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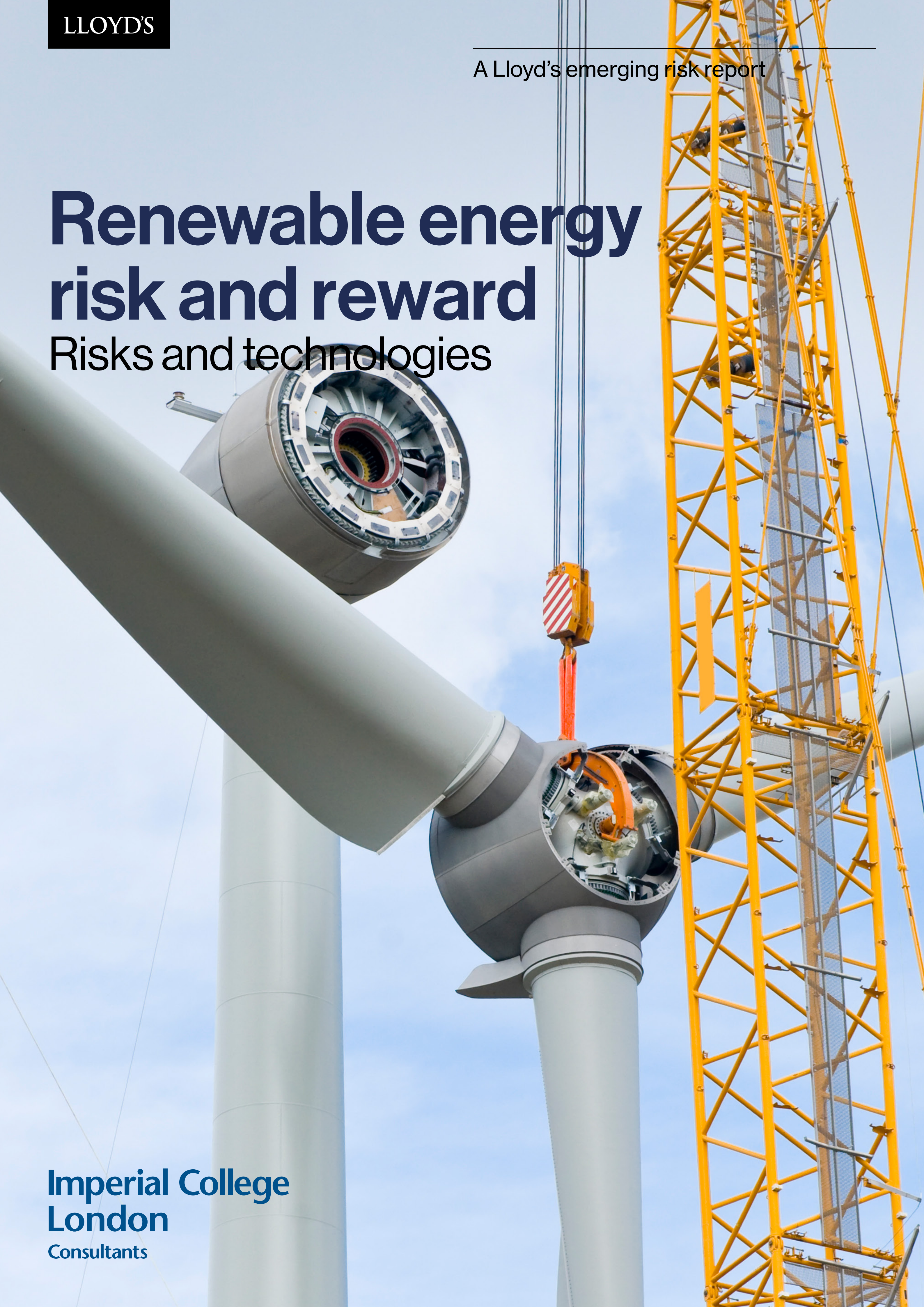
A Lloyd's emerging risk report

Renewable energy risk and reward

Risks and technologies



Imperial College London
Consultants

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Based at Imperial College London, this centre provides an interface between technology and policy and produces analysis and policy advice for governments, industry, NGOs and other stakeholders worldwide.

Learn more at https://www.imperial.ac.uk/icept

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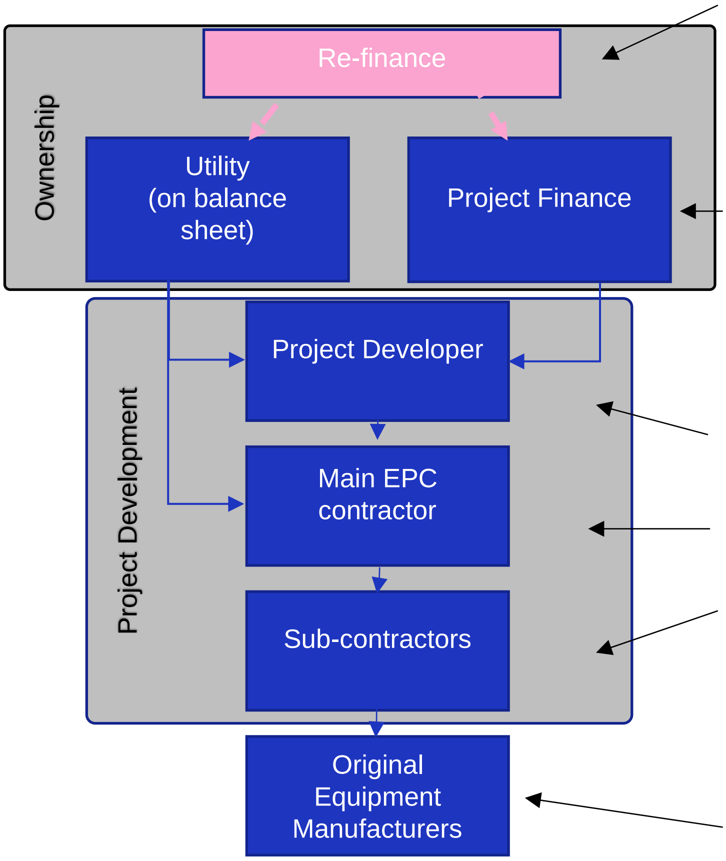
Contents

1. Risk factors for renewables

Over the past 10 years rapid policy-driven growth in the supply of renewable energy has led to economies of scale for technologies such as wind and solar power, driving costs down by around a factor of four. This 'virtuous circle' of increasing volumes and declining costs means that renewable energy sources have expanded to such an extent they are now the dominant source of new power capacity additions in many countries.

However, in many ways, energy markets are still evolving to accommodate the influx of renewable energy, and the balance of risks across the energy market has not yet settled down to a stable long-term pattern. In this context, it is likely that the role of insurance, and the demand for different products will evolve as the market develops and matures. This will include for example the balancing of risk between the insurances provided to project developers and EPC contractors on the one hand and the warranties provided by equipment manufacturers on the other. Whilst the industry is in a state of flux, finding these balance points remains a challenge. Solutions include risk-sharing approaches such as allocation of first-loss risks to equipment manufacturers, and inclusion of appropriate deductibles. Insurers and project developers also need a clear understanding of the risk allocation consequences when equipment passes out of warranty. Lack of data on what has happened under warranty (e.g. multiple low-level incidents) along with lack of operating data or difficulties in its acquisition are barriers for underwriters to better understand risks and develop more bespoke pricing. Finally, clients will need to understand the implications of projects being out of warranty (e.g. higher deductibles) compared to what they have seen in the first 2 or 3 years.

Figure 1: Risk allocation across the project development cycle



Refinancing often occurs after operational performance is established and risk profiles are better understood. However, financial institutions often have lower risk tolerance, and insurance requirements may be increased.

Ownership: on-balance sheet owners such as utilities may be more risk tolerant requiring less insurance compared to special purpose vehicles using project finance which typically use higher debt levels and have lower risk tolerance.

Supply-chain. Risks are distributed through the project development cycle, but insurance cover typically provided on a 'cradle-to-grave' basis. Loss claims are often concentrated at the level of the main engineering, procurement and construction (EPC) contractor, even if losses are caused as a result of poor design by developers, or further down the chain by multiple levels of subcontractors. Insurers can try to improve risk allocation by early involvement in project design and specifying insurances by contractor tier level with appropriate deductibles.

Equipment manufacturers are a key partner in risk allocation, with warranties performing a complementary role to insurance. Once warranties have expired, higher deductibles may be needed on insurance covers.

Source: Lloyd's and Dr Gross from Imperial College London, 2020

The following risk typology (Table 1) is adapted from a classification in Gatzert (2016), originally developed for wind power projects, and drawing on synthesis of the literature industry surveys, extended here to include some additional risk relating to a broader set of renewable technologies. Additions to the Gatzert typology include health and safety risks, end-of-life & decommissioning risks, and raw material cost risks.

Table 1: Overview of risk factors in renewables energy projects

Risk Type	Description	Entity / actor
1.Strategic/ business risks		
a) Financing risks/ insufficient expertise / insufficient management know-how	Risk arising from scarcity of capital (e.g. debt) and/ or investors' insufficient expertise and/ or insufficient management know-how resulting in potential revenue losses	Debt providers/ investors/ project developers
b) Technology and innovation risk	Risk arising from inaccuracies in early planning regarding resource assessment and supply of renewable energy technology (see also risks 2 and 3a) and innovations inducing a lower technological efficiency/ obsolete technology along with insufficient public (and political) acceptance causing a potential adverse change in policy support schemes (see also risks 1c and 7) resulting in lower than expected revenues.	Project developers/ supplier/ general public (see also Risks 1c, 2, 3a, 7, 3e)
c) Insufficient public acceptance	Risk arising from potential adverse changes in public acceptance and/ or resistance of end-users to renewable energy resulting in resistance to construction and/ or adverse changes in policy support schemes (see also risk 7)	General public/end-users/national level (see also risk 7)
d) Complex approval processes	Risk arising from inefficient or opaque administration regarding licensing and permits of renewable energy projects resulting in delays and/or higher than expected payments	Public sector's administrators
2. Transport/ construction/ completion	Risk arising from various types of disruptions during the transport and construction phase and/or damages or theft resulting in start-up delays, completion risk and thus revenue losses.	People/ supplier/ grid operator/ natural hazards/ project developer
3. Operation/ maintenance		
a) General operation and maintenance risks	Risk arising from damages to physical assets due to negligence, accident, wear and tear, and/ or possible unplanned closure due to unavailable resources/ replacements and/ or unreliable/ inefficient renewable energy technology resulting in revenue losses (see also risk 1b). Shortages of skilled labour also a contributing factor.	People/ supplier/ project developers
b) Damage due to severe weather & natural hazards	Risk arising from damages due to natural hazards resulting in revenue losses	Natural hazards
c) Damage due to serial losses	Risk arising from defective components resulting in lost revenues	Supplier
d) Revenue loss due to business interruption	Risk arising due to potential business interruptions resulting in revenue losses	(see risks 3a, b, c)

e) Raw materials volume and price variation	Risk of changes in availability and price of raw materials	Energy market / environment (supply and demand)
f) Health and safety risks	Risk of accidents or other safety-related costs, or health impacts from local pollutant emissions / spillages etc.	Project developers/ supplier (see also risk 1b)
g) Decommissioning and repowering risk	Risks associated with end of project life: ability to re-power, renewal of permits, land remediation costs	Public sector's administrators/ project developers
4. Liability / legal risk	Risk arising from liabilities to third parties due to potential environmental damages and/ or uncertainty regarding resulting legal disputes and/ or contracting risks due to complex legislation or processes resulting in revenue losses	Nature (see also risk 3b)/ supplier (see risks3a and 3c)/ national level and public sector's administrators
5. Market / sales risks		
a) Variability of revenue due to weather / resource risk	Risk arising from uncertainty regarding future renewable energy resources due to inaccurate resource or capacity assessment resulting in lower than expected revenues	Project developers/ nature
b) Variability of revenue due to grid availability / curtailment risk	Risk arising from limitations in grid management/ infrastructure resulting in lower than expected revenues	Utility/ transmission company/ grid operator
c) Variability of revenue due to price volatility	Risk arising from uncertainty regarding future energy prices resulting in lower than expected revenues	Energy market / environment (supply and demand)
6. Counterparty risk		
a) Supplier of Operations & Maintenance (O&M) services	Risk arising from a counterparty's poor credit quality resulting in revenue losses	Supplier
b) Counterparty risk power purchase agreement (PPA)	Risk arising from a counterparty's poor credit quality resulting in revenue losses	Power purchaser
7. Political, policy, regulatory risks	Risk arising from uncertainty regarding potential adverse changes in country-specific policy support schemes or regulations in regard to renewable energy investments resulting in lower than expected revenues	National level/ legislators, policymakers

Source: Adapted from Gatzert, 2016

Strategic and business risks

Strategic and business risks include, for instance, insufficient management know-how,insufficient access to capital or a lack of cooperating partners to share technical expertise, financing and market access, as well as the diversification of risks and the exploitation of economies of scale to reduce costs. Technological and innovation risk on the one hand refers to inaccuracies in early planning regarding resource assessment and supply of renewable energy technology (also impacting construction and operations), and to obsolete technology in the future on the other hand, which may imply a lower efficiency as compared to newer plants, as well as also potentially induce a diminishment of public (and political) acceptance, thus also potentially causing an adverse change in policy support schemes *(Gatzert, 2016).*

Potential risk mitigation techniques include: effective project management and careful contracting; use of proven technology and suppliers to reduce the risk of technological inefficiencies and/ or supply chain shortages; establishment of contingency plans and the consideration of lessons learned and industry information, to improve the understanding and identification of risks *(Gatzert, 2016)*.

Technology risks will tend to spill over into many areas of project preparation and will be more acute for less developed technologies. Complex and long approval procedures are especially relevant for newly emerging technologies and markets, since some of the risks (e.g. environmental impacts) are less well established, and authorities may take a more cautious approach. These kinds of risk are particularly pronounced in large strategic infrastructure projects. Examples include the proposed South Wales tidal lagoons. An independent public review established in Feb 2016, reported a year later recommending the government to proceed *(Hendry, 2017)*, but was rejected by the government in June 2018 (BEIS 2018) on cost-effectiveness grounds. Even for mature technologies, complex and lengthy approval processes create a significant business risk, and these are very specific to conditions countries. For example, in France, the average time for realising plans for wind power is reportedly 7-9 years, compared to 3-4 years in Germany (MTES, 2018).

The extent to which business risks can be planned for will depend on the maturity of a technology, and the extent to which project design can learn from the experience of previous projects. Even in relatively mature technologies such as solar PV, risks can still arise. Project design needs to account for potential risks from environmental factors (e.g. climate, salt, sand, dust that may affect project performance), weak supplier qualifications, weak components qualification, project construction being fit for purpose, layout errors (e.g. cabling, grounding, electrical dimensioning), uncertainty in irradiance estimation, using wrong assumptions for yield prognosis, weak O&M planning (e.g. maintenance intervals, spare part requirements, weak EPC qualification (Jones Brown, 2017).

Focus on the future

The number of green energy patents (defined as solar power, wind energy, biofuels, hydropower, geothermal energy and waste-generated energy) filed globally doubled over the period 2013-17 *(Geary, 2018)*. Over the course of a low carbon transition, significant innovation across all low carbon technologies is expected. In response, firms in markets with high associated growth potential will try to ensure they receive a proportion of the benefits of this growth. These developments could lead to IP disputes in court, be they over corporate licensing or public disclosure of green IP. The most relevant insurance products to these cases will be financial loss cover, for example, income, revenue or value, and could grip when companies incur legal expenses.

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Technology and innovation risks

As discussed, renewable energy markets are expanding rapidly, with new types of equipment entering the market that may have a short track record of performance data, which makes it harder for insurers to assess equipment reliability. In well-established sectors such as wind power, new innovative designs can obtain 'type certification' which an accreditation by a trusted third-party certification body that a manufacturer is selling a wind turbine that meet relevant standards and codes. However, often such certification is not in place before insurance is requested, putting additional risk in the hands of insurers. Insurers may be able to support new technology by working with clients to understand the design and testing of the new technologies that has been carried out. This will require collaboration and transparency from customers. Use of higher deductibles may also be employed to facilitate risk sharing in this phase of development. In the long-run, these pressures should reduce as quality becomes properly priced-in to the market.

For some technologies it is not always possible to rely on a track-record of past performance from other projects to evaluate risks.

Examples include some biofuels and waste to energy plants projects where productivity can be strongly impacted by local conditions such as the quality of feedstocks. In these circumstances, niche insurance products may be available which rely on the quality and reputation of equipment manufacturers, combined with risk engineering approaches to assess likely exposures based on design criteria of projects, and data arising from pilots and demonstration plant, and comparing to failure rates in other analogous industries.

Performance insurance solutions for breakthrough technologies

Innovation comes with risk, but that should not stop companies from paving the road to the future. New Energy Risk ("NER"), a California-based MGU, works with pioneers in the new-energy arena to support technology breakthroughs, advancing the critical projects needed to accelerate the transition to sustainable energy. To do so, NER structures customised performance insurance products that seek to mitigate technology risk for clients, and their customers and lenders as a result.

NER-developed policies are underwritten and issued by one of the affiliated insurance companies of AXA XL (S&P AA-) and administered by its subsidiary Complex Risk and Insurance Associates, LLC, licensed in California (#0I24307). Policies stand behind the client's technology performance and ultimately protect project debt-lenders or end-customers from certain losses associated with the underperformance of an asset. By incorporating a double-trigger mechanism—wherein the technology has to perform below a pre-determined, conservative threshold, and the technology provider has to default on performance warranties that match or exceed the insurance terms—the policy seeks to align the interest of developers, customers, and investors with the insurer to provide technology risk transfer to the insurer, without introducing moral hazard or misaligned incentives.

With a team of scientists and insurance professionals, NER has developed a data-driven methodology for evaluating technical risk, bringing a new class of diversified risk to the insurance market. The company's proprietary modelling uses Monte-Carlo analysis techniques that simulate a range of potential project outcomes to assess uncertainty around performance and reliability of a client technology, including the impact on relevant economics. The result is well-structured and profitable packages delivered in conjunction with insurance partners, and client access to financing that is minimally dilutive and optimally priced.

In only five years, NER's clients have already deployed over $2 billion in capital, supported by AXA XL's insurance companies, and their global reinsurers, including various Lloyd's syndicates. NER's diverse and global client -base represents a wide range of technologies and industries, from fuel cells and waste-to-value to nuclear medicine, all focused around the mission of mitigating global challenges through smart business. Clients include:

- Fulcrum BioEnergy, a trash-to-biofuel developer building their first commercial facility in the US;
- Bloom Energy, the leading supplier of solid-oxide fuel cells for reliable, resilient, and cost-effective on-site electricity; and
- RES Polyflow, an innovative plastic waste-to-fuel technology company building a recycling project in the US.
- SHINE Medical Technologies, a development-stage company working to become the world's leading producer of medical isotopes.

Learn more about New Energy Risk at www.NewEnergyRisk.com

Construction and completion risks

The construction period is generally considered the riskiest project phase, and these risks increase the larger and more remote the project, and the less established the technology and immature the supply chain concerned. Supply chains can be complex, for example with wind turbine equipment typically being sourced from manufacturers in three or four different countries before final assembly usually either in China, Europe or the US.

For wind projects, given the size of the components and the specialist equipment needed, there is risk of damage during transportation or construction of the wind farms. Specialist construction equipment may come in short supply during periods of increased construction activity during the growth phase of a particular renewable sector. For example, offshore wind farms have considerably more complex transportation and construction processes than onshore windfarms and require highly specialised construction vessels which caused bottlenecks earlier in the decade due to a lack of vessels to transport offshore equipment to the project sites (Turner, 2013). Bottlenecks are likely to come and go depending on the specifics of the project cycles and will be affected in the future by technology change such as potential shifts to floating offshore wind turbines which allow construction to be carried out in the port (see Section 4.3). However, even a mature sector like onshore wind can be subject to supply chain bottlenecks that can create delivery and cost risk in certain circumstances. For example, in the US, 70% of wind projects are typically constructed in the fourth quarter of the year driven by weather conditions (restrictions on wind speed during construction) and the cyclical nature of Production Tax Credit (PTC) legislation. Turbines are usually transported just before a project starts construction, meaning that peak transportation periods for large wind turbine components occurs in the third quarter of the year. 2020 is expected to see record number of projects, and potential supply chain constraints (Wood Mackenzie, 2019).

For solar PV, technical construction risks are relatively low, but risks can nevertheless arise through interaction with regulatory risks, depending on the complexity of the regulatory regime in place. Guerin (2017) reports on the regulatory risks and burdens associated with large-scale PV projects in Australia, noting that the environmental and community risks of greatest concern (including dust control, optimising vegetation growth under the panels, waste management and a lack of common understanding of expectations for local job opportunities), while planned and eventually managed, could have been more efficiently addressed by further upfront investigations, and questioning and enhancing the governance processes by the engineering procurement construction entity. In the example studied by Guerin (2017), managing the recycling or disposal of end-of-life packaging materials (EOLPMs) was a specific unexpected risk on the project during the construction stage, which can be overcome on future remote location projects by enhancing the design and execution of project-level contracts and securing partners such as resource recovery companies or other end users at the earlier, planning stage.

Quality and contractors

Rapid growth in the renewables industry means that supply chains, contractors and subcontractors are also having to expand rapidly, leading to bottlenecks in some areas of installation equipment, and a shortage in some markets of necessary skills and construction experience. In terms of construction risks and quality the insurance market used to see issues with contractors (poor quality due to inexperience) in emerging markets, but now, due to the rapid expansion of the sector, contractors' negligence losses can also be experience in mature markets such as the US, Australia-and Western Europe. But sector growth is also an opportunity for new jobs.

Subcontractors would be insured under a 'All Risks policy', but if they are tier 3 or 4 they might often be unknown. In the future insurers might start limiting coverage to include/exclude sub-contractors.

Installation risks across all technologies may arise from weak material inspection regimes and poor project management regimes such that installation faults that cannot be corrected get insufficiently compensated and leading to follow-up problems during the project lifetime. These in turn can lead to time or cost over-runs for the construction phase. Risk mitigation can be managed by ensuring that liabilities lie with project developers or EPC contractors for these kinds of errors, as well as damages occurring during construction. To the extent possible, these should include liquidated damages so that pay-outs are agreed in advance for potential losses occurring for example in the case of delays in start-up). These arrangements should also ensure appropriate liability arrangements with component suppliers, including product liability (third party & safety), workmanship warranties and yield warranties (Jones Brown, 2017).

Operation and maintenance risks

General operation and maintenance risks

This includes damages to physical assets due to for example accident, negligence, wear and tear, and possible unplanned closure (e.g. due to unavailable resources or replacements, which can cause considerable delays). These risks are closely linked to the technology risks discussed in Section 3.1. The extent to which these risks play out will be affected strongly by project design and location. For example, compared to onshore wind, offshore wind projects are more exposed to operational risks arising from technical faults due to the difficulty of accessing the sites for maintenance. Such risks can also accumulate in parts of the infrastructure such as relay stations or high-voltage connecting cables serving multiple areas; problems in these areas can affect multiple projects (Gatzert, 2016).

For PV projects, operations risks include downtimes being higher than expected, inappropriate maintenance intervals, spare part demand higher than planned (leading to delays and/or higher costs), default by warranty providers, higher than expected maintenance effort due to poor project setup, and need for re-powering (installation of replacement modules, inverters and other equipment) to achieve design goals of the project. The liabilities of the operations & maintenance provider need to be clearly established and should be include financial damages related to poor availability or yield (e.g. shadowing due to uncontrolled vegetation growth or soiling) (Jones Brown, 2017).

Managing O&M depends on a reliable supply chain which is subject to several risks going beyond physical damage of components/ materials to include unplanned IT or telecommunications outage, cyber-attacks and data breach events, loss of talent/skills and outsourcer failure, and transport network disruptions (BCI, 2018). Supply chain risks tend to be more significant for more specialist sectors, which includes large renewables projects such as off-shore wind. This means that insurance companies should pay more attention than usual to how supply chain risks are managed by project developers. Over time, as the market increases, more companies are engaged with offering components and O&M services deepening the supply chain and reducing these risks, though further de-risking of the supply chain remains essential particularly for projects at the cutting edge in terms of size or technology type (WTW 2018a). For example, this can include identifying elements of the design where there is a risk of serial losses which can be more severe, i.e. where loss or damage to one component or part of a structure has knock-on damages to other structures, parts of structures, machines or equipment of the same type. Insurance coverage tends to manage this risk by limiting the degree of coverage for such knock-on losses.

Damage due to natural hazards

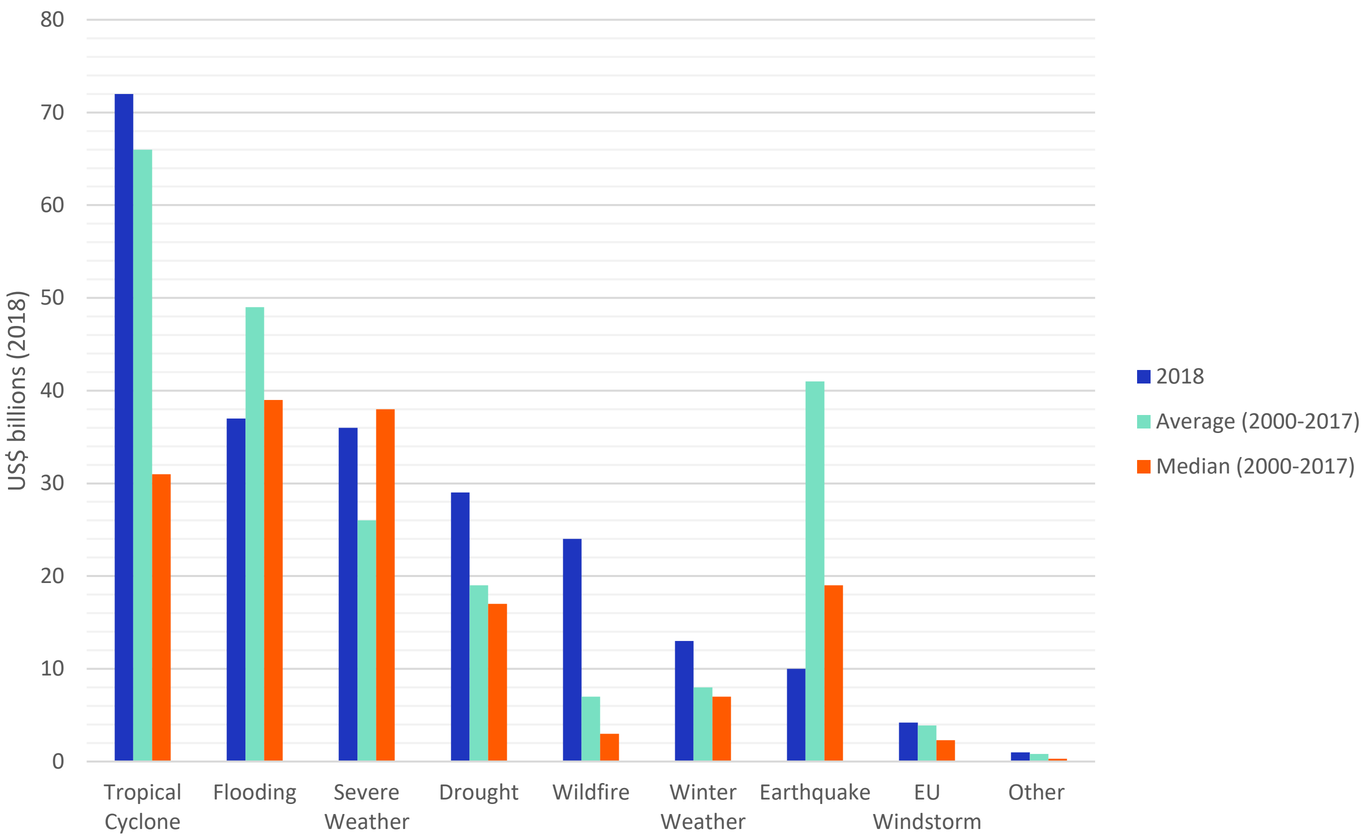
Renewable energy projects such as solar and wind power can often be sited in exposed and / or remote locations and are vulnerable to a range of natural hazards. For PV, these include (Jones Brown, 2017):

- Lightning strikes resulting from improper lightning protection, and leading to destruction of components and potential undetected malfunctions.
- Grid overvoltage due to improper surge protection leading to component failures.
- Wind loads leading to damage to mounting structures and modules.
- Damage caused by snow loads / hail, including risk of module breakage, frame deformation loss of roof cladding.
- Fire: including PV systems affected by building fire, and PV systems causing fire.
- Animal impact including glass breakage or contamination by birds, rodent bites in cable insulation grounding and mounting, roof damage due to installation work, overloading the roof structure, water ingress beneath PV systems.

Offshore wind projects present a challenge to insurers as wind turbines are subject to damage from heavy winds. For example, the east coast of the US has favourable economic conditions for wind generation but are exposed to risk of damage from hurricanes. The Block Island Wind Farm was designed to withstand a Category 3 hurricane, the strongest hurricane strength to make landfall in New England in recorded history. Additionally, insurers have concerns with potentially extended repair periods as the project locations are less accessible and getting cranes to the locations to facilitate repairs can be challenging and expensive (WTW 2018a).

Analysis by Aon insurance (Aon 2019) indicates that total global economic losses from weather-related natural disasters in 2018 were US$215bn, close to the total average rate for the previous 10 years (Figure 2). At US$72 billion, the tropical cyclone peril was the costliest of 2018. While this marked a substantial drop from the record US$312 billion incurred in 2017, it was still the second highest year for the peril since 2012. Other perils with aggregate damage costs beyond US$25 billion included flooding (US$37 billion), severe weather (US$36 billion), and drought (US$28 billion). For the second consecutive year, wildfire damage exceeded US$20 billion; most of which was incurred in the US.

Figure 2: Total global economic losses from natural disastours



Source: Aon, 2018

Insurers are also reporting an increase in losses from lower level weather events that are not sufficiently severe to results in large losses but can nevertheless lead to O&M insurance claims. These include storms, hail stones, high winds and flooding. Risks are exacerbated for renewable energy projects such as wind and solar, which require large land areas (compared to traditional energy projects which are more concentrated and centralised), making renewables projects more exposed to these kinds of weather-related risk. Projects are also often more remote, more exposed to weather-related risks, with performance more dependent on localised conditions. Anecdotal evidence suggests that vulnerability to these risks is increasing due to new projects being sited in sub-optimal, more exposed locations (e.g. flood plains) because prime sites have already been used, especially in more matured market. This would result in projects being exposed to more losses and insurers having to carefully consider underwriting and premiums.

Consultations for this study indicates that a trend towards increasing frequency of events is developing, and the industry needs to adjust expectations of risk to match that. Losses are starting to occur out of expected seasons for everything from hurricanes and tornadoes to wildfires. Indeed, the very concept of a Californian wildfire 'season' has been brought into question, with suggestions that fires are now a year-round risk. The recent Australian bush fires further demonstrate new volatile situation with the fires starting a month earlier than normal, while also being expected to last longer than average and being more instance year-on-year (Klein, 2020)

Recent events combined with regulators' work on climate change should prompt insurance to learn to analyse exposures more thoroughly, considering not simply exposure to potential property damage, but also to sites issues that could impact accessibility, slow reconnection to the grid, site security expenses. Better understanding of losses will also result in better preparation and risk mitigation.

Developers, contractors, financiers, suppliers and site owners should move away from the attempt to reduce costs of new installations and a focus on building projects to withstand the elements to which they are potentially exposed.

From a research perspective there are opportunities to develop models exploring the impact of weather events on renewable energy projects in less mature markets and understanding new sites suitability to regular weather events.

Impacts of climate change on renewable generation technologies

Gradual climate change will progressively affect the operation of energy installations and infrastructure over time. Possible changes in the frequency and intensity of extreme weather events (EWEs) as a result of climate change represent a different kind of hazard for them.

Thermal power plants can be designed to operate under diverse climatic conditions, from the cold Arctic to the hot tropical regions and are normally well adapted to the prevailing conditions. However, they might face new challenges as a result of climate change. A general impact of climate change on thermal power generation (including bioenergy, CSP and geothermal generation) is the decreasing efficiency of thermal conversion as a result of rising temperature that cannot be offset *per se*. Another problem facing thermal power generation in many regions is the decreasing volume and increasing temperature of water for cooling, leading to reduced power generation, operation at reduced capacity, and even temporary shutdown of power

The resource base of hydropower is the hydrologic cycle driven by prevailing climate and topology. The former makes the resource base and hence hydropower generation highly dependent on future changes in climate and related changes in extreme weather events. The possible impacts of climate change on hydroelectricity are complex, but assessments to date indicate that regarding changes in the amount, the seasonal and interannual variations of available water, and in other demands, the conclusion from the literature is that the overall impacts of climate change and EWEs on hydropower generation by 2050 is expected to be slightly positive in most regions (e.g., in Asia, by 0.27%) and negative in some (e.g., in Europe, by –0.16%), with diverging patterns across regions, watersheds within regions, and even river basins within watersheds.

All types of solar energy are sensitive to changes in climatic attributes that directly or indirectly influence the amount of insolation reaching them. If cloudiness increases under climate change, the intensity of solar radiation and hence the output of heat or electricity would be reduced. Efficiency losses in cloudy conditions are less for technologies that can operate with diffuse light (evacuated tube collectors for TH, PV collectors with rough surface), but could be higher for CSP since diffuse light cannot be concentrated. The exposure of sensitive material to harsh weather conditions is another source of vulnerability for all types of solar technologies. However, climate change and EWE hazards per se do not pose any particular constraints for the future deployment of solar technologies. Technological development continues in all three solar technologies toward new designs, models, and materials. An objective of these development efforts is to make the next generation of solar technologies less vulnerable to existing physical challenges, changing climatic conditions, and the impacts of EWEs.

For wind power, the key question concerning the impacts of a changing climate regime concerns how climate change will rearrange the wind resource. In the next few decades, wind resources are estimated to remain within the ±50% of the mean values over the past 20 years in Europe and North America. The wide range of the estimates results from different assumptions about the circulation and flow in climate models. Yet little is known about changes in the interannual, seasonal, or diurnal variability of wind resources. Wind turbines already operate in diverse climatic and weather conditions (Arent 2014).

Sabotage and terrorism

A report by Willis Towers Watson (WTW 2018a) notes that the last three years have seen steady increments in the number of terrorism and political violence events globally. Whilst actual attacks against the power industry have mostly been in the Middle East, Africa and Central Asia resulting from ongoing conflict, in Europe and North America several terrorist plots against the power industry have been foiled. For example, the perpetrators of the Belgium airport and subway attacks in 2016 had plans to attack a power plant, while a self-described neo-Nazi from Florida, who was arrested in 2017, had plans to blow up power lines in the Everglades and launch explosives into a power plant. The threat of strikes, riots, civil commotion and protests also remain an ever-present risk to the power industry. Many new construction projects around the world will continue to face environmental activism and local opposition, including those where land disputes and population displacement may arise.

Revenue loss due to business interruption

Business interruption causes loss of profits due to disruption of normal operations of a firm, usually referring to interruptions caused by external or internal human factors that may cause material damage to property (CII, 2016). Disruptions may occur because of a wide range factors which could affect all or parts of a renewable energy installation leading to it generating less electricity than planned (Jones Brown, 2017), but business interruption generally needs to be accompanied by physical damage before the policy comes into force.

The insurance industry has reported increasing problems in the UK with theft from solar PV projects, involving both copper cables and the solar panels themselves. With large land areas and often relatively isolated rural locations involved, wind farms have a potentially higher exposure to these risks than traditional power generation sources, given though improvements to security arrangements are available to make these risks manageable (WTW, 2018).

Fire risks can also be significant for key components of solar farms such as transformers and inverters. In a case study for Ontario, Jones Brown (2017) report that whilst the value of a transformer for a $10m solar might be around $0.5m, business interruption costs may be $0.5m per month in lost income. A major transformer fire could equate to $0.5m + 6 – 8 months of downtime resulting in a claim of around $3.5m - $4.5m. In these circumstances it is important for project developers to minimise any downtime for example by ensuring accessibility of replacement parts.

Cyber risks

Regarding cyber risks, a review of insurance claims in the US (GCube 2018) suggests that cyberattacks currently pose a low risk, but are likely to rise in prominence in the coming years; with online attacks in all sectors on the rise, tensions between the US and Russia leave the North American power sector particularly at risk. For wind energy projects, this risk has been elevated by technological advancements; to streamline project operations and enable remote access control, wind farm developers have sought to develop systems connecting all the turbines in a wind farm.

This interconectivety leaves projects more vulnerable, since access to one turbine can be used as a hub from which to control the entire farm, e.g. manipulating blades or paralysing the system altogether. The resulting business interruption costs and reputational damage could be significant.

Some interviews in the sector have suggested that because of their distributed nature, and the relatively small size of renewable projects compared to large centralised fossil-fuelled power generators, they are less likely to be a target, meaning that for now, cyber-attacks remain a low-incidence (though potentially high impact) risk. Others have pointed out that the reliance of wind and solar projects on remote monitoring techniques leaves control systems vulnerable to attack, and the fact that 43% of cyber attacks target small businesses (Sophy, 2016).

A number of cyber attacks have happened that could provide data for insurers to understand the risks and possible scenarios. In October 2019, a Utah based renewables energy company, Spower, experienced temporary disruption to their communications with solar and wind installations after a denial-of-service (DoS) attack (Lyngaas, 2019). Norsk Hydro, a Norweign renewables company, lost £45m due to the ransomware LockerGoga infecting their systems during 2019 (Tidy, 2019). The largest such attack took place in Ukraine 2015, three domestic energy companies were targeted with a 'well-known trojan' named *BlackEnergy,* this resulted in power cuts across the country for a number of days over the Christmas period (Bernat, 2016).

Lloyd's 2015 report *Business Blackout* in collaboration with the Cambridge Centre for Risk Studies estimates of the potential losses that could arise from a severe, yet plausible, cyber-attack. A scenario is developed in which an attack causes failures in part of the grid in Northeastern USA which then cascade through a much wider area, leaving 93m people without power, and causing $243bn in economic damages, with insured losses of between $21-71bn.

From an insurance perspective it is possible that more work will be done to move coverage for cyber-related events affecting renewable energy projects to stand-alone cyber policies since All Risks policies will typically exclude damage arising from cyber-attacks, and non-damage cyber insurance products are being developed by the market specifically for renewable energy projects. Importantly, cyber covers should be included subject to meaningful additional premium and exposure information. Non-affirmative cyber will remain a very important topic that requires further understanding by clients, brokers and insurance. Further research and modelling will be required. In the meantime, it is possible that exclusion clauses to help underwriters manage cyber losses could be introduced in policies that unintentionally suggest protection for undefined cyber risks (IUA 2019).

Protecting your company from cyber-attacks

GCube have recently launched a new insurance product to provide coverage for cyber losses resulting in non-physical damage an important new gap in coverage that has emerged for their clients in the last half decade.

Renewables have endured a great number of these losses, ranging from individual ransomware cases like that of Sabella tidal project and Norsk Hydro, to widespread attacks like Dragonfly and Energetic Bear, as well as attacks which might not be public. The sources of cyber risk are multiple and include nation states, hacktivists, organised crime, rogue employees and human error. It is important for renewables companies to assess their cyber exposures and take sensible measures to mitigate them, and new tailored products provide an ideal tool to be used in this process.

GCube's product covers the following:

1. Business interruption
2. Contingent business interruption
3. Digital Asset Destruction – including loss of use or theft of SCADA data
4. Cyber Extortion and ransomware
5. Incident Response Expenses

Caused by the following cyber events:

1. Security breach (breach by an unauthorised non-employee, e.g. hacker)
2. Administrative error (error by an employee in using digital assets or computer system)
3. Power failure (failure in in electrical power supply caused by a security breach)

While administrative errors (e.g. migrating to new system or accidental data deletion) used to account for the majority of losses, the proportion of losses due to Security Breaches has rapidly grown and in some sectors now accounts for the majority of losses. Losses caused by power failures, by contrast, are very rare.

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Decommissioning and repowering risk

Many projects are now coming to the end of their lifetimes of around 20-25 years. Most of these are suitable for redevelopment, and many projects get re-powered more frequently to make use of larger and more efficient power generation equipment. Again, the risk allocation of re-powering, and role of warranties from any new equipment needs to be clearly specified. Decommissioning of sites is less common, but may create issues that insurers need to be aware of in terms of to cover against the risk that an operator fails to fulfil its decommissioning obligations at the end of the lease term, usually as a result of default of the operator.

One risk presented from decommissioning is with PV solar panels. Typically, these have a lifespan of 25 years, and it can be considerably difficult to recycle the waste of decommissioned PV, with worldwide waste estimated to reach 4%-14% of total generation capacity by 2030 and rise above 80% by 2050 (Chowdhury et al, 2020). Therefore, disposal of PV's is going to become a permanent environmental issue in the coming decades. PV recycling regulation is expected to extend the duties of recycling and disposal to the manufacturers of PV materials.

The EU Waste of Electrical and Electronic Equipment (WEEE) Directive entails all producers supplying PV panels to the EU market to finance the costs of collecting and recycling EOL PV panels in Europe (Chowdhury et al, 2020). No other regulation has been laid out worldwide and it is likely that the EU's regulation will guide other countries regulation with manufacturers carrying much of the risks once PV panels are decommissioned. This could provide opportunities for new insurance products and at the very least extend the market for recycling polices.

Liability and legal risks

Liability risk to third parties and law costs are further major risks associated with wind power, including liability arising from environmental damage. The risks associated with offshore wind strongly differ from onshore wind and relate to increased traffic volume at sea and the complexity of the construction, operation and maintenance phases (heavy parts, installation at sea) imply new loss patterns and volumes, e.g., a higher risk of liability from property damages and bodily injuries of persons. In addition, legal contracts for offshore windfarms are mostly international contracts designed to incorporate all parties involved in the construction and erection of wind projects (Gatzert, 2016).

Market and sales risks

Market and sales risks refer to the variability of financial income due to, e.g., deviations of power prices, or the inability to sell electricity due to regional grid oversupply (curtailment risk). In more established markets (e.g. in Europe and the US), these risks have been relatively low due to policy and market design which has traditionally provided project developers with a fixed price for electricity through a feed-in tariff or power purchase agreement, and in addition has often guaranteed that all the production from the project could be sold through take-or-pay obligations on offtakers. In some jurisdictions, risks have re-emerged in cases where PPA rates have been retrospectively altered (see section on policy risk). In future, as renewables gain a larger market share, it seems unlikely that renewable energy projects can continue to be fully insulated from market price and sales risk, particularly given the link between variable renewable energy generation and price volatility.

Variability of revenue due to weather/resource risk and price volatility

Project-level risks arise from the intermittent nature of production. Adverse weather conditions can result in significant drops in the amount of electricity produced, which might negatively affect revenues from selling the commodity in the marketplace. Analysis by GCube (2017) suggests that unforeseen underperformance due to lack of wind may be linked to climate change impacts, and these risks are likely to increase in the future.

New developments up-wind of an existing wind farm can also have significant detrimental impacts on the output of the existing windfarm due to the wake (i.e. the disruption and turbulence caused to downstream wind flow patterns). Such new developments might include new high-rise buildings, new wind farms or other structures. For example, the wake caused by the front row in an array of wind turbines can cause the output of the turbines further back in the array to drop by 10% (reference). New developments by third parties which disrupt wind flow patterns for existing wind farm assets can therefore cause significant legal disputes relating to the rights to use the wind in a particular location.

As the renewables' share of electricity generation has increased, so have the financial consequences of risks associated with the renewables' intermittent nature. In principle, these risks affect all the players within electricity markets but the players' opportunities to mitigate risk clearly differ, for example in terms of company size and ability to diversify risk. Unhedged renewable energy portfolios are very risky compared to existing asset classes (Hain, 2018). The exposure of renewables projects to revenue risks associated with intermittency depends to some extent on the contract structure of the offtake agreement. Power purchase agreements (PPAs) have traditionally been based on a fixed price per unit, with guaranteed off-take of all output. However, the structure of PPAs is evolving to facilitate system-wide integration of larger amounts of renewables. Projects are becoming exposed to weather risks that include the timing (shape) and price of generation, as well as the total generation. This is something new in the wind industry, which has seen an increase in interest in weather risk transfer to alleviate volatility (GCube, 2017).

Diversification across multiple sites (and sometimes across technology types to include wind and solar) is the main risk management option, particularly for larger companies. Other options include investment in storage, improved long-distance high-voltage interconnectors, and improved demand side response to reduce economic impact of supply variability. From a single project perspective, prior to construction, a weather assessment should be conducted to predict the future impact of poor wind yields using advanced site investigation techniques as undertaken by service providers (Gatzert 2016).

Financial hedging is an option for larger projects, though some analysis suggests the risk transfer by standard electricity futures is very ineffective, especially for the case of solar. New weather-related derivative instruments ("wind-power futures") introduced by the EEX in late 2016 show promising results in terms of hedging efficiency. Currently though, contracts lack liquidity, and are mostly limited to locations with large installed capacity, though in the longer-run, the hedging efficiency of electricity futures would be expected to rise due to the increasing role of wind power in the formation of wholesale spot prices, but will remain very dependent on location, season and technology (Hain 2018).

An alternative risk transfer option would be the use of parametric products based on (index) triggers linked to the weather resources that renewable production relies on, as a way to offer insurance products that transfer the volatility associated with resources and smooths revenues for the producer as a result (Artemis 2017). This type of insurance does not indemnify the loss itself, but instead pays out on the occurrence of a triggering event based on parameters directly related to the risk that the protection buyer seeks to acquire coverage against. Traditionally, these products were mostly linked to extreme weather events, but weather risk transfer products are now available that would also trigger in the event of resource underperformance such as lower-than-expected wind speeds that adversely affect the output of a wind farm (GCube, 2017).

Variability of revenue due to grid availability/curtailment risk

In addition, completion risk can arise from potential problems associated with the connection to the grid. These risks will vary considerably according to local context, in particular the requirements on electricity utilities to provide such connections. For example, in Germany until 2012, the grid infrastructure supplier was not responsible for grid connection, which created a serious timing mismatch and major delays in completion (EWEA 2013). New obligations on the grid operator have largely addressed these problems in Germany but may remain a risk in less established markets.

Again, curtailment risk is increased when there is local congestion in the network, as has been experienced in northern Germany where there is a concentration of wind generation, whilst major demand centres are further south in the country. An important potential solution is to increase investment in the long-distance high voltage transmission system to reduce such congestion. This helps distribute renewable energy across a wider geographical area, connecting regions which are far enough apart that they are likely to be in a different part of the weather system so that wind speeds and solar irradiation are not subject to the same correlations as localised grid conditions.

Weather underperformance insurance

Using insurance/financial products to protect companies against adverse weather conditions began in the 1990s – the first structure being a hedge against cold weather in New York in 1996 – and has since evolved considerably. For renewables these products are typically used to protect against periods of lack of resource; so a lack of wind, irradiance, or rain for wind, solar, and hydro projects respectively. Naturally, periods of resource underperformance lead to lower than expected energy generation and therefore lower revenues. The purpose of these products therefore, put simply, is to pay out when resources underperform, and to make up (at least in part) for these periodic revenue shortfalls.

From a financial perspective there are typically one of two motivations when a company engages in weather risk transfer to stabilise revenue flows:

1. Risk aversity – predictable financial returns are attractive to certain groups of stakeholders
2. Improving financing terms – lenders attracted by the higher minimum revenue guarantees afforded by these products will be able to offer more favourable loan terms. Improvements to debt coverage ratios enable an increase in the debt equity ratio which increase returns on investment and can have tax shielding benefits; further, the improved guarantees of cash flows can also lower lending rates

The means of measuring weather conditions is an important part of these structures since payment ultimately depends on measured *weather* performance and not on actual generation or actual revenues of renewable energy projects. Lower generation/revenues are not themselves used to trigger payouts because they can be affected by technological breakdown, power pricing fluctuations and various other factors separate to weather performance. Therefore weather risk products rely directly on weather measurement indices, of which there are two broad types: The first are global data sets which provide worldwide round-the-clock measurements of weather conditions, and the second is to use the SCADA (supervisory control and data acquisition) data from the project themselves. Each has advantages and disadvantages relating to basis risk, privacy and convenience.

Weather risk transfer has in recent years also evolved to incorporate power price risk hedging in some cases. Products will now sometimes combine the two covers to hedge against proxy *revenue*, which depends on two factors – resource *and* power price performance, rather than just resource. These will compensate renewable energy projects whenever they suffer from lower than expected revenues due to either resource or power price underperformance, or some combination of the two. It has risen in popularity as the availability of competitive long term Power Purchase Agreements for renewables has declined in some markets, and these products are often treated as a substitute for PPAs.

GCube is proud to have offered its clients products hedging against both pure weather risk, and weather and power price risk for a number of years. We are at the forefront of the expansion of this market and have had particular success in supporting renewable projects in developing economies transfer their wind resource risk.

Learn more about GCube at www.http://www.gcube-insurance.com

Counterparty risks

Supplier of O&M services

To ensure that contract fulfilment, as well as guarantees and warranties, can be met (along with replacement parts), the financial stability of the supplier of operation and maintenance (O&M) services (typically the original equipment manufacturer, OEM) is critical. This has been a particular issue for offshore windfarms that have experienced numerous contractor insolvencies in the past. BP, for instance, faced lower sales prices when trying to sell their US windfarms, which used components of the insolvent manufacturer Clipper Windpower (Gatzert, 2016).

Typically, insurers carry higher risk of loss once OEM warranties expire. Renewable energy insurance specialist G-Cube estimates that approximately 1/3rd of all wind turbines globally are reaching the end of original equipment manufacturer (OEM) service agreements and entering long-term operations and maintenance (O&M) contracts either with their OEMs, non-OEM operators or, in the case of large project owners, self-operation (WTW 2018a).

Counterparty risk power purchase agreement (PPA)

PPAs involve the buyer agreeing to purchase power from the provider for a fixed long-term price along with a guaranteed access to the electricity grid. In principle, this provides very low commercial risks for renewable projects as long as the contracts are honoured. This depends largely on the jurisdiction of the project, and reliability of the rule of law in particular countries. PPAs in Europe and the US have generally been a very reliable commercial arrangement. As markets spread to emerging economies, counterparty risk should still be considered in cases of a power purchaser exhibiting poor credit quality or problems regarding the corporate governance, management, or operational track-record of the power purchaser. In the case of developing countries, partial risk guarantees by a development bank or guarantees by local governments that ensure that payments of a utility's PPA are met can be used as a risk transfer instrument (Gatzert, 2016).

Solar credit default insurance

The photovoltaic solar energy market in the US has grown substantially over the past decade, driven by increased demand and price improvements. However, installations in the residential and utility scale segments have outpaced those in the commercial & industrial segment (“C&I”). This is because energy “offtakers” (i.e. the buyers of the electricity generated by the solar installations) in the C&I segment are primarily small to mid-cap businesses that do not have publicly available credit ratings. This poses a risk to solar project financiers, because offtaker electricity payments are needed to generate revenue for project developers and repay financiers for construction and operation debt. Small to mid-cap credit underwriting can be onerous and many banks are inexperienced in the solar lending space, so individual financiers inevitably limit the proportion of their overall sector exposure without investment-grade ratings to manage this risk. The result has been constrained investment in the C&I segment, a problem Energetic Insurance is looking to solve with their first of its kind insurance product EneRate Credit Cover™.

As the price of solar installations has decreased dramatically over the past several years due to advances in technology and manufacturing efficiency, the United States has reached a “tipping point” where, in most areas, it is cheaper for a business to pay for solar-generated electricity rather than from their local electric utility. Further improving the value proposition are the decreasing costs of batteries which help provide round-the-clock energy and parking canopies or “carport” solar, which provide shade to customer and employee vehicles and can more easily serve as electric vehicle charging stations. For businesses without ample roof space or open land, utilising parking lots for solar is an effective way to increase the value of their available space.

Energetic Insurance recently participated in a solar installation on a prominent retail outlet mall in southern California. The mall owner wanted to install solar carports in their parking lot to provide electricity for the mall and shade from the California sun for their customers. Doubling as a popular highway rest stop, the mall owner also could provide cheaper electric vehicle charging stations with the solar installation.

When CalCom Energy, a solar energy project developer in California, first started working on the solar project at this retail outlet mall last year, they thought it would be a strong candidate for project financing from a bank lender. The outlet mall was in an attractive location and operated by a large, experienced firm with solid financials. However, because the outlet mall was held in an unrated standalone limited liability company (LLC), lenders could not rely on the corporate parent’s credit rating, making it difficult to obtain debt financing.

Due to this difficulty, CalCom approached Energetic Insurance to provide credit support to their outlet mall project. Following a novel and data driven underwriting approach, Energetic Insurance was able to use its EneRate Credit Cover™ policy to cover the risk of offtaker payment default. With the policy in place, CalCom’s $2.1 million outlet mall project was able to secure debt from Live Oak Bank, with additional tax equity investment from Symbiont Energy. EneRate Credit Cover™, gives lenders more confidence and certainty in project payment streams, because they can benefit from the insurer’s credit rating.

Energetic Insurance had personally witnessed the financing challenges in solar and realised that a credit insurance product was the solution that developers like CalCom needed to expand their projects to previously hard-to-finance transactions. Project developers can purchase EneRate Credit Cover™ to protect against default risk for up to a 10-year term on solar projects with unrated C&I customers, as well as community solar projects.

Energetic plans to expand to international markets in the coming years and it expects that EneRate Credit Cover™ will improve transaction velocity in the C&I solar market and allow project developers to access more customers, convert more sales and do more solar projects with unrated and sub-investment grade offtakers.

Learn more about Energetic Insurance at http://www.energeticinsurance.com

Political, policy and regulatory risks

The revenue for renewable projects is often set through policy or regulatory mechanisms such as feed-in tariffs or PPAs, or government-mandated auction processes. This means that prices and/or quantities of electricity sold from renewable energy projects are subject to considerable intervention from the policy and regulatory process, compared to other types of power generation.

Policy risk therefore arises for example through potential changes in governmental priorities, resulting in reversed, modified or abandoned renewable energy support schemes (e.g., feed-in tariffs and tax benefits).

In the US, production tax credits have been the main policy instrument to incentivise investment particularly for wind power. However, the tax credit policy has tended to be enacted through a series of short-term extensions to the original policy, each lasting typically 1-2 years, leading to a stop-start nature to the industry (Plumer, 2012). More recently, in 2015, a longer 5-year production tax credit regime was introduced giving greater levels of foresight and a more stable investment environment.

At worst, these risks are associated with retrospective changes to renewable support mechanisms that directly affect the revenue of established projects (e.g. changes to feed in tariffs that alter the terms of an established PPA contract). Jurisdictions where such changes have occurred in the past (e.g. in Spain, Bulgaria, Greece, and the Czech Republic), may face much higher commercial risks, and thereby higher costs of capital to offset these. However, these commercial risks are becoming less pronounced as feed-in tariff (FiT) rates approach prevailing spot-market prices, which provide an alternative source of revenue for selling the electricity produced Gatzert & Vogl (2016a).

From a forward-looking point of view for the renewables sector, there is more general uncertainty regarding the future policy arrangements in any particular jurisdiction as policy-makers balance competing demands to stimulate the market whilst keeping control of the total cost of public subsidies, and market design considerations as renewables become mainstream and start to compete on cost with traditional generation sources. Future market arrangements are likely to evolve to achieve a fair distribution of risks and maintaining competition across market players as renewables gains a larger market share. This could include changes to curtailment risk for example, with renewables projects not necessarily being fully compensated in cases of curtailments. Policy risk may therefore increase in the future (Gatzert 2016).

2. Technologies: outlook and risks

The major types of renewable energy (in order of current utilisation) are hydropower, wind, bioenergy, solar, geothermal and ocean / marine. Table 2 shows their current consumption, together with estimates of their total theoretical potential, measured both in energy terms and as a multiple of total global primary energy supply (585 EJ/year in 2017). This indicates that for all technologies, apart from hydro power, the theoretical resource far exceeds current levels of power generation.

The potential also far exceeds global energy consumption for solar in particular, and also for wind and ocean technologies, implying that renewable energy supply is constrained by practical social and economic conditions, rather than resource constraints.

Given the focus of this report the section on hydropower can be found in Appendix A.

Table 2: Comparing technical potentials and current utilisation of renewable energy sources

	2017 generation	Technical resource	Technical resource
	(EJ/yr)	(EJ/yr)	(multiple of total global energy supply)
Hydropower	14.8	147	0.3x
Wind Energy	3.9	6,000	10.3x
Bioenergy	2.2	1,548	2.6x
Solar Energy	1.6	3,900,000	6667.0x
Geothermal Energy	0.3	1,400	2.4x
Ocean Energy	0.0	7,400	12.7x

Sources: 2017 generation, (IEA 2018)
Technical resource: (IPCC, 2011 Table 1.4 p183)

Solar PV

Costs and market outlook

Solar photovoltaics (PV) dominates renewable capacity growth in the next five years, with 575 GW expected to become operational; utility-scale projects represent 55% of this growth, while distributed generation capacity growth accelerates (IEA 2018a). China alone accounts for almost 45% of global solar PV expansion (IEA 2018a). Thus, the size of the global PV market is highly dependent on policies and market developments in China, where the government has phased out FITs and introduced deployment quotas. As a result, China's solar PV deployment is expected to be slower than in 2017 (53 GW) in the short term, reducing global demand. Consequently, the global module supply glut is anticipated to result in lower module prices, a factor that increases speculation that recent low auction prices may not necessarily be reflective of longer-term trends. With increasing cost-competitiveness and continuous policy support, demand recovery is expected after 2020, with global additions of over 110 GW by 2023 in the IEA's main scenario case – led by China, the United States, India and Japan, with growth in Latin America and Africa accelerating because of improving economic attractiveness and continued policy support (IEA 2018a).

Photovoltaics is the direct conversion of light into electricity using certain semiconductors. They are manufactured in 'cells' (typically around 6 inches by 6 inches), which are then interconnected and assembled into larger 'modules' for installation. Various types of semiconductor are used, but the large majority are based on crystalline silicon (Table 3). Two types of silicon technology are used; historically monocrystalline silicone systems dominated the market, but in the past 5 years polycrystalline systems have almost caught up in terms of efficiency (within about 1 percentage point), and its cheaper manufacturing process means is it is now taking a larger share of the market. Both types of silicon systems are physically rigid, meaning they must be installed as flat panels.

Thin film systems use a range of different semiconducting materials. The most deployed thin-film technologies are Cadmium-Telluride (CdTe), Copper-IndiumGallium-Selenide (CIGS) and amorphous silicon (a-Si). Their advantage is cheaper manufacturing, offset by lower efficiencies (thereby requiring greater installed area to achieve the same capacity). However, efficiencies have been increasing to within around 5 percentage points of silicon systems. Thin film systems can be applied to more flexible substrates, and come in different shapes and sizes, meaning they potentially are open to a wider set of applications.

For example, work is underway to 'tune' the panels so that they only absorb light outside of the visible spectrum, making them transparent and suitable for use on windows.

In areas where there is an established grid structure, Building Integrated Photovoltaic (BIPV) technology presents a sizable opportunity for distributed energy to fundamentally alter the current electricity market mechanisms. BIPV is when photovoltaic panels are directly integrated into the materials used in the construction of a building. The BIPV market is mainly focused on creating PV rooftops and facades however solar PV cells can be incorporated into almost every glass layer structure such as street furniture, advertising billboards and skylights (Polysolar, 2018). The global BIPV market is growing rapidly, spurred by increasing cell efficiency and decreasing prices. With an expected CAGR of 23.4% from 2018 to 2024, the market value is predicted to expand from $6.7 Billion to $32.2 billion in 2024 (Energias Market Research, 2019). There is a good chance that the solar BIPV era will begin in 2020 (Solar Power Europe, 2018), spurred by a Bill coming into effect in 2020 by the state of California mandating that all newly built houses include solar power systems installed onto the buildings (California Legislate, 2019). The chance that more states, cities or even countries will follow this example means that the outlook for BIPV is becoming increasingly optimistic.

Table 3: Share of different solar PV technologies in 2017

		Production (GWp)	Share (%)
Multi-crystalline Silicon		60.8	62
Mono-crystalline Silicon		32	33
Thin film		4.5	5
(of which)	*CdTe*	*(2.3)*	*(2)*
	CIGS	*(1.9)*	*(2)*
	a-Si	*(0.3)*	*(<1)*

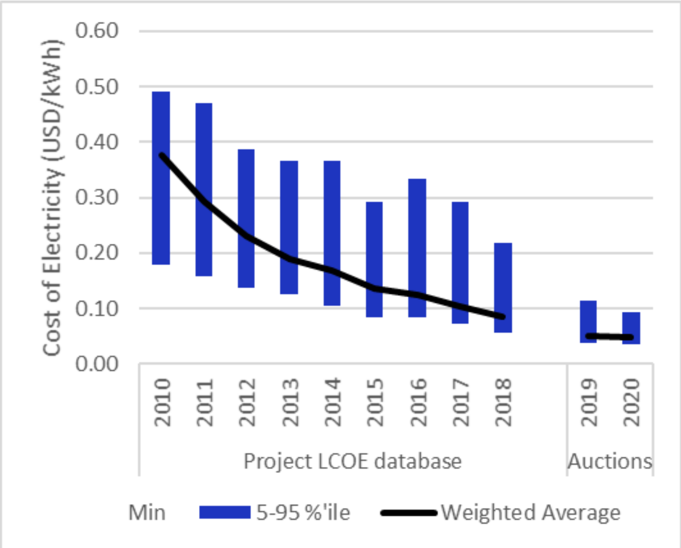
Source: Fraunhofer ISE, 2018

The conversion efficiency of sunlight to electricity has been steadily increasing as the technology improves. By 2024, industry expects the efficiency of mass produced of crystalline silicon-based cells to be in the range 19.8-25% depending on cell type and architecture up from a current range of 18.8-23.5%, which is around 5 percentage points higher than a decade ago (Fraunhofer ISE, 2018).

Current crystalline module efficiencies are typically at least 2% lower than efficiencies at the cell level due to losses at various stages in the assembled module. Efficiencies of thin-film systems are now reaching a range of 18.6-22.9% in the laboratory (Fraunhofer ISE, 2018), though achieved efficiencies for mass-produced modules are lower; First Solar, the largest CdTe manufacturer reported fleet average efficiencies increasing from 12.9% in 2012 to 16.6% in 2016 for their CdTe modules, whilst Solar Frontier reports module efficiencies between 12.2%-13.8% for their CIGS modules (IRENA, 2018).

Average costs of solar PV have come down by about a factor of four over the past decade and are expected to continue to drop in response to further economies of scale and technology improvements. Figure 3, shows an outlook for solar PV costs based on a global database of projects from IRENA, together with data on prices achieved in recent solar auctions, as well as projections made for 2025 based on analysis of technology pathways. This demonstrates, the weighted average (black line) is trending towards the bottom of the range indicating growing maturity of the PV industry. Larger projects are now costing less and, there are more of them now than a decade ago when costs were higher due to lack of technology advancement.

Figure 3: Solar PV costs fallen dramatically over last 10 years and are now competitive with other energy markets



Source: IRENA, 2018 and 2019

China is expected to continue to dominate investment (as well as production) in the installation of new solar PV capacity. The breakdown across the top 5 countries is shown in Table 4.

Focus on the future

New approaches to PV are being developed, including new materials for thin-film cells such as Perovskites, improvements to manufacturing techniques for silicon systems.

Research is also being carried out on more exotic approaches such as quantum dot technology, which allows greater efficiency by 'tuning' cells to respond to different frequencies of light (Nozik 2002, Yang 2017). These developments are helping solar technologies to continue a decades-long trend of improvements to the efficiency of solar cells, as shown in Figure 4. The theoretical efficiency limit for a single layer solar cell is 33%, but this can be increased by adding multiple layers (with obvious cost implications). The very high efficiency cells indicated by purple lines are all multi-layered devices designed for operation in space where cost is less of a consideration. The thin film technologies (Green lines) are less efficient but are transparent so can be layered onto glass or other building materials vastly increasing the surface area available.

Table 4: Expected solar PV capacity growth 2018-23

Top Countries	GW
China	255.8
USA	70
India	62.9
Japan	21.2
Mexico	15.8

Source: IEA, 2018a

Photovoltaic performance warranty insurance

Demand for sustainable energy sources is fast growing, and with it, driving rapid development of new technologies. Renewable energy is already cost competitive in many applications and areas, however, new technologies bring uncertainty and higher volatility, which can disincentivise innovation and investment.

Whilst the solar industry is accustomed to growth and expansion, investors in photovoltaic (PV) technology have also been confronted by turbulence and barriers to entry. Security of investment is a major concern – and an even greater concern during industry developments is that manufacturers might cease to trade. Developers and investors are concerned that PV manufacturers may become insolvent, rendering performance and product warranties worthless – a development that would drive up operating costs and decrease return on investment.

The Munich Re Innovation Syndicate at Lloyd's is addressing this with the Photovoltaic Performance Warranty Insurance product that aims to reduce this risk by protecting investors and developers of solar parks from underperforming technology of insolvent manufacturers, which would disrupt the going concern of these solar installations. The dual trigger product requires a proven decrease in power output of the client's photovoltaic module and the insolvency of the manufacturer. Munich Re's Green Tech Solutions team has a ten year successful track record of establishing this business enabling coverage in the global solar market.

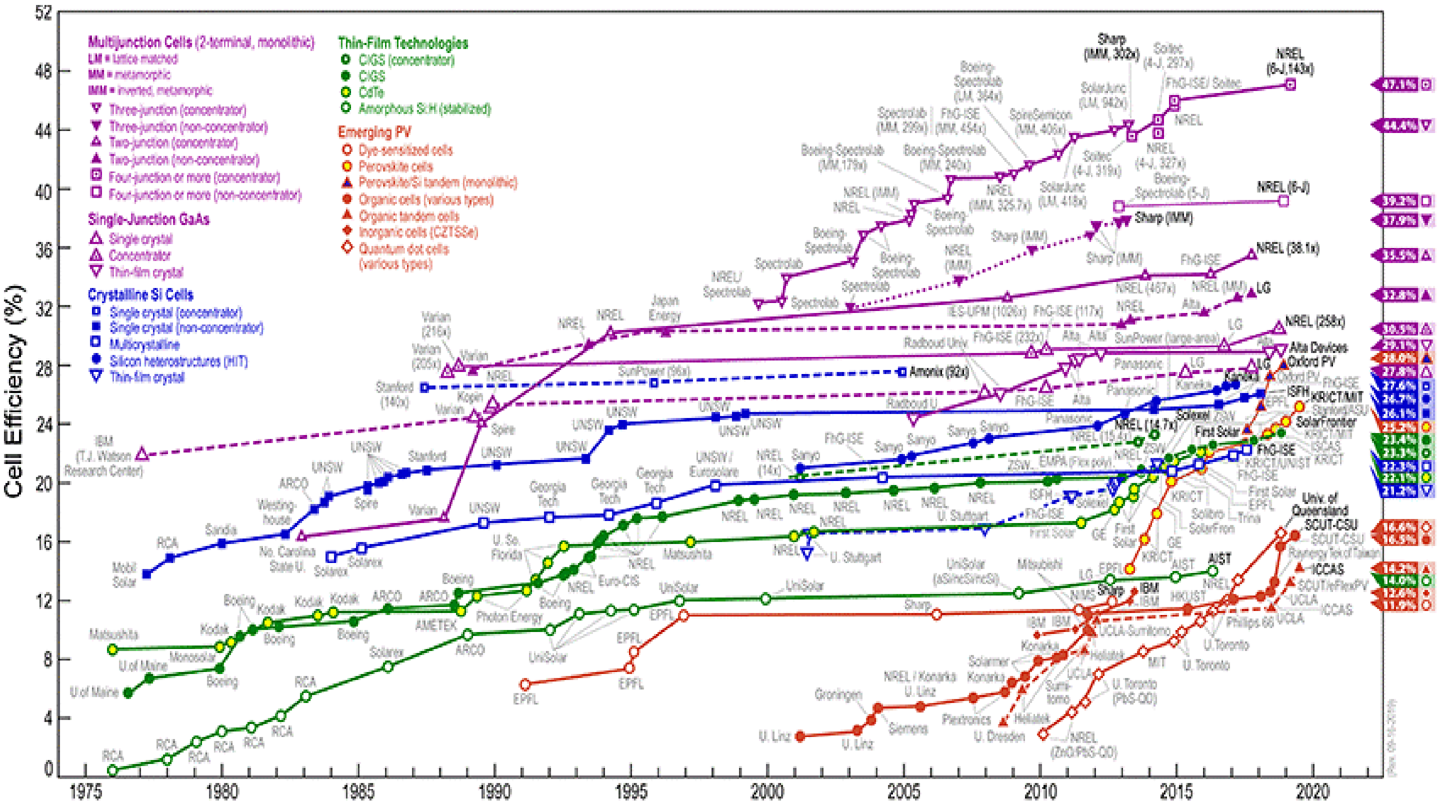
The coverage provides significant risk transfer for up to 10 years from policy inception and ensures reliable loss pay-out, with no financial reliance on the now insolvent PV manufacturer. This protects both developers and investors in solar energy production, providing an element of balance sheet protection a clear support to investment, protecting the large up-front capital cost and long expected lifespan of a solar panel.

This product is specifically designed to meet the needs of small to mid-sized solar operations and it provides key benefits for all parties involved as manufacturers can attract investors and clients as a financially secure counterparty.

With this warranty insurance product, the technology risk is transferred into the insurance market, benefitting from the diversified capital of Lloyd's.

Learn more about Munich Re Innovation Syndicate at https://www.munichre.com

Figure 4: Cell efficiency improving across solar technologies, all being more efficient than photosynthesis that converts UV at only 16%



Source: US National Renewable Energy Laboratory, 2019

Despite these promising developments in new materials, the bulk of the PV market at least for the next decade is expected to be based on well-established and mature technologies that have very little technical risks.

Risks in this sector are mostly either commercial in nature or relate to natural perils.

- Commercial risks vary according to local conditions including the policy support mechanisms in place, and related project financial risks such as currency risk, offtaker risk (e.g. solvency of local utilities) etc. These risks are not substantively different from the types of commercial risk facing other types of energy projects. System integration risks arise in contexts where there is already relatively high share of intermittent variable renewable energy on the system. In these contexts, the performance of utility-scale PV projects, in terms of the degree to which energy can be utilised in the system, will depend on other investments made to ensure the system is sufficiently flexible that it can absorb the electricity generated. In high renewables penetration scenarios, these constraints can alter the choice of technology, for example potentially favouring flexible generation plant such as CSP (see next section).

- Natural perils that can cause physical damage include wind, rain, hail, lightning and wildfire. Damages from non-traditional CAT perils such as tornado, hail, and wildfire tend not to have sub limits on insurance policies and solar PV is extremely exposed to all these and experience has shown increasing issues with the unpredictability and volatility of these events particularly in the US where solar PV is growing quickly. One response will be for the insurance industry to start applying sub limits to policies for these risks.

Solar power: insurance solutions for cyber risk and system failure

Solar Power facilities utilise increasingly sophisticated technologies to maximise energy output and reduce the Levellised Cost of Energy (LCOE) for the site.

The LCOE for utility scale Solar PV has dramatically fallen in the last decade, driven by the introduction of single and variable axis tracker technologies, which maximise sun irradiation and thus plant efficiency. Sector growth has also resulted in the selection of sites with more challenging terrain necessitating new types of plant design. These developments have increased the mechanical and electrical complexity of PV facilities.

Wireless tracker technology is now deployed for Concentrated Solar Power or 'Solar Tower' facilities, being essential for directing sunlight from heliostats to a steam generation system. Wireless control not only reduces the cost of energy but also reduces field erection time of heliostats, however introduces a number of risks, such as an internal network failure or firewall breach.

As solar power facilities become more sophisticated and reliant on connected devices and wireless systems alongside their core ICS and SCADA systems technology, the scope for, and impact of, network attacks increases.

A breach of a control system or network in a Solar PV or Solar Tower plant can cause a loss of system functionality and an insured's facility is at risk of physical damage and or financial loss due to unavailability.

Liberty Specialty Markets (LSM) offers a specialist cyber product, which can insure against business interruption as a result of both malicious attacks and, in some cases, unplanned outages. LSM can also cover voluntary shutdown to mitigate a loss and the business interruption impact of regulatory shutdown arising from a cyber event, whether damage has occurred or not. This could be due to an unexpected failure of the SCADA system or wireless network leading to a loss of tracker or control functionality.

LSM also provides coverage for physical damage and subsequent loss of revenue as a result of a malicious attack.

Insurance products such as this will enable the successful development of more advanced and reliable Solar technologies sustaining the continued expansion of the sector.

Learn more at:

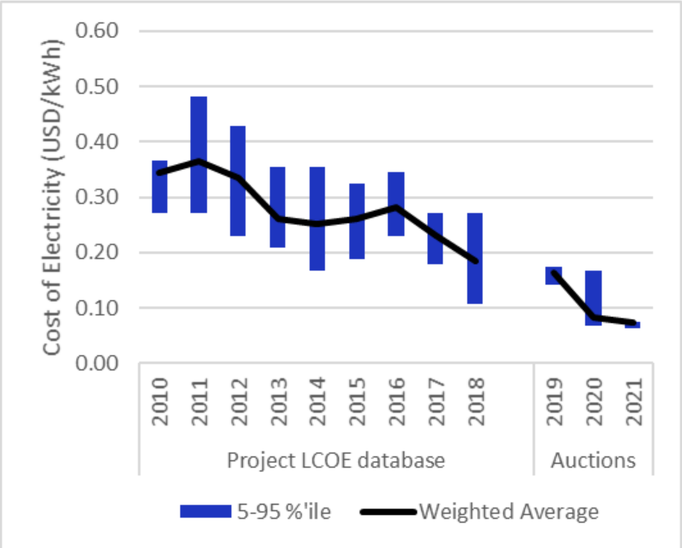
https://www.libertyspecialtymarkets.com/insurance

Concentrated Solar Power (CSP)

Costs and market outlook

Concentrated solar power (CSP), uses mirrors to concentrate solar rays. These rays heat fluid, which creates steam to drive a turbine and generate electricity in the same way as for conventional power generation. CSP is used to generate electricity in large-scale power plants. The two main CSP systems that have been deployed commercially are parabolic trough and solar towers. In parabolic troughs, the thermal fluid is contained in pipes that run along the focal line of a series of reflectors, collecting heat, and then returning it to a central power generating station. Tower systems use mirrors to reflect solar energy from a wide area onto a central collecting point at the top of a tower. These can produce very high temperatures, and potentially are suitable for heat storage using molten salt technology. This has the advantage of allowing electricity to be generated when it is needed, for example after the sun has set. However, it is also much more technically complex than solar PV, comprising both large areas of reflector panels, together with steam cycle turbine and potentially heat storage systems. The cost outlook over the next 5 years is shown in Figure .

Figure 5: Falling cost of CSV, it is expected to compete with PV and batteries in the future when it falls below 0.1.



Source: IRENA, 2018 and 2019

Given the large scale of projects involved, the high capital costs, and the large space requirements, installation of CSP is much smaller than for solar PV. It has tended to be favoured in countries such as North Africa where land availability constraints are less pronounced, though China again remains in the lead regarding expected future activity (Table 5).

Table 5: Expected solar CSP capacity growth 2018-23

Top Countries	GW
China	1.90
Morocco	0.73
UAE	0.70
South Africa	0.30
Israel	0.23

Source: IEA, 2018a

CSP is expected to grow 87% (4.3 GW) over the forecast period, 32% more than in 2012-17. China leads at 1.9 GW, followed by 1 GW from projects receiving multilateral development bank support in Morocco and South Africa, 1 GW in the Middle East and 300 MW in Australia and Chile. Spain and the United States, the two countries with the most installed capacity, are not expected to commission projects over the forecast period, so China is expected to overtake the United States to have the second-largest CSP installed base by 2023. Recent auction results indicate significant cost reduction potential, but technology risk, restricted access to financing, long project lead-times and market designs that do not value storage continue to challenge CSP deployment (IEA 2018a).

Technology developments and risks

In addition to parabolic trough and solar tower technologies, other approaches have included linear Fresnel collectors (potentially cheaper because they use flat mirrors rather than curved mirrors), and Stirling dish systems which employ a Stirling engine at the focal point of individual parabolic dishes. Whilst each of these has their own pros and cons, neither has been deployed at similar scale.

In general, CSP remains much further from mass deployment than solar PV. This is mainly due to a combination of technology risks (associated with the relative complexity and technical immaturity of projects), country risks, large project size and development costs, which have tended to stifle access to financing for CSP projects. A range of potential technical risks (Table 6) is identified in Amato (2011), though technology developments in successive projects will continue to address and mitigate these risks.

Table 6: Examples of potential technical risks for CSP projects

Title	Frequency	Severity	Risk
Orientation system stopped	High	High	Very high
Water Hammer	Very High	Medium	High
Turbine Failure	High	High	High
MV Switchgear tripping	High	High	High
Low pumping (SG pumps)	High	High	High
Salt solidification due to no pumping	High	High	High
No pumping (Solar Field)	High	High	High
Salt solidification due to no flow	High	High	High
Steam generator internal leakage	High	High	High
Turbine leakage	High	High	High
Salt solidification due to loop isolation	High	High	High
Salt solidification due to prolonged bad weather conditions	High	High	High
Salt solidification due to failure of three pumps	High	High	High
Salt solidification due to short power failure (cold spots)	Medium	High	High
Salt solidification due to prolonged power failure	Medium	High	High

Source: Amato, 2011

Ongoing CSP projects have relied on generous feed-in tariffs (China, Israel) and access to low-cost financing (the Middle East and Africa) to make them viable (IEA, 2018a). However, research and development, technology learning and mass deployment promise significant cost reduction potential. The IEA projects limited CSP deployment until 2023, but its long-term scenarios forecast a more pronounced role for CSP, with thermal storage after 2030, especially owing to the flexibility and energy security it can provide to power systems that incorporate high shares of variable renewable energy (IEA, 2018a).

Wind power

Costs and market outlook

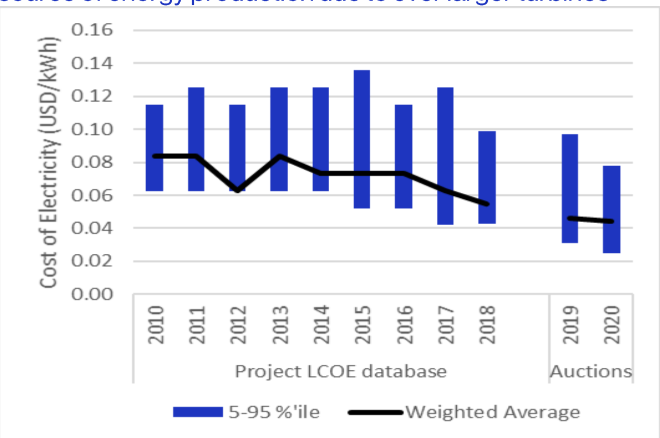
Wind capacity is forecast to grow almost 324 GW to reach 839 GW by 2023; offshore wind accounts for 11%. In 2020, cumulative solar PV capacity surpasses that of wind as annual onshore wind growth remains within 45 GW to 52 GW in the main case forecast. The phase-out schedule of federal tax incentives in the United States, the expiration of FITs and grid integration challenges in China, and the timetable of auctions in Europe, India and other regions make the trend for annual additions volatile. Offshore wind capacity is expected to almost triple to nearly 52 GW in 2023, with half the growth driven by the European Union and the other half by China and other Asian countries (IEA, 2018a). Onshore and offshore wind costs have dropped steadily over recent years and are expected to continue to fall in coming years and with top countries' outlooks for investment in Table 7 and Table 8.

Table 7: Expected onshore wind capacity growth 2018-23

Top Countries	GW
China	109
USA	43
India	32.5
Germany	16.7
Brazil	6.4

Source: IEA, 2018a

Figure 6: Onshore wind cost trend, now very competitive source of energy production due to ever larger turbines



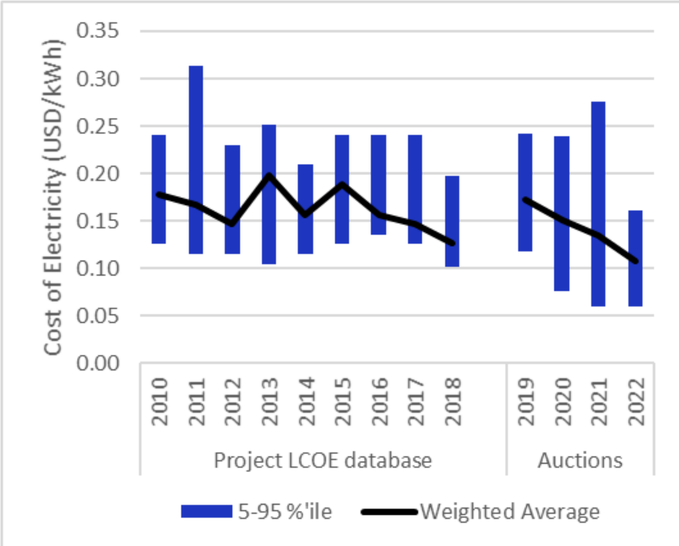
Source: IRENA, 2018 and 2019

Table 8: Expected offshore wind capacity growth 2018-23

Top Countries	GW
China	10.5
UK	6.7
Netherlands	3.2
Germany	2.4
Denmark	1.7

Source: IEA, 2018a

Figure 7: Offshore wind cost trend, logistics make it more expensive than onshore



Source: IRENA, 2018 and 2019

Technology developments and risks

The output of a wind turbine is very sensitive to wind speed, varying with the cube (i.e. to the power of three) of the wind speed. This is because a doubling of the wind speed not only doubles the volume of air flowing past the blades in a given time period, but the kinetic energy of that air will increase by a factor of four (since energy is proportional to speed squared), making a factor of 8 increase in energy overall. This creates an incentive to make wind turbines as tall as possible, since wind speeds are on average significantly greater (and less variable) at higher elevations from the ground. Taller wind turbines also allow longer blades to be used, so the swept area is higher, leading to larger peak capacity. The industry is therefore pushing innovating towards larger and larger turbines. There are currently 8 MW offshore wind turbines supported on grounded monopile foundations deployed in UK waters (e.g. Burbo Bank Extension), and the industry is moving forward towards 10MW and more; EU-funded projects have been working on the design of 10-20 MW wind turbine concepts for some time (WTW, 2018a). One of the key risks for insurers linked to this rapid technology development is the lack of performance track record associated with the new technologies.

Analysis of claims data by GCube has been published in a series of reports identifying key sources of risk:

- Gearbox failures. GCube (2015a) reports a failure rate of 1:145 per year, half of these from a failure in the bearings within the gearbox. Together with blade damage, this makes gearbox failure one of the leading causes of loss claimed on insurance. Average downtime amounts to 18.5 days per incident, though with longer downtimes in the US. Greater standardisation of design across manufacturers is leading to significant reductions in repair costs.
- Offshore Cable failures. GCube (2016) reports that incidents involving failure of subsea cables and associated components represent 77% of total offshore wind losses. Inter-array cables are currently rated at 33kV, but the industry standard is moving to 66kV. This is more of a commodity market, with more supplier over-capacity, and downward pressure on prices causing compromises on quality. The failure rate is around 1:460, with average downtimes of around 100 days, and losses typically around $5m per claim. Causes include: environmental factors (such ground conditions, obstacles, dragging from ship's anchors etc.) equipment failure, and poor installation or human error in handling causing mechanical damage. Overall, 67% of failures can be attributed to contractor errors. Risks can be best managed by designing in constructability and routing at an earlier stage of the project, and by incorporating new continuous monitoring sensors to assess the condition of cables and diagnose problems prior to commissioning.
- Transformer outage. GCube (2015b) indicates that transformer outage remains the greatest source of Probable Maximum Loss, particularly for large sites, and particularly where only a single transformer has been installed as a cost reduction measure. Onshore wind sites typically require transformers worth in the region of $3-10m, and there are 15-20 reported incidents per year, though it is likely that the are several times more outages that go unreported. Major causes include poor equipment quality, damage sustained during transit, poor workmanship during installation, overloading during operation (e.g. caused by outages of other linked transformers), and natural causes such as lightning.
- Fire risk. GCube (2015c) data shows fires to be infrequent, with 50 incidents per year (incident rate of 1:6000 per year), but high consequences with downtimes typically 9 months and costs amounting to $4.5m on average. There is also a knock-on risk of triggering bushfires in some areas, with higher fire risks overall in hotter countries where temperature limits on components such as bearings and control cabinets are more likely to be exceeded. Key risk reduction measure is to enforce required maintenance schedules.

The challenge for the industry is not just proving these large systems commercially but expanding the range of locations. One significant constraint for offshore wind is to attach the foundations to the seabed, which becomes uneconomical beyond depths of around 30m. A solution is to use floating bases which could unlock more deep-water sites, and in principle since they can be constructed at a port and towed out to their final location, the installation and O&M processes can potentially be more cost-effective than fixed systems. Installations of the technology have been growing but are still considered to be at the advanced pilot stage, providing lessons in terms of design, fabrication, installation and operation. These include (WTW 2018a) WindFloat, a pioneering 2MW floating prototype design, deployed in 2011 off the coast of Portugal. Funds are currently being assembled to expand the project to 3 turbines of 8.4MW each, the largest floating turbines to be installed, bringing the technology to the cusp of commercial scale (Hill, 2018). The Hywind project in the North Sea off the coast of Scotland, has the principal objective to verify new scaled-up designs on a multiple wind turbine basis in order to demonstrate the viability of a future commercial scale farm. Starting operations in 2017, this development has 5 turbines of 6 MW each, giving a total capacity of 30MW, and achieved an average capacity factor of 65% between November 2017 and January 2018 (Klippenstein, 2018).

Whilst the floating offshore wind sector is growing, and the potential for significant cost reductions makes it an attractive bet for future market share, it is subject to a number of risks not faced by fixed structures (see ORE Catapult 2017 for a discussion). These include:

- Manufacturing and technical risks are currently higher in general, associated with relative immaturity of the sector, and current lack of scale and experience.
- health, safety and environmental risks, including the additional risks to personnel associated with working on a moving structure.
- operations and maintenance (O&M) costs could in principle be reduced compared to fixed structures as major repairs could be carried in port.

Laying of cables is one area of offshore wind farms where there has been a high frequency of claims (arising from cabling risks and control technologies) (ORE Catapult, 2017). In fact, power-cable failures offshore are often the main risk affecting the development and operation of offshore wind farms (Subsea World News 2018). These can be attributed to damages sustained during cable installation, thermodynamics, impact (e.g. by an anchor), as well as seabed alterations that can lead to cable exposure.

The cost of fixing a damaged cable can be significant because of the specialist vessels required for the job. Between 40% and 70% of the cost of a typical offshore wind cable claim is basically the vessel costs which can be up to $150,000 a day if hired at short notice (Lloyd's 2014).

In floating wind, the situation is further complicated by the necessity for dynamic cables. These are exposed to additional loads (e.g. wave loads, impact loads from drifting objects, and most importantly additional fatigue due to substructure motion), as they have to be flexible enough to absorb the motion of the floating wind turbine and installed in the water column (e.g. they cannot be buried or covered by rocks), hence the higher probability of cable damage. Floating wind turbines are also exposed to larger motions compared to bottom-fixed wind turbines, which can be damaging to the wind turbine. Floating wind systems require control algorithm modifications to reduce the loading. Depending on the size of these modifications, the warranty provided by the wind turbine manufacturer can be invalidated, raising the project insurance costs and putting off turbine OEMs and project developers (ORE Catapult, 2017).

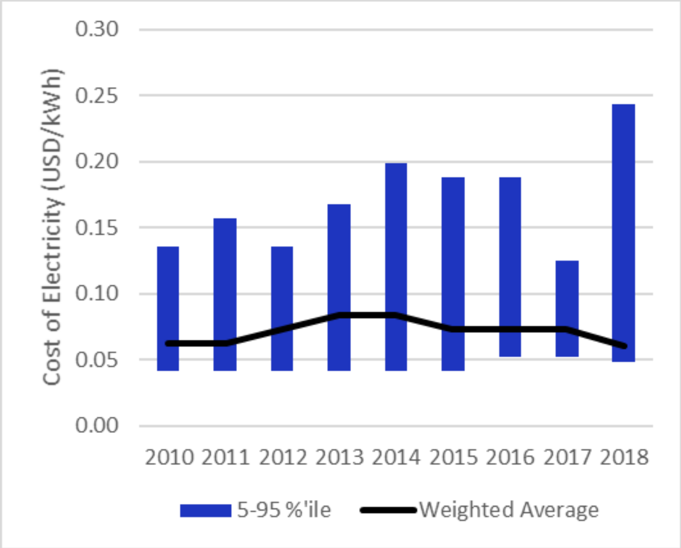
Biomass

Biomass power is based on thermal power generation technology, using a variety of biomass sources as the feedstock. It is considered a renewable energy source because the carbon dioxide released during combustion is assumed to be reabsorbed within the natural carbon cycle as the harvested plants re-grow. The biomass power industry generally consists of three main parts: production of feedstocks; logistics and supply chains; power conversion. In general, biomass power generation technologies are mature, and are a competitive power generation option wherever low-cost agricultural or forestry waste is available.

Costs and market outlook

The costs of power from bioenergy have been relatively stable since 2010, reflecting the mature nature of the underlying thermal technology. Cost variations, and the prospect for cost reductions, are largely tied up with availability of the bioenergy raw materials. Availability and cost of inputs can vary according to climatic conditions, as well as other market conditions such as commodity prices in competing markets for wood products, causing price variations (Figure 8). The investment outlook for key countries is shown in Table 9.

Figure 8: Cost timeline for bioenergy a stable technology so trend is broadly flat



Source: IRENA 2018 and 2019

Table9: Expected biomass capacity growth 2018-23

Top Countries	GW
China	13.7
Japan	2.6
UK	2.1
India	2.1
Brazil	1.7

Source: IEA, 2018a

Bioenergy is anticipated to grow 37 GW by 2023, 10% lower than deployment over 2012-17. Global additions remain relatively stable at between 5 GW and 8 GW throughout the forecast period. The forecast has been revised up from last year to reflect a more optimistic outlook for China, where a new policy initiative is expected to drive robust co-generation and energy-from-waste (EfW) deployment. China therefore accounts for 37% of bioenergy deployment, but markets in Asia-Pacific and Brazil also make key contributions based on diverse policy support mechanisms. The forecast for bioenergy in the European Union has been revised down, although the United Kingdom and the Netherlands remain major markets. While bioenergy is not expanding rapidly into many new markets, Mexico and Turkey do show signs of growing deployment (IEA, 2018a).

Technology and development risks in bionenergy systems

Modern bioenergy systems involve a wide range of feedstock types, residues from agriculture and forestry, various streams of organic waste, and dedicated crops or perennial systems. Existing bioenergy systems rely mostly on wood, residues and waste for heat and power production, and agricultural crops for liquid biofuels. The economics and yields of feedstocks vary widely across world regions and feedstock types. Production competes with the forestry and food sectors, but the design of integrated production systems such as agroforestry or mixed cropping may provide synergies along with additional environmental services.

A large power station will require biomass to be grown over a large area to provide the necessary volumes. Handling and transport of biomass from production sites to conversion plants are therefore substantial and may contribute 20 to 50% of the total costs of bioenergy production. Factors such as scale increases, technological innovation and increased competition have contributed to decrease the economic and energy costs of supply chains by more than 50%. Densification via pelletisation or briquetting is required for transport distances over 50 km (Chum, 2011), including transport by ship, rail and truck.

Conversion to electricity is usually through conventional thermal power plant (steam turbines). These may be in dedicated biomass plant, or biomass may be co-fired together with other fossil fuels, usually coal, to reduce overall greenhouse gas emissions from the plant. Use in combined heat and power units is also common for smaller units. An alternative approach at an earlier stage of commercialisation is to gasify the biomass and generate electricity in a gas turbine. Gasification has the advantage of producing a more concentrated stream of CO2 in the exhaust, which lends itself to carbon capture and storage (CCS). Biomass energy with CCS (BECCS) has the potential to remove CO2 from the atmosphere (so-called negative emissions technology) and is projected to play a major role in later decades of this century to try to control the effects of climate change.

Risks and barriers to deployment are found all along the bioenergy value chain. On the supply side, there are challenges related to securing quantity, quality and price of biomass feedstock. There are also technology challenges related to the varied physical properties and chemical composition of the biomass feedstock, and new these may raise health and safety issues for workers handling materials, such as accumulation of pesticides or other agricultural products. On the demand side, the main challenges are the stability and supportiveness of policy frameworks and investors' confidence in the sector and its technologies, and the need to demonstrate reliable operation of new technologies at commercial scale. Competition with other renewable electricity sources may also be an issue. Public acceptance and public perception are also critical factors in gaining support for energy crop production and bioenergy facilities. In general, as a component of the much larger agriculture and forestry systems of the world, traditional and modern biomass affects social and environmental issues ranging from health and poverty to biodiversity and water quality. Land and water resources need to be properly managed in concert with each specific region's economic development situation.

Geothermal

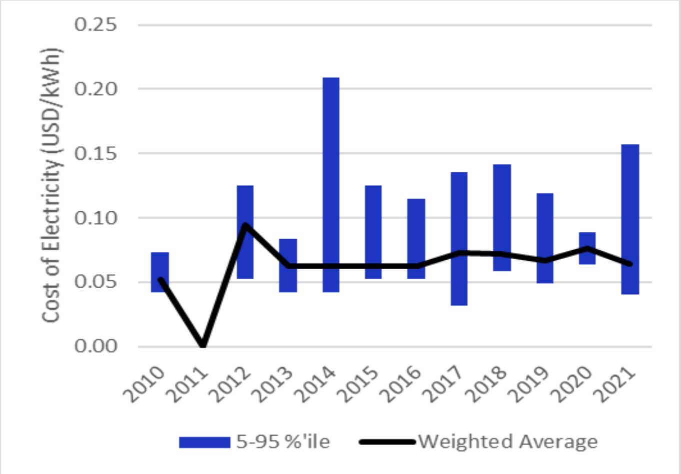
The most common way of capturing energy from geothermal sources is to tap into naturally occurring hydrothermal convection systems, where water seeps into the earth's crust from the surface and rises back up as steam of heated water. When this reaches the surface, the heat is captured and used to drive a turbine connected to a generator for production of electricity. The most common types of geothermal system are:

- Flash steam. Underground geothermal water sources can exist at high temperatures (reaching more than 180°C) because the pressure of the sub-surface environment is much greater than at the earth's surface. When drawn to the surface, the water 'flashes' into super-heated steam and can be used directly to drive a steam turbine.
- Binary cycle. When temperatures are too low to 'flash' water into steam, the heat must be transferred through a heat exchanger to a 'working fluid' with a lower boiling temperature (Zeyghami 2015). Lower temperature geothermal sources may also be used for other industrial or residential applications such as space or water heating rather than electricity generation.
- Combined flash-binary system. Additional energy may be extracted from the output of flash steam generation systems by using it as an input to a binary cycle system to generate further electricity.
- Engineered geothermal systems. An enhanced geothermal system uses drilling, fracturing, and injection to provide fluid and permeability in areas that have hot—but dry—underground rock. In this case, water is injected from the surface down into geological formations, and then extracted through a second borehole.

Costs and market outlook

The cost trajectory over recent years is shown in Figure 9, showing relatively stable and flat costs, reflecting the mature nature of the geothermal sector.

Figure 9: Cost timeline for geothermal, it is operating at close to full efficiency



Source: IRENA, 2018 and 2019

Geothermal capacity is set to grow 28% (4 GW) to reach just over 17 GW by 2023 as projects in nearly 30 countries come online, with 70% of the growth in developing countries and emerging economies. The Asia-Pacific region (excluding China) has the largest growth (1.9 GW) over the forecast period. Indonesia's expansion is the strongest, propelled by abundant geothermal resource availability and a strong project pipeline in the construction phase supported by government policies. Kenya, the Philippines and Turkey follow, responsible for 32% of additions. Although pre-development risks are still an important barrier to securing financing for geothermal projects, exploration and construction of facilities in Latin American and Caribbean countries is expected to take off because geothermal technology generates stable, carbon dioxide (CO2) emissions-free baseload power (IEA, 2018a). Outlook for investment up to 2023 is set out in Table 10.

Table 10: Expected geothermal capacity growth 2018-23

Top Countries	GW
Indonesia	1.20
Kenya	0.52
Philippines	0.37
Turkey	0.30
New Zealand	0.17

Source: IEA, 2018a

Technology and development risks for geothermal projects

A key risk factor for geothermal is exploration risk. Exploration risk for geothermal is similar in some ways to exploration risk in the oil and gas sector: the geothermal resource depends both on the temperature and the volume of the water in the reservoir being accessed. In principle, heat can be extracted from a well at the same rate that it is replenished from the underground hot rocks. In practice, energy is often extracted at a faster rate, giving a well a finite useable lifetime, though a good site would potentially last for several decades. However, the performance of a well will often not be fully understood until production starts. As for oil wells, the geothermal resources from any particular well may be larger or smaller than estimated based on geological surveys carried out prior to drilling the test wells. If the resource falls below a certain threshold, the output may not be commercially viable to exploit. Given the capital costs involved, electricity production in particular requires sufficient temperature and volume of water to be viable. Capital used for exploration is at risk until the geothermal resource has been proven.

Willis Towers Watson (WTW, 2018a) reports that drilling costs represent around 30% of total investment and can be higher in ECG projects, whilst failure rates run at approximately 1 out of 3 projects for wells of 3MW, and about 25 % of wells below 1MW are dry. These risks create a significant hurdle for geothermal projects, as the sector is generally not large enough to have attracted companies of sufficient size to self-insure these risks as has typically been the case in the oil sector.

Marine / Ocean

As noted above in Table 11 the technical potential of ocean technologies is high, but they remain amongst the least developed renewable energy technologies. This is at least in part because of the harsh and sometimes inaccessible environment that oceans tend to present for projects. Marine technologies continue to account for the smallest portion of renewables growth, as expansion typically comes from small-scale demonstration and pilot projects of less than 1 MW. However, larger projects (6 MW to 15 MW) emerging in United Kingdom and France are boosting capacity growth. Globally, tidal technology is expected to account for 50% of all marine-based additions, followed by wave projects (IEA, 2018a). Resource assessments for marine energy in the US are relatively well mapped (NREL 2018). Table 11 indicates the current outlook in terms of the top five countries for ocean technologies globally up to 2023. These figures are at least an order of magnitude lower than for other renewable technologies presented above.

Table 11: Expected marine capacity growth 2018-23

Top Countries	GW
UK	0.026
France	0.022
Korea	0.013
Indonesia	0.012
China	0.008

Source: IEA, 2018a

Technology developments and risks

The key technology types and their status of commercial development is shown in. The only option considered close to commercialisation is tidal range systems, but a number of other technologies are under development.

Table 12: Development status of different marine technologies

	R & D	Demo & Pilot Project	Early-Stage Commercial	Later-Stage Commercial
Wave		X		
Tidal Range				X
Tidal Currents		X		
Ocean Currents	X			
Ocean Thermal Energy Conversion		X		
Salinity Gradients		X		

Source: IPCC, 2011

Each category represents a range of different technology types, which may be more or less suited to conditions at different locations (Lewis 2011).

1. Wave power comprises three main technology types: oscillating water columns, in which the waves alternately compress and decompress air in a chamber, driving a turbine; an oscillating body system in which a floating buoy moves up and down relative to a fixed component containing a power take-off device; overtopping devices in which the water surge from the waves enters a collection reservoir at a level above the free water surface, and the potential energy is converted to electricity as it drains out. Some of these systems are suitable for installation in deeper waters, whilst some are more suited for installation on shorelines or breakwaters.
2. Tidal range hydropower has usually been based on estuarine developments, where a barrage encloses an estuary, which creates a single reservoir (basin) behind it and incorporates conventional low-head hydro turbines. These systems are attractive from an engineering perspective as the barrage can be relatively short, and still enclose a substantial body of water. However, they can be disruptive to sensitive estuary environments. The technology itself is mature, although the only utility-scale tidal power station in the world is the 240 MW power station built across the estuary of La Rance river in

France, which has been in successful operation since 1966. More recent developments have focused on tidal lagoons. These are manmade breakwaters built to enclose an area of coast line and generate power as water enters and leaves the lagoon. A 320 MW tidal lagoon was recently proposed at Swansea, South Wales, at an estimated CAPEX of £1.3bn which could have served as a demonstration for further UK projects (Hendry 2016) but was turned down by the UK government (BEIS 2018).

3. Tidal current systems are devices which extract energy from the tidal flows in an analogous way to wind turbines, although they have to deal with cavitation and harsh underwater marine conditions (e.g., salt water corrosion, debris, fouling, etc). Schemes are usually designed to be bottom-mounted.
4. Ocean current systems are based on similar technology but are sited further from shore and rely on the energy of deep-water currents rather than tidal movements. These systems could deploy significantly larger turbines, though mounting poses a greater challenge than tidal systems. Mounting on existing off-shore structures could be feasible.
5. Ocean thermal energy conversion uses the difference in temperature between different layers of the ocean to drive a steam turbine. Warm surface waters are used to vaporise a working fluid (either water evaporated in a vacuum chamber or a secondary working fluid such as propane or CFC), which is used to drive a turbine, before being returned to liquid phase using cooler water drawn from lower depths.
6. Salinity gradient systems use chemical potential energy created when at the interface of freshwater and seawater, such as where a river flows into a saline ocean. Systems can either utilise this chemical potential within an electrical cell arrangement (reversed electro dialysis) or by using the tendency of fresh and salt water to mix (osmotic power) to create an increase in pressure in an enclosed volume of seawater to drive a turbine.

Marine projects will in general incur several site-specific risks, including risks to the projects themselves relating to damage from the marine environment, as well as risks of negative impacts on the environment. These environmental impacts are difficult to assess due to the lack of deployment experience. The potential effects will vary by technology and location, but may include competition for space, noise and vibration, electromagnetic fields, disruption to ecosystems and habitats, water quality changes and possible pollution (Lewis, 2011).

Appendix A

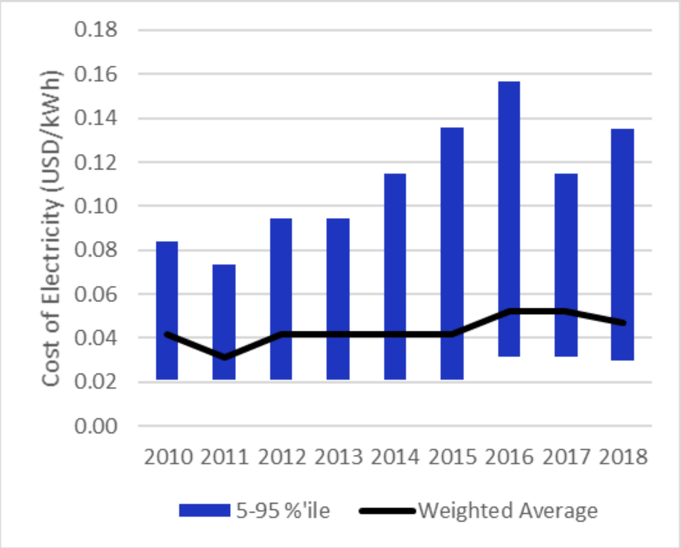
Hydropower

Hydropower uses the potential (gravitational) energy of water either stored in reservoirs or flowing in rivers to drive turbines to generate electricity. The technology for both run-of-the-river and storage (dams) systems is mature. Water can also be pumped uphill into reservoirs in pumped storage systems to provide output when it is most needed, increasing the flexibility of power systems.

Costs and market outlook

The costs of generation depend largely on site-specific factors relating to the hydrological cycles and conditions, and the nature of any flood areas (e.g. value of land, impact on displaced populations and economic activities etc.) that may be created when dams are built. For run-of-the-river systems, the economics depend on factors such as the flow rates of the river and seasonal variability. All hydropower projects will have some effect on the hydrological systems they are installed in, for example tending to slow down flow rates, altering silting rates and changing conditions for other human and natural uses of the river. The range of costs over the past 7 years is shown in Figure 10 and key investments expected over the coming 5 years in Table 13.

Figure 10: Cost timeline for hydropower, mature technology so trend is broadly flat



Source: IRENA 2018 and 2019

Table 13: Expected hydro capacity growth 2018-23

Top Countries	GW
China	47.3
India	9.3
Brazil	8.3
Ethiopia	5.1
Turkey	3.2

Source IEA, 2018a

Hydropower capacity is expected to increase 125 GW – 40% less than in 2012-17 due mainly to less large-project development in China and Brazil, where concerns over social and environmental impacts have restricted project pipelines. Meanwhile, deployment in India, Africa, and Southeast Asia accelerates in response to new demand, untapped resource potential, and attractive economics to improve electricity access affordably. One-fifth of overall growth (26 GW) is from pumped-storage hydropower projects that help integrate variable renewables (IEA 2018a).

Technology developments and risks

Though hydropower is a proven and well-advanced technology, there is still room for further improvement, for example, through optimisation of operation, mitigating or reducing environmental impacts, adapting to new social and environmental requirements and more robust and cost-effective technological solutions. Large hydropower turbines are now close to the theoretical limit for efficiency, with up to 96% efficiency when operated optimally. but this is not always possible and continued research is needed to make more efficient operation possible over a broader range of flows. Older turbines can have lower efficiency by design or reduced efficiency due to corrosion and cavitation damage. Potential therefore exists to increase energy output by retrofitting new equipment with improved efficiency and usually also with increased capacity. Most of the existing hydropower equipment in operation today will need to be modernized during the next three decades, allowing for improved efficiency and higher power and energy output and improved environmental performance (Kumar, 2011).

The structural elements of a hydropower project, which tend to take up to 70% of the initial investment cost for large hydropower projects, have a projected life of up to 100 years or more. On the equipment side, some refurbishment can be an attractive option after 30 years. Advances in technology can justify the replacement of key components or even complete generating sets. Typically, generating equipment can be upgraded or replaced with more technologically advanced electromechanical equipment two or three times during the life of the project, making more effective use of the same flow of water. Generation from conventional hydropower in the US could increase by 2-6% because of efficiency improvements by installing new equipment and technology and optimizing water use. In Norway it has been estimated that an increase in energy output from existing hydropower of 5 to 10% is possible with a combination of improved efficiency in new equipment, increased capacity, reduced head loss and reduced water losses and improved operation (Kumar, 2011).

Corrosion, cavitation damages and abrasion are major wearing effects on hydropower equipment. Hydropower projects are particularly prone to damage when water contains abrasive particles in sediment, especially if these contain hard minerals like quartz. These problems are becoming more acute with increasing hydropower development in developing countries with sediment-rich rivers. New materials and improved turbine design can help to alleviate these risks.

Generally, projects with a head (height of water above the generator) under 1.5 or 2 m are not viable with traditional technology. Hydrokinetic turbines can use these small water elevation changes, by utilising the kinetic energy in the stream flow as opposed to the potential energy of the hydraulic head. A study from 2007 concluded that the potential in the US for hydrokinetic generation in rivers and constructed waterways was 12,800 MW, compared to total installed capacity of hydropower at that time of 75,000 MW (EPRI, 2007).

Climate change may impact on risk factors for hydropower in several ways (Kumar,2011):

- Changes in river flow (runoff) related to changes in local climate, particularly in precipitation and temperature in the catchment area. This may lead to changes in runoff volume, variability of flow and seasonality of the flow (e.g., by changing from spring/summer high flow to more winter flow), directly affecting the resource potential for hydropower generation.
- Changes in extreme events (floods and droughts) may increase the cost and risk for hydropower projects.
- Changes in sediment loads due to changing hydrology and extreme events. More sediment could increase turbine abrasions and decrease efficiency. Increased sediment load could also fill up reservoirs faster and decrease the live storage, reducing the degree of regulation and decreasing storage services.

In Nepal, landslides triggered by the magnitude 7.8 earthquake in 2015 earthquake were found to be a major cause of damage to hydropower plant. This is leading to a re-evaluation of the potential for future hydropower projects in the Himalaya and other parts of Asia to factor in the risk of landslides, which had not previously been fully considered (Qiu 2018).

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