entitles the lender to repayment only from the profits of the project the loan is funding and not from any other assets of the borrower.
70 Climate Tech VC 2023. Given the inherent uncertainty around FOAK (or even the first few 'early-of-a-kind') projects, climate tech projects are challenging, from securing financing to building risks and many unknowns about the rewards and returns on the investment.
71 Fernandez 2023.
72 A surety acts as a guarantee that a person or an organisation assumes responsibility for fulfilling financial obligations in the event that the debtor defaults and is unable to make payments. The party that guarantees the debt is referred to as the surety or the guarantor.
73 Delays, failures or lack of performance can result in compensation payments like Liquidated Damage (LD) from project developer or contractor to the owner.

	TRL	Types of projects	Financing	Insurance-related issues of concern to project developers
At-scale commercial development	**TRL 8 –** **Early commercial deployment**	- First commercial-scale projects or equipment financing, depending on the technology. There can also be consideration of a licencing business model so the technology owner does not have to raise capital and develop the project alone. - Increase in both the number and size of projects due to technology maturity. - All elements related to the market readiness of the technology indicated in the ARL (Table 1) must be addressed to prepare for wide-scale deployment in TRL 9.	- Rely on private equity and development capital. However, project owners/developers are looking for long-term cost-effective capital through project finance.	- Project developers need access to a full suite of insurance solutions, which are required by lenders (banks and bondholders), who are often heavily influenced by their advisors. - Annual insurance costs can be more than 1–2% of asset value depending on location and type of asset and operation. - Projects might still be unproven and possibly considered 'uninsurable,' or have limited or partial insurability.
At-scale commercial development	**TRL 9 –** **Wide-scale commercial deployment**	- The technology is deployed at full commercial scale and replicated. - The main goal is to address unique challenges related to scaling up the project's operational capacity and replication. Operating on a larger scale will have risk implications – the risk profile of the project may be different. - All elements related to the market readiness of the technology are in place (in principle) and have been considered during project design and deployment.	- Long-term favourable investments through debt and capital market solutions with scaled participation of institutional investors.	- Project developers need access to risk management standards, codes of practice and guidelines for project replication. - A full suite of insurance solutions are required to address risks throughout the project lifecycle. - Debt capital providers and customers seek the benefits of performance insurance, possibly at lower levels of total coverage. As technologies become more widely deployed, risks are mitigated or become better understood through demonstrated performance, and a greater share of the remaining risk can be transferred to insurers. - Continuous technological innovation makes assessing the risk profiles challenging and can lead to limited availability or outdated insurance covers.

Appendix 2: Insurability Readiness Framework

This Insurability Readiness Framework (IRF) has been developed as a guide to translate risks associated with the TRL and ARL frameworks into seven risk categories from the insurance lens. IRF enables all stakeholders involved in the climate tech ecosystems to have a more holistic view of the risks and their interconnectivities. This enables more informed dialogue about various risks, related issues and data needs to explore insurability conditions, consider risk management strategies, what may or may not be insured through the commercial insurance markets, motivate insurance product innovation for the insurable aspects and explore ways to address the uninsurable aspects through other means, such as public-private partnerships or even the government as the insurer of the last resort. [74]

1. Technology risk

Potential risks for applied technologies, such as key components for upscaled features, prototypical designs, integration of technologies and processes, and risks of technology and equipment underperformance or failure.

Relevant risks from ARL framework (Table 1): Functional performance (no. 2); Ease of use/complexity (no. 3); Manufacturing & supply chain (no. 10); Materials sourcing (no. 11)

1.1. **Basic technology overview and the scale-up strategy,** for example:
- 1.1.1. What manufacturing methods are used in mass production?

1.1. **Material selection,** for example:
- 1.1.1. Corrosion and materials of construction study

1.3. **Development process,** for example:
- 1.3.1. Development history, including descriptions of previous generations of prototypes or pilots, the performance of each generation, and the changes made between each generation.
- 1.3.2. Has any third-party certification been carried out on the technology and at project level?
- 1.3.3. Is an independent engineer's report available on the technical design?

1.4. **Technology performance,** for example:
- 1.4.1. Proof of functional performance of components and sub-components, new or prototype and upscaled technology sections
- 1.4.2. Provision of performance metrics, e.g. lifetime/number of cycles, specific power consumption, turndown flexibility, product quality specifications
- 1.4.3. Proof of both short-term and long-term reliability and durability, e.g. accelerated stress testing and accelerated lifetime testing
- 1.4.4. Proof of scale and quantity
- 1.4.5. Proof of integration with existing systems

1.5. **Risk assessment of technology and level of technology maturity,** for example:
- 1.5.1. Are the complete details of the testing and validation process for the technology available?
- 1.5.2. What level of protection and/or automatic shutdown features does the project have to prevent damage to equipment?

1.6. **Due diligence activities and results**, for example:
- 1.6.1. Have all external commercial operating conditions (such as interface risk, power interruption, grid instability, surcharge event etc.) been taken into consideration in the scenario testing?[77]

1.7. **Quality assurance and control,** for example:
- 1.7.1. Is there a quality process in place?
- 1.7.2. Are there inspection and test plans in place?

1.8. **Risk management of the development process, testing and validation in a real-world environment, for example:**
- 1.8.1. Proof of performance with real-world feedstock or input
- 1.8.2. Proof of acceptance of final product with the applicable customer or offtaker
- 1.8.3. Validation that the extent of piloting or prototyping is commensurate with level of novelty. Should consider scale, level of integration, duration, operating window, etc.
- 1.8.4. Environmental, health and safety risk evaluation and mitigation plan
- 1.8.5. How are risks identified through the development process and how are they addressed?

74 While this is a standard process, no supporting operational data is available.

2. Project information and organisation risk

Risks associated with the development, organisation and management of the project.

Relevant risks from ARL framework (Table 1): Functional performance (no. 2); Ease of use/complexity (no. 3); Project development, integration & management (no. 8); Infrastructure (no. 9); Manufacturing & supply chain (no. 10); Materials sourcing (no.11); Workforce (no. 12)

2.1. Risk identification, for example:
- 2.1.1. What are the key technologies and components of the project?
- 2.1.2. Have risks of each component of the project been identified?
- 2.1.3. Have the risks at the interfaces of the components of the project been identified, systematically?

2.2. Risk assessment/benchmarking, for example:
- 2.2.1. How have interface risks been identified?
  - i. Are these risks being managed in the design of the project?
  - ii. Which parties are engaged from early stages?
  - iii. Where does responsibility lie for interface risks?
  - iv. Are contractors and suppliers willing to accept any risk here? (Note: this would be seen as a positive to insurers)
- 2.2.2. Has a selection and/or quality criteria process or a certification process been put in place by the developer or contractor to prove and demonstrate proven capability for those needing to construct, test, operate and maintain the machinery?
  - i. How does the developer ensure only personnel with the proven credentials may carry out critical tasks on the project?

2.3. Risk monitoring and communication approach[78]

2.4. Risk philosophy (i.e. broad overview of risk identification and management policy and key addressable considerations)

2.5. Risk management process and results (with a life cycle approach to ensure continuous improvement), for example:
- 2.5.1. Will working permits be used and deployed on the project for anyone working near or operating the plant?
- 2.5.2. From a business interruption perspective, what types of risk assessment have been carried out? For example:
  - I. Machinery breakdown
  - II. Contingent business interruption
  - III. Internal supply chain disruption
- 2.5.3. Is there one overarching EPC contractor the whole production unit and dictating that standards and engineering practices be adopted?

2.6. Certification and warranties

2.7. Due diligence information for stakeholders (i.e. investors, insurers)

2.8. Standard erection all risk evaluation

2.9. Critical operational risk aspects[79]
- 2.9.1. What are the limits/interface points from an operational standpoint for each and every part of the project?

2.10. Access to materials, equipment, supply chain, workforce

2.11. Readiness of the underpinning infrastructure (physical and digital large-sale systems that need to be in place to support, enable and facilitate project deployment), and alternative options

2.12. Change management, for example:
- 2.12.1. Who is going to produce a gap analysis between construction basic design and installation execution for the entire project if units are managed by different contractors?

2.13. Testing and handover process, standards and requirements, for example:
- 2.13.1. Which standard of performance test will be adopted for the project? A shared one or specific by unit?
- 2.13.2. What are the criteria used for performance testing and handover?

2.14. Contingency plan/business continuity plan
- 2.14.1. Is it comprehensive?

75 Details of risk monitoring dependent on development phase.

76 For new technologies, developers have no operational and maintenance experience and/or workforce and struggle to find companies who can take this on.

3. Legal, finance, compliance and litigation risk

Encompasses any legal or contractual aspect of the project and interactions between stakeholders that could halt the project, such as issues with licences, contractual obligations and statuary compliance. It also includes any financial aspects, such as solvency or sanction-related topics. Additionally, it covers issues related to inadequate compliance by stakeholders that could halt the project, such as not adhering to antitrust rules, and potentially lead to financial troubles.

Relevant risks from ARL framework (Table 1): Delivered cost (no. 1); Capital flow & availability (no. 7); Regulatory environment (no. 13); Policy environment (no. 14); Permitting & siting (no. 15); Environmental & safety (no. 16); Community perception (no. 17)

3.1. Risk provisions in the budget

3.2. Budgets for warranties/solvency management of project

3.3. Company's legal aspects

3.4. Licences and patents

3.5. Legal framework of project and status of testing

3.6. Approval processes and responsible authorities, for example:

3.6.1. Are permits in place?

3.7. Project financing arrangements (e.g. financing structure and structure of interdependencies between all stakeholders)

3.8. Directors & Officers (D&O) relevant topics of involved management team (e.g. liabilities from legal actions, regulation/legislation, and/or from shareholders)

3.9. Contractual requirements from subsidies, guarantees, feed-in tariffs and provisional acceptance certification

3.10. Litigation risk associated with environmental aspects or brought forward due to community perception

4. Location-specific physical climate risks (extreme events and slow-changing climatic trends)

Location- or portfolio-location-specific extreme events (Nat Cat, e.g. severe storms, floods, wildfires, extreme heat) that may impact the project over its lifetime. Takes into account any risk management measures that are being considered to build resilience.

Relevant risks from ARL framework (Table 1): Infrastructure (no. 9); Manufacturing & supply chain (no. 10); Workforce (no. 12)

4.1. Geographical exposure to extreme events, accumulation of risks for portfolios and mitigation approaches in place, for example:

4.1.1. Description of location- or portfolio-location-specific extreme events (Nat Cat and other perils)

i. Have the project, processes and equipment been designed to accommodate extreme weather conditions outside the normal expected range (i.e. beyond what may be considered typical based on historical records)?

ii. Has this been discussed with all manufacturers, suppliers, operators, etc.?

iii. What mitigation measures have been built into site design as a consequence?

iv. What additional factors are built into the project design to monitor, anticipate and conduct preventive risk management?

v. Has the impact of extreme weather events on workforce and operational capacity been considered to avoid business interruption?

4.1.2. Description of location- or portfolio-location-specific slow-changing trends (prolonged extreme heat, water scarcity, etc.) outside normal conditions that may lead to recurrent business interruption, damage to equipment, compromised performance of the system.

4.2. Design/resilience of the project, including equipment and processes, supply chain, underlying infrastructure

5. Business interruption and supply chain risk

Any aspect that can lead to delays in the project, such as supply chain issues, as well as any aspect that can impact production during operation and impact profitability.

Relevant risks from ARL framework (Table 1): Downstream value chain (no. 6); Infrastructure (no. 9); Manufacturing & supply chain (no. 10); Material sourcing (no. 11); Workforce (no. 12)

5.1. Risk assessment – which risks could lead to business interruption and have mitigation measures been considered from an early stage? For example:

- 5.1.1. Cyber risk and resilience
- 5.1.2. Resilience of the underpinning infrastructure
- 5.1.3. Compounding impacts of extreme events leading to business disruption
- 5.1.4. Possible supply chain disruption
  - i. Is there a replacement part/repair strategy?
  - ii. Are there any agreements in place to guarantee/expedite repair (e.g. long-term service agreements, predictive maintenance, critical spares holding, remote monitoring)?
- 5.1.5. Has the manufacturer been involved in the design stages of the project?
  - i. Have all necessary safety and protective features recommended by the manufacturer to protect equipment from possible damage been considered?
- 5.1.6. How would loss of key utilities impact the project (e.g. loss or curtailment of power)?
  - i. What measures are bring taken to mitigate this risk?

5.2. Business continuity plan, for example:

- 5.2.1. Does your project require delay in start up and business interruption insurance? This would likely increase the onus on TRL requirements, etc. given the increased risk to insurers.
  - i. Are investors, manufacturers and suppliers willing to take some share of this risk – particularly for more unproven/prototypical technologies or new/unproven manufacturing processes?
- 5.2.2. What sparing philosophy have you adopted for critical equipment?

5.3. Emergency response plan

5.4. Redundancy and backup systems to ensure continued operations

5.5. Supply chain diversification

5.6. Data protection and cybersecurity

5.7. Employee training

5.8. Regular testing and drills

6. Long-term risk

Any long-term issues that could have a significant impact on the profitability and success of the project.

Relevant risks in ARL framework (Table 1): Market size (no. 5); Downstream value chain (no. 6); Infrastructure (no. 9); Manufacturing & supply chain (no. 10); Material sourcing (no. 11); Workforce (no. 12); Regulatory environment (no. 13); Policy environment (no. 14); Environmental & safety (no. 16); Community perception (no. 17)

6.1. Liability or emerging risks, for example:

6.1.1. Technology obsolescence risk

6.1.2. Risks that have not yet fully materialised, e.g. cyber risks, future climate changes, future legislation

6.2. Litigation risks

6.3. Long-term risks of extreme events and slow-changing climatic trends on the project

6.4. Climate-related public policy and regulatory risks (e.g. changing laws to hinder operations, water laws, environmental policies)

6.5. Any change in ESG risk

6.6. Long-term warranty obligations

7. Environmental, social and governance risk

Risks related to issues such as carbon footprint, labour practices, human rights, board diversity, community engagement, biodiversity and nature-related management, and transparent reporting.

Relevant risks from ARL framework (Table 1): Workforce (no. 12); Permitting & siting (no. 15); Environmental & safety (no.16); Community perception (no. 17)

7.1. Environmental impact assessment, for example:

7.1.1. What are the environmental risks associated with the supply chain of the technology (e.g. mining of materials, transportation, production)?

7.2. Sustainability strategy (e.g. environmental protection, sustainable use of resources)

7.3. Supply chain and resource sustainability, for example:

7.3.1. Does the water for your project come from any sources with scarcity issues?

7.3.2. Where are the materials for equipment manufacture sourced from (e.g. issues related to workforce and related practices)?

i. Where is your manufacturing and assembly plant located?

7.4. Carbon footprint, for example:

7.4.1. What is the carbon footprint of the project over its life cycle, including Scope 1, 2 and 3 emissions?

7.4.2. What is the carbon footprint of the project's value chain?

7.5. Biodiversity and nature-related financial risks

7.5.1. Details of any environmentally sensitive areas, impact on biodiversity, destruction or damage of natural systems/sites of special scientific interest within close proximity to project locations

7.5.2. Other nature-related financial risks

7.6. Labour practices, community engagement and human rights (e.g. displacement of indigenous communities, modern-day slavery, promoting local content)

7.7. Board diversity

7.8. Transparent reporting

Glossary of terms used in the IRF

Business continuity plan: strategic playbook created to help an organisation maintain or quickly resume business functions in the face of disruption, whether that disruption is caused by a natural disaster, civic unrest, cyberattack or any other threat to business operations.[77]

Business interruption insurance: coverage that replaces business income lost in a disaster, such as fire.[78]

Delay in startup insurance: coverage for project owners for the financial consequences of a delay in project completion arising from an insured physical damage event.[79]

Directors & officers insurance: covers the liability from legal actions as a result of serving as a director or an officer of a business or other type of organisation from regulators, legislators and shareholders, e.g. class action against company.[80]

Engineering, procurement and construction contract: contractual agreement between a project owner and the contractor that enables the owner to transfer the complete risk of design, procurement and construction to the contractor. The contractor is solely responsible for completing the project and handing it over to the owner in a turnkey condition.[81]

Erection all risk insurance: covers losses arising from the erection and installation of machinery, plant and steel structures, including physical damage to the project, equipment and machinery, and liability for third-party bodily injury or property damage arising out of these operations.[82] Also known as builders all risk or construction all risk in the U.S.

Operation & maintenance: Combination of maintenance, management, training, budgeting and business to run an organisation.[83]

Operation all risk: considerations that are typically covered by project safety management requirements, including hazard and operability analysis undertaken during design, construction and pre/post-commissioning phases. For example, maintainability (including inspection), spares availability, operator selection and training, health and safety of operations.

Original equipment manufacturer: company whose goods are used as components in the products of another company.[84]

Power purchase agreement: long-term agreement to buy power from a company that produces electricity.[85]

Provisional acceptance Certification: typically outlined in a contract between the project owner and the construction/design/technology licensor company. It is granted upon the fulfilment of various contractual obligations, such as meeting performance criteria and confirming compliance with safety standards. While the criteria can be complex, the key feature of a PAC award (or equivalent) is the transfer of 'care, custody and control' of the facilities to the plant owner. From this point onward, the owner assumes responsibility for operating and maintaining the facilities. Subsequently, the contractors are typically only obligated to meet longer-term performance criteria, such as efficiencies and power consumption, and address equipment warranty-related issues for a defined period. Upon expiration of this period, a 'Final Acceptance Certificate' or equivalent is issued, relieving the contractor/designer of further liabilities for the plant, except as defined through legal action.

77 CIO 2023.
78 Kagan 2023a.
79 Marsh 2022.
80 Kagan 2022.
81 Blackridge 2023.
82 IRMI (n.d.).
83 Agarwal 2024.
84 Kagan 2023b.
85 Thumann 2009.

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