WORLD ENERGY COUNCIL
CONSEIL MONDIAL DE L'ÉNERGIE
For sustainable energy.

World Energy Perspective

The road to resilience − managing and financing extreme weather risks

Project Partners Marsh & McLennan Companies and
Swiss Re Corporate Solutions

WORLD ENERGY COUNCIL
CONSEIL MONDIAL DE L'ÉNERGIE

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World Energy Council

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Contents

Foreword by Christoph Frei 2

Executive summary 4

Introduction 8

1. Extreme weather – impacts on energy infrastructure 13

    Drivers and impacts of extreme weather 13

    Regional impact of extreme weather on energy infrastructures 17

2. Increasing the resilience of energy infrastructures 20

    Energy supply 22

    Electricity generation 24

    Energy transport 28

3. Financing resilient energy infrastructures 31

    The challenge of financing adaptation measures 32

    The role for improved insurance products 36

    Extreme weather adaptation bonds 42

Conclusions 43

Appendix A: Project participation 46

Foreword by Christoph Frei

New emerging risks are posing ever greater threats to the energy sector, impacting both the physical structures and the capital returns needed to evolve our energy system to a more sustainable future. Without a solid understanding of the nature of these risks, appropriate adaptation of infrastructure design and of financing mechanisms we may well see an investment impasse which could threaten to cripple global energy systems. This issue is steadily moving up the agendas of global energy leaders.

For this reason we have joined forces with Swiss Re Corporate Solutions and Marsh & McLennan Companies to identify how much additional energy infrastructure investment will be required to address these emerging technical and physical risks. Supported by specialists from the European Bank for Reconstruction and Development and a network of experts from all regions we have undertaken an in-depth assessment of what resilience means for the energy sector.

At a time when energy systems are increasingly integrated, resilience is no longer only about returning single assets to full operation after a sudden event. When interdependent parts of a system are blacked out, the system can become deadlocked. As Hurricane Sandy and other extreme weather events have illustrated, re-starting of the entire system can be delayed by days if such parts cannot be restarted autonomously. The World Energy Council's resilience project seeks to understand how entire energy systems can bounce back, and how they can prepare for future disruption and system stress.

This is the first report in a series of resilience studies. Focusing on the impacts of extreme weather on the energy sector, this report makes it clear that we need to be smarter, not just stronger. The energy system of the future needs to integrate concepts such as soft resilience, local empowerment to ensure quick disaster response, weather risk coverage as part of financing, and must consider the downsides of lengthy public procurement in relation to disaster response. It is also clear that current estimates for the cost of energy system adaptation do not fully account for the additional financing required to respond to the increasing extreme weather risks.

Extreme weather has become the focal point of boardroom and cabinet discussions. It is the theme for the 2015 Asia-Pacific Economic Cooperation agenda, which views resilience measures as the best means of protecting the world's most vulnerable regions. Japan has launched national resilience studies and organised high-level meetings to identify resilience measures in preparation for unanticipated disruptions in the energy sector, and to keep its citizens safe. Hurricane Sandy and its impacts on the eastern United States showed that a more strategic approach to resilience is needed to prepare, protect, and restart the energy system during and after extreme weather events.

The extreme weather report shows how the energy, finance and policy community must engage to provide effective energy resilience. For the financial community, this risk assessment highlights both risks and opportunity. For an investment area longlabelled as high-risk, this report surveys the ways in which financing can be both innovated, and better secured, providing ample opportunities for investors looking for new areas of investment − particularly in emerging economies. As a result, we show how resilience can turn risks into rewards.

As the report concludes, "Increasing the resilience of energy infrastructure to extreme weather events is not an option – it is a must". To realise the opportunity that this presents we need to focus on better information management, clearer and adapted standards, aligned to more dynamic and forward looking planning to unlock new investment models in a changing risk landscape.

This report is just the beginning of a process to align interests and inform debate, which ultimately will lead to a more sustainable energy system. I hope you find these insights informative and valuable as you look to build a resilient and sustainable energy system.

Christoph Frei
Secretary General, World Energy Council

Executive summary

Lights out in Manhattan after Hurricane Sandy, nuclear and thermal power plants being shut down due to long-lasting heat waves in Europe, years of rebuilding needed after Typhoon Haiyan hit in the Philippines, droughts in Brazil and changing rainfall patterns in Kenya impacting hydropower: the list could go on. The common denominator in all of these events is extreme weather – a deviation from typical weather patterns that current energy infrastructure was not designed to handle.

The frequency, severity and exposure of energy systems to extreme weather events are increasing. The number of extreme weather events increased more than 4 times from 38 in 1980 to 174 events in 2014.[1] Severe convective storms' contribution to overall insured losses (last 5 years compared to last 20 years) alone has increased to over 40%.[2] Many more events are expected in the future, driven by the increase in global average temperature.[3] Extreme hot and cold temperatures will raise overall energy demand and strain peak capacity. The energy supply also faces reduced efficiency of thermal plants, cooling constraints on thermal and nuclear plants and increased stress on transmission and distribution (T&D) systems. More extreme events such as tropical storms, droughts or floods may not only impact energy production and revenue streams, but also the equipment itself.

While in the past impact-resistant – 'fail-safe' – structures were built, today's system complexity and increased incidence of extreme weather require a shift towards having energy infrastructures operating under a 'safe-fail' approach. The solution appears to be 'smarter not stronger'. This soft resilience approach can make energy supplies more secure, more reliable and can contribute to the quicker restoration of services in case of disruptions. Soft adaptation measures are increasingly complementing traditional hard resilience measures.

Taking a systemic approach to identify technical risk naturally enables the development of innovative financing for the energy sector. Shifting from historical mind-sets towards future-focused planning can incentivise private investors, who have otherwise considered energy too high-risk for traditional sources of financing.

Financing resilient energy infrastructure

Protecting energy infrastructure assets from extreme weather will add significantly to the estimated US$48–$53trn in cumulative global investment needed in energy infrastructure by 2035.[4] This figure does not include estimates for investment needed

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[1] Swiss Re Economic Research and Consulting, 2015: Sigma world insurance database (last accessed 10 September 2015)
[2] Swiss Re, 2015: Sigma Report No. 2/2015 – Natural catastrophes and man-made disasters in 2014: Convective and winter storms generate most losses
[3] Pachauri, R K, Allen M R, Barros V R et al, 2014: Climate Change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)
[4] International Energy Agency (IEA), 2014: World Energy Investment Outlook; The 2°C scenario would require double the investments in low-carbon technologies and energy efficiency.

in energy infrastructure adaptation. The impact on developed economies with highly interdependent energy systems is likely to add significantly to this already large figure.

It is clear that governments alone cannot cover the costs of ensuring secure and reliable energy systems that meet our current and future energy demand and at the same time are able to withstand the impact of extreme weather events. Private investors must join in the funding. To attract private sector investors, energy investments must receive adequate and stable returns over an asset's lifetime. To get private money flowing into energy infrastructures and resilience measures, it is critical for all stakeholders involved in developing new or operating existing energy infrastructure projects to communicate and have the tools necessary to compare the costs with the benefits of investing in resilience.

However, limited data and a lack of best practice sharing is creating an information vacuum which is reducing the ability of both the energy and finance sector to properly price the investment risk presented by increased extreme weather. All stakeholders must cooperate and share best practices and data to overcome the information deficit. Similarly energy companies and project developers must move on from simply using historical operational data, to embrace dynamic modelling for the planning, operation and maintenance of their energy investments. Fully reflecting extreme weather risks in the cost benefit analysis of project financing can greatly enhance the project risk profile. These measures, aligned with risk transfer options for residual risks, will reduce exposure, unlock capital and ultimately reduce cost.

Setting a framework for financing resilience

Adaptation measures often lack regulatory guidance regarding what is necessary to increase resilience. There is currently no agreed goal or metric for adaptation, or specific responses to extreme weather. Nor is there agreement on how much resilience is sufficient and how increased resilience can be related to an additional revenue stream and so become attractive for investors. Government and regulators should implement regulatory frameworks to clearly define the levels of resilience required for energy infrastructure. This could enable the finance sector to create suitable financial vehicles which would help the private sector to carry their responsibility in resilience.

Currently institutional investors like pension and insurance companies cannot invest substantially in energy infrastructure because of solvency regulations. Introducing a new asset class that includes long-term investments in infrastructure can make large funds available for future energy supplies. With greater transparency, insurance companies and banks could take advantage of extreme weather risks to create unique financial vehicles that help fill project financing gaps. Long-term and institutional investors could use this approach to overcome regulatory restraints by incorporating extreme weather and climate in investment planning, by using responsible investment standards, to help de-risk energy investments.

Call to action

Increasing the resilience of energy infrastructure to extreme weather events is not an option – it is a must. While stakeholders are driven by diverse motives, everyone has a role to play, and there are some common obstacles to be overcome together to ensure that energy supply is secure and reliable, now and in the future. The energy system will only be able to play its crucial role as the backbone of the global economy if all stakeholders work together.

The road to resilience – managing and financing extreme weather risks

The global energy sector is exposed to unprecedented uncertainty and faces a number of emerging risks. Extreme weather events pose a real threat to existing energy infrastructures and affect the security of supply. Building resilient energy systems is critical for meeting future Energy Trilemma goals.

The number of extreme events increased more than 4 times from almost 38 recorded extreme events in 1980 to more than 174 extreme events in 2014.

2014

4 x more frequency

1980

Extreme weather risks

These events pose direct risks to infrastructure, and their consequences can further stress the energy system.

heat waves

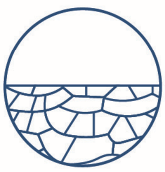
convective storms

hurricanes and typhoons

strong cold/ heavy snow

flooding

rising sea levels



drought

Impact on energy infrastructure

Oil & gas assets

Tropical cyclones and hurricanes can damage assets and reduce production rates.

Oil & gas pipelines

Thawing permafrost, floods and landslides can affect the asset itself, pipeline flow and associated revenue.

Transmission and distribution

Strong winds and ice-storms can damage above ground T&D lines and affect associated revenue streams.

Renewables

Strong winds, storms but also increased cloud conditions can result in equipment damage, erratic output and lost revenue.

Thermal electricity generation

Floods, storms and cyclones can damage equipment and restrict generation. Rising air and water temperatures affect thermal efficiency, with impacts on cost and revenue.

Hydropower

Hydropower plants are highly vulnerable to changes in the hydrologic cycle, including water stress, drought, floods, cyclones and higher temperatures. Equipment can be damaged and output reduced.

Nuclear

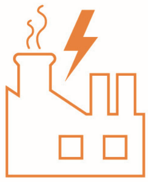
Storms, cyclones, water stress, floods or increasing water temperatures may damage or disrupt critical equipment and processes and affect generation

Smarter not stronger

Resilience for energy infrastructure refers to its robustness and ability to recover operations to minimise interruptions to service. Resilience also implies the ability to withstand extraordinary events, secure the safety of equipment and people, and ensure the reliability of the energy system as a whole.

Hard resilience

Focus on resistance. 'Fail-safe' – building single infrastructures to withstand sudden impact. Looks to strengthen individual Infrastructures and single assets.



Soft resilience

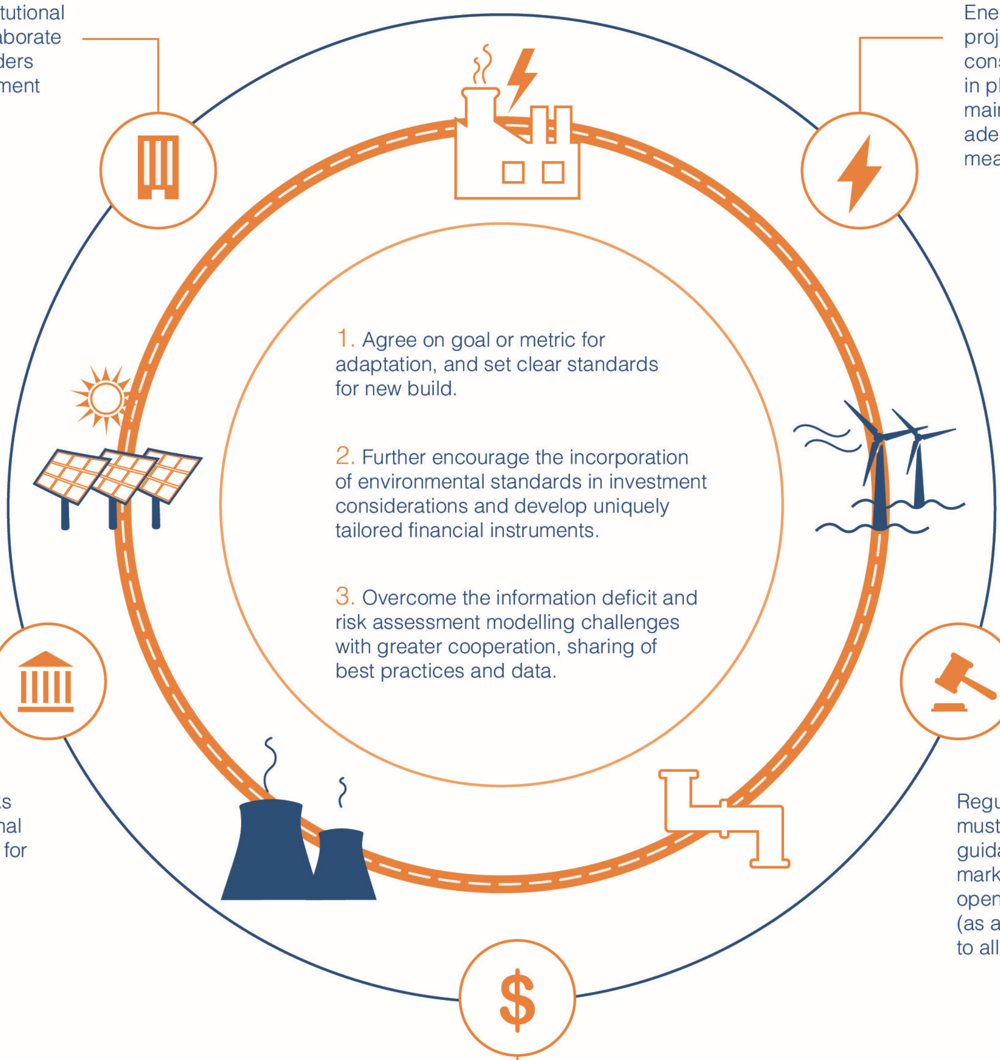
Focus on absorption. 'Safe-fail' – building infrastructures that recover quickly from sudden impacts. Looks to reduce impact of disruption by taking a systemic view.

Call to action: creating systemic resilience

Increasing the resilience of energy infrastructure to extreme weather events is not an option but a must. Resilience can only be achieved by moving from individual to joint efforts to build systemic energy systems that will support the growth of the global economy.

Long-term and institutional investors must collaborate with other stakeholders to overcome investment barriers.

Energy companies and project developers must consider extreme weather in planning, operation and maintenance, and implement adequate soft/hard resilience measures.



Insurance and banks must create additional risk transfer options for residual risks.

Regulators (governments) must provide regulatory guidance for resilience and market regulation, but also by opening energy infrastructures (as an asset class) to all investors.

The financial services industry must develop models that fully reflect extreme weather risks and include soft/hard resilience in cost-benefit analysis.

Introduction

The financing resilient energy infrastructure series

Energy benefits people far beyond what they use individually at home, at work or on the road. Energy is critical to maintaining and driving economic growth. Access to energy enables the development of a modern economy, be it for agriculture, transport, computing, manufacturing, construction, health and social services, and communication. Energy is part of people's everyday lives and is a critical component to the global political economy.

The energy sector today is exposed to unprecedented change and uncertainty in demand and supply. The world's current population of 7.3 billion people is predicted to grow to 9.7 billion by 2050 and 11.2 billion by 2100.[5] The urban population in 2014 accounted for 54% of the total global population, up from 34% in 1960, and is expected to grow steadily over the next decades.[6] The global economy will continue to grow, but changes will be more significant in terms of income distribution, and the 'new middle class' are expected to affect the path of the world economy. For example, higher incomes will support increased mobility, with car ownership increasing from 124 per 1,000 people in 2010 to between 193 and 244 in 2050.[7] Meeting the growing energy demand in a sustainable and reliable way is a key challenge for today's energy sector.

Emerging risks

The energy industry is also exposed to a greater number of emerging risks. These include volatile weather patterns, technical disruptions such as deliberate disruption of computer networks and connected systems, and also greater citizen and consumer awareness and concerns about the siting and the use of energy infrastructures. Changes and events impacting on one aspect of the energy infrastructure can lead to unforeseen chain reactions across the whole system.

Emerging risks must be effectively assessed and understood so that their impact on the whole energy system, on individual infrastructure assets, energy production and companies' earnings can be minimised. Existing infrastructure must adapt and new energy infrastructures must be developed to withstand risks so that current and future energy supply is reliable and secure.

[5] UN Department of Economic and Social Affairs, Population Division, 2015: World Population Prospects: The 2015 Revision

[6] UN Department of Economic and Social Affairs, Population Division, 2014: World Urbanization Prospects: The 2014 Revision

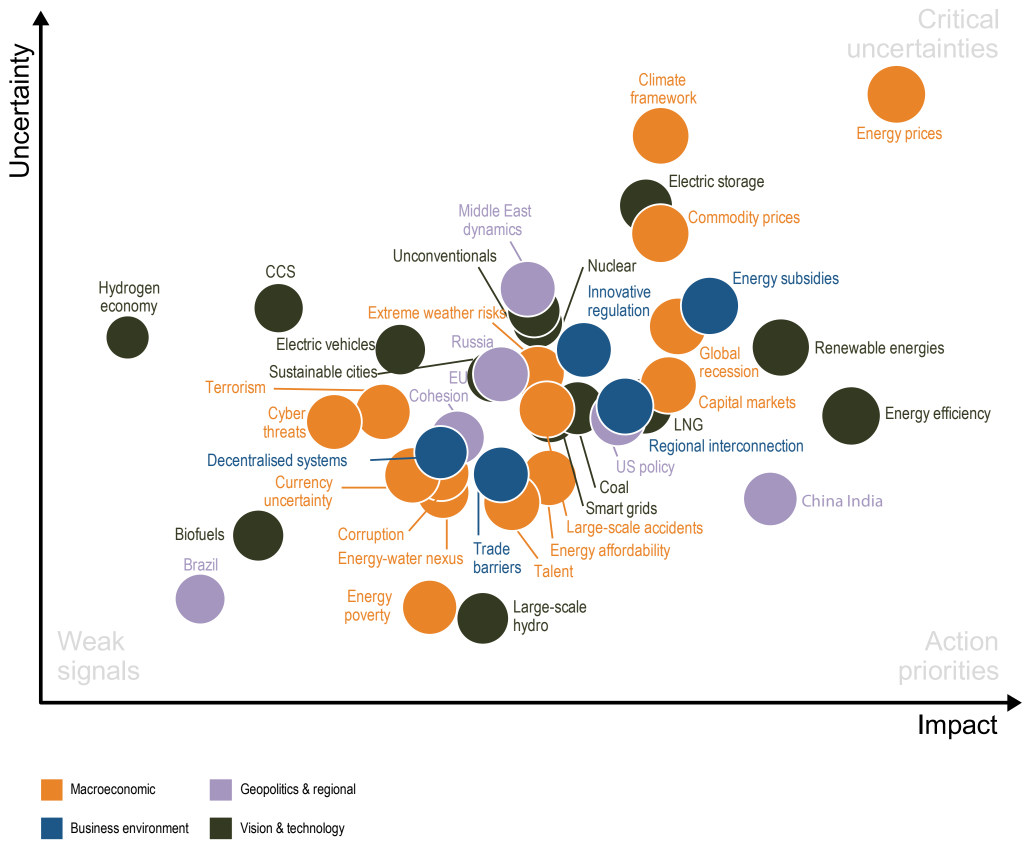
[7] World Energy Council, 2013: World Energy Scenarios: Composing energy futures to 2050; The lower number refers to the Council's 'Symphony' scenario, which focuses on achieving environmental sustainability through internationally coordinated policies and practices, while the higher number reflects the Council's 'Jazz' scenario, which focuses on energy equity with priority given to achieving individual access and affordability of energy through economic growth.

To make energy systems more resilient, policymakers and regulators must address emerging risks by providing a framework for all stakeholders, with appropriate incentives for making systems secure and reliable. Incentives could also stimulate the private sector to invest in replacing ageing infrastructure, building new energy infrastructure assets and associated supply chains, and developing new technologies to meet current and emerging energy needs.

Figure 1

Extreme weather risks, cyber threats and the energy-water nexus emerge as new risks on the global issues monitor

Source: World Energy Council, 2015: World Energy Issues Monitor



A better understanding of risks and the benefits of resilience could be promoted by increased collaboration among all stakeholders with improved information and where possible data sharing. To help advance the understanding of the new critical factors, the World Energy Council, Marsh & McLennan Companies and Swiss Re Corporate Solutions with the support of the European Bank for Reconstruction and Development (EBRD) and a network of global experts from close to 40 countries, has developed a series of reports: Financing Resilient Energy Infrastructure. The reports will focus on identifying and characterising the nature, frequency and severity of key emerging risks. By understanding how to technically and financially address these risks, the energy industry can work with the financial community, investors and policymakers to share and promote measures that must be incorporated into energy infrastructure design and investment decisions. The following three risks have a growing impact on the energy sector and will be examined through this series:

- Extreme weather: any kind of weather that is severe, unusual or not seasonal. Apart from very strong storms, typical examples are droughts or heat waves over unusually long periods.
- Energy-water-food nexus: the interdependency of the human use of water, food and energy that impacts directly and indirectly on economy, society, personal wealth, environment, ecology, health and commerce.
- Cyber risks: include offensive manoeuvres by individuals or organisations to target infrastructures, information systems, computer networks and personal devices.

Defining resilient energy infrastructures

While there is no single definition of resilience for energy infrastructure, literature review reveals that resilience implies a functioning and stable system, one that provides continuity. Some sectors, such as utilities, have defined performance requirements set by regulators. In other instances, companies will use industry benchmarks or internal performance measures to gauge their resilience and ability to provide continuity of service.

Resilience for energy infrastructure refers to its robustness and ability to recover operations to minimise interruptions to service. Resilience also implies the ability to withstand extraordinary events, secure the safety of equipment and people, and ensure continued and reliable energy production. Achieving increased resilience requires improved risk assessment and modelling, better planning and design, increased communication and collaboration. Improved technologies are needed to ensure that energy infrastructure can absorb, and recover from hazardous events throughout its estimated lifetime (30 years or more for most energy infrastructures). At a country level, energy infrastructure resilience also means balancing the three dimensions of the 'energy trilemma' – energy security, energy equity and environmental sustainability. To achieve these trilemma goals, energy systems must be built and equipped to achieve long-term durability.

An evolving approach to resilience

Resilience measures for energy infrastructure are typically classified as 'hard' (focus on resistance) or 'soft' (focus on absorption) measures (see Table 1). To date, the energy industry has typically relied on hard, single-asset approaches geared towards ensuring that individual infrastructures can withstand a sudden event or impact and return to full performance. Infrastructures were built 'fail-safe' – for a single-asset failure.

Faced with emerging and evolving risks, the concept of 'safe-fail' is increasingly being incorporated into resilience approaches. This recognises that there is a risk, that the individual infrastructure is part of a system that may go down. It incorporates smarter, not just stronger, solutions into the design and operation. Soft resilience can be best thought of as how to include and adapt infrastructures to be better prepared to absorb a hazardous event. It allows for partial system failure in a way that tries to control impact.

To improve overall resilience, industry and policymakers should take an integrated approach and use a combination of hard and soft measures.

Table 1

A comparison of hard and soft resilience approaches

Source: World Energy Council, Marsh & McLennan Companies, Swiss Re Corporate Solutions, 2015

	Hard resilience	Soft resilience
Definition	Focus on resistance. 'Fail-safe' – building infrastructure to withstand sudden impact with the assumption that strength will make it safer and less prone to failure. Looks to strengthen individual infrastructures and single-assets.	Focus on absorption. 'Safe-fail' – building infrastructure that recovers quickly from sudden impacts, assuming that infrastructures will fail and preparing for the inevitable failure. Reducing the impact of disruptions by taking the view that energy infrastructure is part of a system.
Overview	Hard adaptive measures are often added to a specific infrastructure. Typically associated with traditional centralised energy infrastructure, for example, fossil-fuel and nuclear-based power generating systems and centralised grid.	Soft adaptive measures build on natural resources and human capital and are associated with decentralised technology – for example, distributed generation systems. They may also include financial hedging of unexpected energy shortages and energy-efficiency measures.
Advantages	Actions are usually taken in isolation. Decisions can be made independently and allow for quicker implementation by the owners of the infrastructure.	Taking a systemic viewpoint supports flexibility to respond to changing conditions. Takes advantage of existing solutions within other aspects of the energy value-chain such as adding other types of energy sources – for example, renewables to back up supply.
Disadvantages	Often more capital-intensive and may involve specialised human resources. Often only reactive to large-scale disturbances to local communities and/or ecosystems; may lack adaptability to changing conditions, and instead, may simply return operations to 'business-as-usual'. May leave infrastructure at an insufficient standard.	Solutions rely on industries, policymakers and communities beyond the energy community and company to adapt to immediate changes and often require a high amount of coordination among stakeholders. Other sectors may be impacted by actions taken by the energy sector.

Financing resilient energy infrastructures

The energy sector relies on financial investments from varying sources, depending on the structure and maturity of the national energy and capital market. Historically, most investment has been made directly or indirectly by governments.[8] Due to continuing financial, economic and debt crises and austerity measures, combined with competing spending priorities, governments are increasingly unable to fund new or modernised, well-adapted energy infrastructure. With increased political and regulatory uncertainty in the investment community, the diversity of energy infrastructure investors must be increased.

For investments to be attractive to the private sector, investors need to have confidence that projects will meet risk–reward expectations. Energy investments are long term, and can last up to 30 years, making them highly susceptible to existing risks – such as political and regulatory, construction, operational, market or currency risk – and also increasingly to emerging risks. Investors need to understand the financial benefits of resilience – for example, more stable revenue streams, or the ability to recover the cost of investments through regulated tariffs.

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[8] IEA, 2014: World Energy Investment Outlook

Policymakers and regulators play a key role in attracting private investments. Policymakers need to give clear guidance on how much resilience is required. For example, incentives may help to ensure that energy companies and project developers comply with standards – and penalties, where appropriate. Greater collaboration between the public and private sector is needed to address the financial gap and determine the necessary level of infrastructure resilience.

1. Extreme weather – impacts on energy infrastructure

Drivers and impacts of extreme weather

Extreme weather is any kind of weather that is severe, unusual, or not seasonal. The increased frequency and severity of extreme weather events is a key issue for energy leaders around the world (see Figure 2). Weather is considered extreme when the current event, compared with the recorded historical weather data at a specific location, is within the most unusual 10%. Apart from very strong storms, typical examples are droughts or heat waves over unusually long periods, hurricanes or typhoons, and floods. These events typically result in physical damage, business interruption, and fluctuations in demand or supply, impacting on prices and companies' profitability. There are also changes in the extremity of weather patterns, with risks like rising sea levels, droughts, crop failures and water shortages placing stress on energy infrastructures (see Box 1).[9]

Box 1: The importance of resilient energy infrastructure to economic and social development in sub-Saharan Africa

Sub-Saharan Africa is particularly exposed to effects of extreme weather. Droughts and floods alone account for 80% of loss of life and 70% of economic losses in sub-Saharan Africa.[10] Reducing the physical vulnerability of both existing and planned energy infrastructure to extreme weather events is crucial to continued economic and social development.

Increasing energy access in sub-Saharan Africa is critical for the economic and social development of the region. Unlocking the capital needed for infrastructure development, both nationally and internationally, is crucial for making progress. There are a number of critical components and enablers to make a project 'bankable', including the overall business environment, the degree and nature of restrictions around foreign investments or ownership in

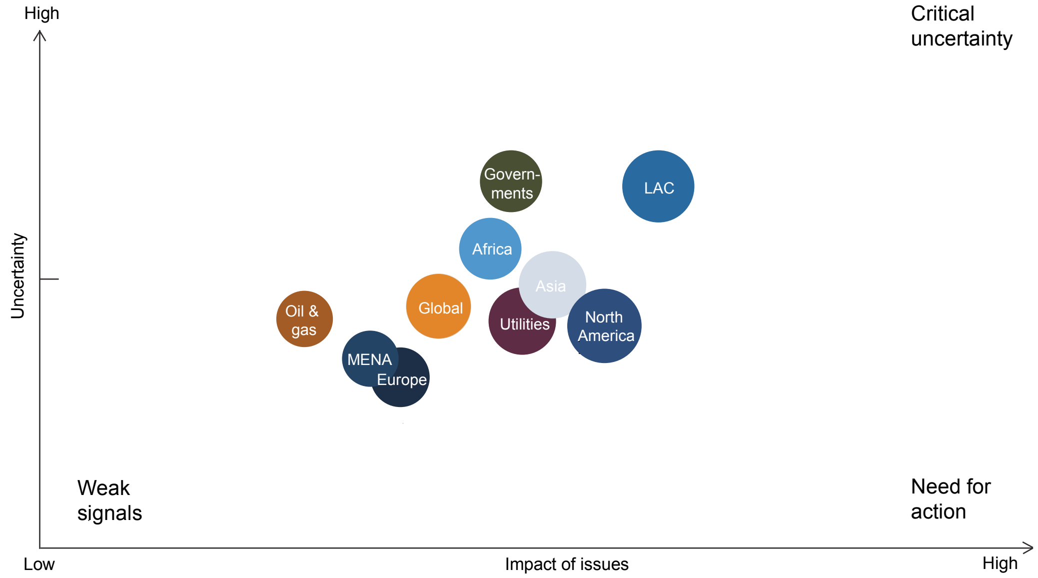
[9] IPCC, 2013: Climate Change 2013: The physical science basis (Working Group I contribution to the Fifth Assessment Report of the IPCC)
[10] Al-Hamndou Dorsouma, 2014: Financing Disaster Risk Reduction and Climate Services in the Context of Africa's Development

energy infrastructure, but also the existence of an overall political, regulatory and legal environment with strong institutions and low administrative barriers that allows enlightened (foreign) investors to make positive investment decisions.[11] To make projects economically viable in Africa energy infrastructure proposals also need to take into account risks related to changing extreme weather patterns such as droughts, floods, and extreme heat waves.

Figure 2

Increased frequency and severity of extreme weather events is of increasing concern to energy leaders in Latin America and the Caribbean, North America and Asia[12]

Source: World Energy Council, 2016: World Energy Issues Monitor (interim results)



Note: MENA = Middle East and North Africa, LAC = Latin America and the Caribbean

The rise in global average temperatures is stimulating more frequent catastrophic weather events. Globally, the 10 warmest years on record all occurred since 1998 and the globally-averaged temperature over land and ocean surfaces for January to June 2015 was the highest on record for those months.[13] The number of extreme weather events in 2014 was the highest on record with 174 events.[14] In 2014, weather events in the United States (US), Japan, Mexico and Europe caused most of the insured

[11] World Energy Council and Oliver Wyman, 2014: Time to get real – the myths and realities of financing energy systems

[12] The World Energy Council's annual issues monitor gathers the views of the Council's energy leadership community from over 90 countries, to assess the evolution of the global energy agenda in a high-level overview. The maps provide an insight into the critical uncertainties affecting the energy sector, identifying key trends while highlighting the areas where action is needed to ensure the sustainable supply and use of energy for the greatest benefit of all.

[13] See National Oceanic and Atmospheric Administration (NOAA), National Climate Data Centre, "Climate Extremes", www.ncdc.noaa.gov/climate-information/extreme-events, (accessed 6 February 2015); World Meteorological Organisation, 2015: January−June 2015 hottest on record: NOAA (21 July 2015)

[14] Swiss Re Economic Research and Consulting, 2015: Sigma world insurance database (last accessed 10 September 2015)

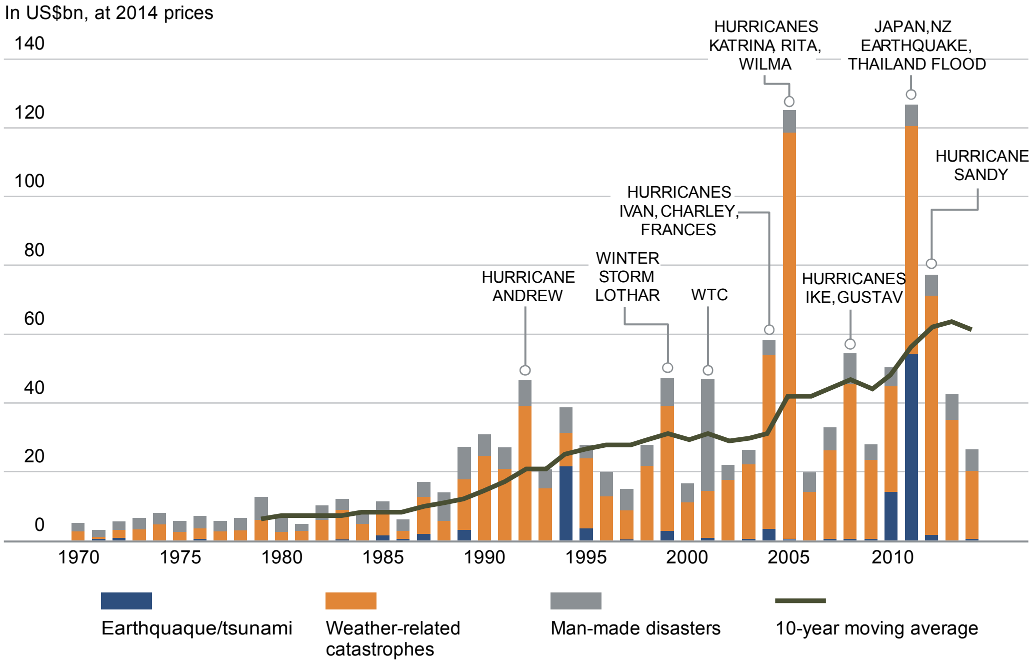
losses, with convective and winter storms generating most losses.[15] Eastern, southern and western African countries also experienced recurrent climatic extremes in recent years such as droughts, floods and tropical cyclones, which affected hydroelectric power generation and, as a consequence, socioeconomic development.[16]

The costs and economic impacts of extreme weather events are also rising. In 2014 the global insured losses from natural catastrophes and man-made disasters were approximately US$35bn and the related global economic losses were around US$110bn. These figures were actually lower than the average of the previous 10 years (see Figure 3). However, uninsured losses from natural catastrophes and man-made disasters have been more than US$130bn per year over the year ending 1 January, 2014.[17] This represents a significant increase in uninsured losses over the past 30 years, driven by a mixture of factors including economic development, population growth, a higher concentration of people and assets (including infrastructure) in exposed areas (often urban areas in high-risk coastal or flood prone areas), and a shift in the frequency and severity of extreme weather events.[18]

Figure 3

Insured catastrophe losses, 1970–2014

Source: Swiss Re, 2015: Sigma Report No. 2/2015



Economic production today is more complex, interconnected and involves assets and inputs with higher economic value than in the past. This means that the destruction of productive assets or infrastructure, including energy, in a disaster event can entail a higher overall financial loss than previously. Business interruption can be severe due

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[15] Swiss Re, 2015: Sigma Report No. 2/2015 – Natural catastrophes and man-made disasters in 2014: Convective and winter storms generate most losses

[16] Garanganga B, 2011: Drought Risk Management in Southern Africa, http://web.undp.org/drylands/docs/drought/AADAF1/1.7.Garanganga.pdf; Pottinger L, 2009: The wrong climate for big dams, International Rivers, 1 December 2009

[17] Swiss Re, 2015: Sigma Report No. 2/2015 – Natural catastrophes and man-made disasters in 2014: Convective and winter storms generate most losses

[18] Ibid.

to the reliance on infrastructure and the supply chain impacted. For example, the Thai floods in 2011 caused nearly US$41bn in economic losses, mainly because they disrupted supply chains for computer and car parts manufacturers around the world.[19] It is estimated that the overall costs of climate change, including the impact of extreme weather events, could amount to 20% of global gross domestic product (GDP) by the end of this century.[20]

Changes in intensity and frequency of extreme weather events as well as unseasonal deviations from average weather affect current and future energy infrastructure and the energy sector's profitability. The extent of exposure is evident when all natural perils that can affect energy infrastructure are considered. There are six main perils: earthquakes; storms (wintry and tropical events); storm surges; tsunamis; flooding; and erosions. Apart from earthquakes and tsunamis, all relate to extreme weather.

The precise impacts are difficult to determine since specific impacts of extreme weather on a site or location are hard to predict. The effect of rising global mean temperatures in the next 20 to 50 years is also unclear. This additional uncertainty can be addressed by making energy infrastructures resilient.

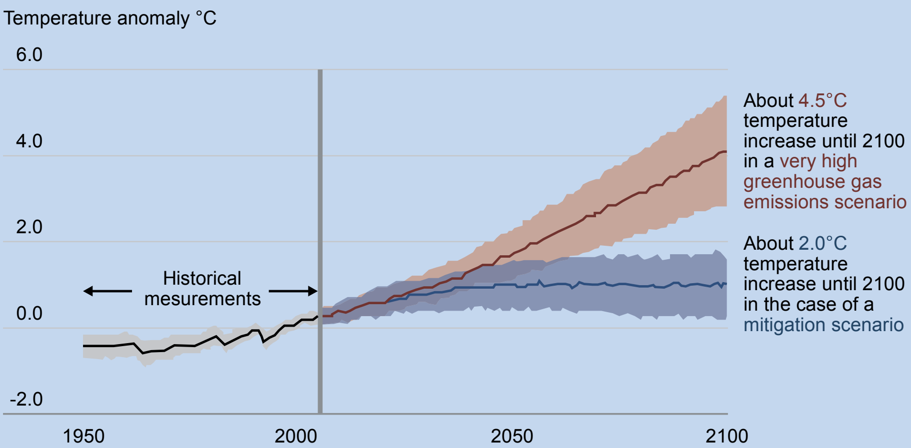
Box 2: The effects of climate change on extreme weather patterns

The rise in global mean temperatures is thought to be the underlying cause of the changing frequency, intensity and duration of extreme weather events.[21] The term 'climate change' is often used to describe the changing nature of weather characteristics over time. Since the beginning of industrialisation, rapid population growth and human activity have led to a significant increase in greenhouse gas emissions which, alongside natural variability, have created an upward trend in global temperatures (see Figure 4).

Figure 4

Global average surface warming, 1950−2100

Source: IPCC Assessment Report 5, 2013



[19] Global Energy Basel, 2013: Infrastructure for a Changing World
[20] Stern N, 2006: Review on the Economics of Climate Change: The Stern Review final report
[21] IPCC, 2012: Special Report: Managing the risks of extreme events and disasters to advance climate change adaptation

The rise in global average temperatures has several effects, disrupting the complex climate system and will likely lead to shifts in the frequency, intensity and duration of extreme weather events.

Some of the effects will be felt on oceans and water systems as they absorb most of the temperature increase, as well as water that was previously stored in glaciers and ice sheets.[22] The acceleration of the increase in water volume and warming of the world's oceans combined will likely lead to an accelerated rise in sea level. There will also be changes in the global water cycles in response to the warming, a particular concern for the energy industry. The contrast in precipitation between wet and dry regions and seasons will increase.[23] There will likely be increases in the length, frequency and/or intensity of warm spells, heat waves or droughts in some regions of the world. The combined impacts could lead to further uncertainty about the occurrence of extreme weather events, which will generate further risks and costs across the globe.[24]

Extreme weather events can have a double impact on energy infrastructure as they can affect both supply and demand, with the associated financial impacts. Events will adversely influence the entire energy value chain, in particular the production and transport of energy, such as power lines being blown down, networks being ripped apart, and indirect impacts such as supply shortages and also construction delays. The oil and gas industry may face more disruption and production shutdowns. Storms or rising temperatures affect energy transport infrastructure, for example, the thawing of permafrost impacts on the stability of gas and oil pipelines. Water shortages affect the cooling systems of thermal and nuclear power plants. Changing hydrological and weather patterns affect hydropower.

Extreme weather events also affect the demand for energy itself, for example, the increased demand for air-conditioning during a heat wave. If the energy production simultaneously decreases while the demand is rising, this further accelerates the impact of extreme weather.

Regional impact of extreme weather on energy infrastructures

The type and frequency of extreme weather events vary from region to region. The infographic on the following two pages shows the regional impact of extreme weather events on energy infrastructure.

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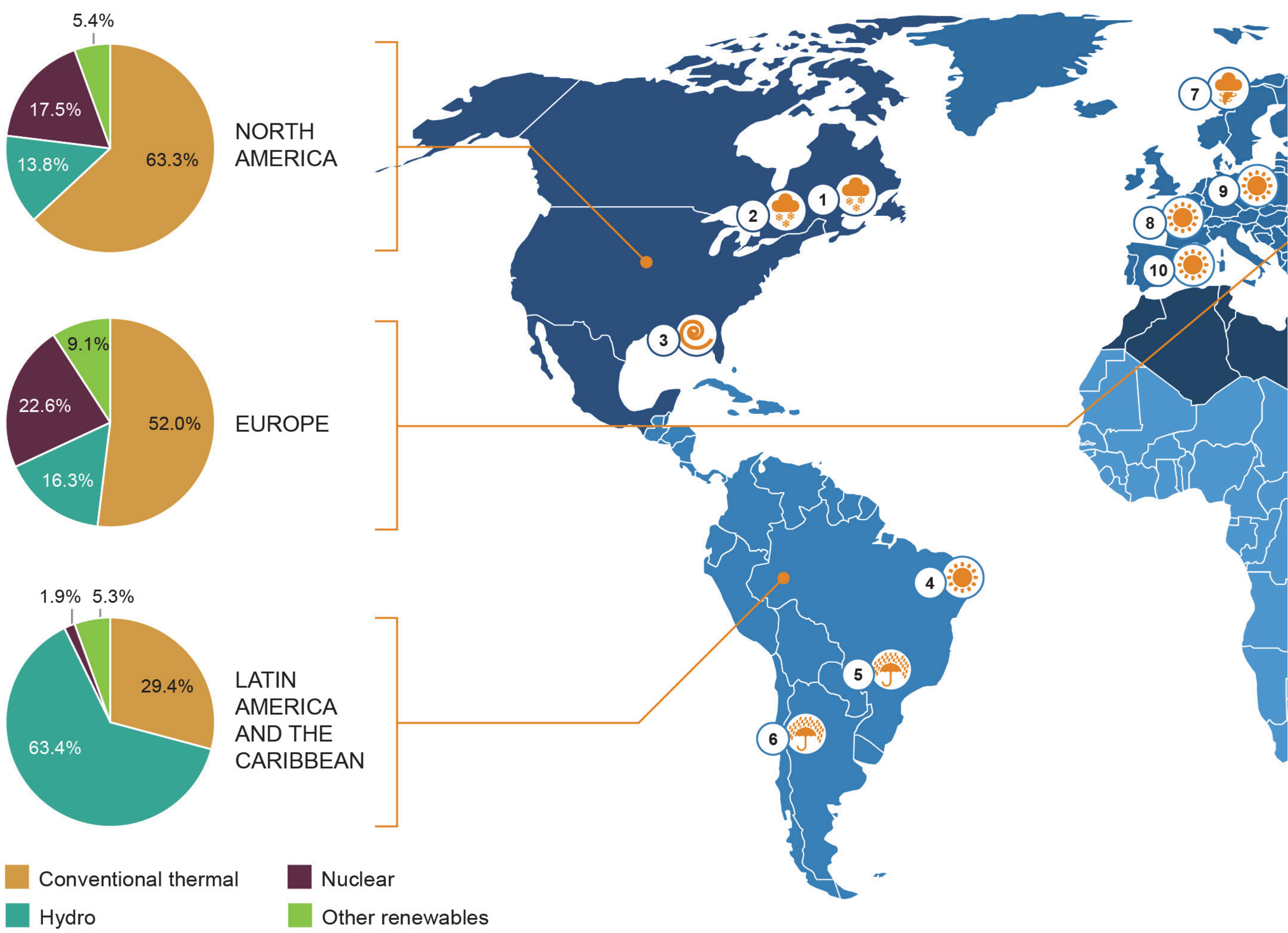
[22] Ibid.
[23] There may be regional exceptions and there will be increases in the length, frequency and intensity of heavy precipitation events over many areas of the globe, especially over most of the mid-latitude land masses and over wet tropical regions.
[24] IPCC, op. cit.

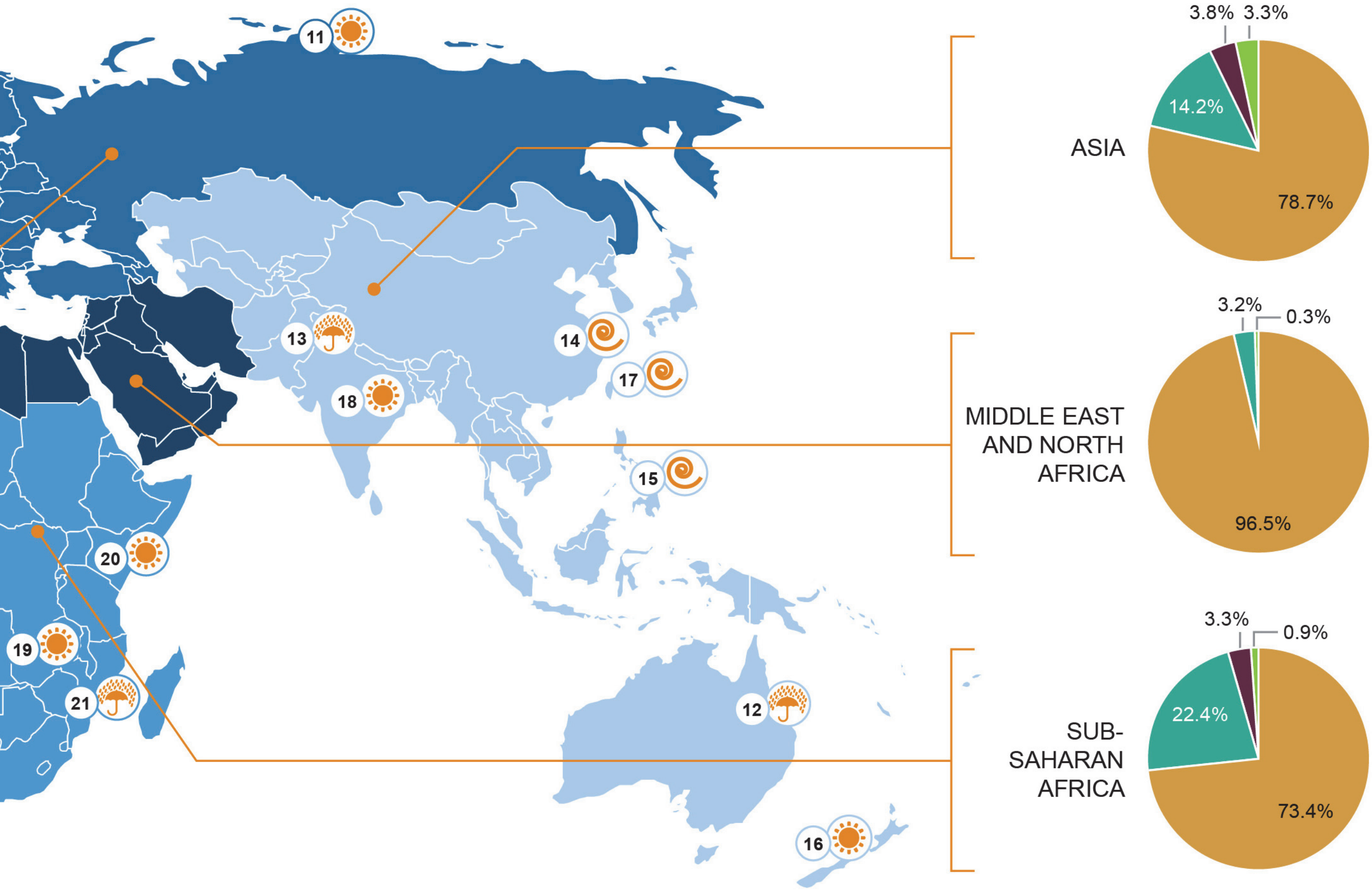
TOTAL PRIMARY ENERGY SUPPLY BY REGION

(Source: World Energy Council)



EXAMPLES OF EXTREME WEATHER EVENTS AND THEIR CONSEQUENCES, (1994–2015)

1. **EASTERN CANADA. January 1998**, ice storm toppled hundreds of transmission towers and downed 120,000 km of power lines.
2. **ONTARIO, QUEBEC. December 2013**, ice storm left 600,000 customers without power. Estimated total cost of the storm for the municipal electricity distribution company was CA$13 million including CA$1 million in lost revenue.
3. **US, GULF OF MEXICO. 2004–2005**, due to hurricanes, 126 oil and gas platforms were completely destroyed and 183 were damaged.
4. **BRAZIL. December 2014**, due to drought, biggest dams in Brazil were at 16% of capacity. Brazil relies on hydropower for over 80% of its electricity generating capacity.
5. **BRAZIL/PARAGUAY. November 2009**, heavy rains and winds caused transformers on a key high-voltage transmission line to short-circuit, causing 20 turbines of the world's second largest hydroelectric dam to shut down. An estimated 87 million people were affected by power loss.
6. **CHILE. March 2015**, torrential storms with the equivalent of 7 years' worth of rain in 12 hours left thousands without electricity due to impact on transmission lines and dam flooding.
7. **NORWAY. 2006**, a severe storm set adrift a drilling rig in the North Sea off the coast of Norway.
8. **FRANCE. July 2009**, due to a long-lasting heat wave, about 20 GW of France's overall 63 GW of nuclear power capacity had to be shut down forcing the government to import electricity from neighbouring countries.
9. **GERMANY. 2006**, the Isar nuclear power plant cut production by 60% for 14 days due to excess river temperatures and low stream flow in the Isar river.
10. **SPAIN. 2004–2005**, a drought reduced hydroelectric production resulting in losses of US$123 million.
11. **SIBERIA AND ARCTIC. 1994**, warming permafrost contributed to an oil pipeline spill of more than 160,000 tons. Correcting pipeline damage and deformations costs the Russian oil and gas industry US$1.8 billion annually.
12. **AUSTRALIA, QUEENSLAND. 2010–2011** deluges swamped coal mines, driving the cost of thermal coal burned in power plants to a 30-month high.
13. **PAKISTAN. September 2010**, flooding led to a month-long shutdown of the country's largest oil refinery, contributing to the country's electricity deficit.
14. **CHINA. August 2015**, a typhoon impacted hydropower production, and caused dam failure which led to further environmental and economic devastation.



15 **PHILIPPINES. November 2013**, Typhoon Haiyan crippled critical infrastructure including transmission and distribution lines. The cost of rebuilding is estimated at more than double the Philippines' GDP.

16 **NEW ZEALAND. March 1998**, a failure of four high-voltage transmission cables, partly due to high demand caused by hot weather and less-than- optimal operating conditions due to high soil temperature and dryness. The event cost the utility NZ$128 million plus costs arising from associated lawsuits.

17 **TAIWAN. August 2015**, Typhoon Soudelor caused power outages for more than 3.22 million households in Taiwan, the biggest power loss ever to result from a typhoon in Taiwan's history.

18 **INDIA. July 2012**, a heat wave led to high energy demand and triggered the largest electricity blackout in history affecting 670 million people, about 10% of the world population.

19 **ZAMBIA. June 2015**, a drought led to decreased water levels at hydroelectric plants and cuts of nearly 25% of the country's electricity generation.

20 **KENYA. 2009**, a drought led to two months of power rationing as more than 30% of electricity generation came from hydropower at the time.

21 **MOZAMBIQUE/SOUTH AFRICA. January 2013**, flooding in Mozambique cut power exports to South Africa by half as key power lines to South Africa were damaged.

TYPES OF EXTREME WEATHER EVENTS BY REGION

	STRONG COLD/HEAVY SNOW	HEAT WAVE/ DROUGHT	HURRICANES/ TROPICAL CYCLONES	FLOODING	CONVECTIVE STORMS
North America	■	■	■	■	■
Latin America and the Caribbean	■	■	■	■	
Europe	■	■		■	■
Asia	■	■	■	■	■
Middle East and North Africa		■	■	■	■
Sub-Saharan Africa		■	■	■	■

2. Increasing the resilience of energy infrastructures

Operating environments will continue to change and there are two approaches to building resilience: adaptation and mitigation.

- Adaptation measures are actions to manage the impact of extreme weather. Adaptation is the adjustment in existing natural or human systems to a constantly changing environment. Measures include improvements such as strengthening and hardening infrastructure (for example, transmission lines) against storms, floods, and other events. Other responses are 'soft' measures such as controlled shut-down procedures, awareness campaigns, and disaster relief and emergency response programmes. Revisiting land use along the coast and inland flood zones, and incentivising relocation to safer places are other examples.
- Mitigation measures are actions taken to reduce the causes of extreme weather events, primarily reducing greenhouse gas emissions as substantially and quickly as possible. Measures include: altering the energy supply mix; making use of all low- and zero-carbon technologies; demand management; improving energy efficiency in supply and demand in all sectors of the economy.

Mitigation measures are key in the move towards sustainable energy systems and in reducing greenhouse gas emissions and impacts on climate over the long term. They have been implemented widely by many countries across the world. For example, new renewable energy – in particular solar and wind – clearly plays an important part in overall mitigation. Increasing the role of renewables in the energy supply will require:

- overcoming financing challenges
- further technological developments to improve the resilience of renewables to extreme weather risks
- improvements in energy storage
- addressing the challenges related to the large-scale integration of renewables into existing energy infrastructure.

Box 3: The importance of mitigation and adaptation

Future energy supply and demand, future environmental and social contexts are subject to a number of uncertainties, including economic growth, geopolitical situations, new technical innovations, but also rising global mean temperatures. These all are difficult to predict.

With the growing unpredictability of weather patterns, the World Energy Council's two scenarios – 'Jazz' and 'Symphony' – can help to paint a picture of the future. The two scenarios pinpoint what is needed to achieve different policy goals under a range of various conditions and different climate scenarios.

The Symphony scenario focuses on achieving environmental sustainability through internationally coordinated policies and practices, while the 'Jazz' scenario focuses on energy equity with priority given to achieving individual access and affordability of energy through economic growth. Both scenarios show that, due to the cumulative effect of emissions in the atmosphere, surface temperature change, sea-level rise and changes in precipitation, the incidence of extreme weather will persist. Therefore, two kinds of measures are needed to cope with this challenge: adaptation and mitigation. The Jazz scenario shows a stronger emphasis on adaptation driven by regional, national and local initiatives, while the Symphony scenario prioritises mitigation, driven by policy intervention at global, regional and national levels. These scenarios highlight that both adaptation and mitigation measures are key for addressing the uncertainty of weather patterns.

To date, adaptation measures have received less attention; energy policy and investments have focused more on mitigation measures. However, as the evidence of the impacts of rising global temperatures and rising sea levels becomes more apparent, the focus on adaptation is growing. Examples include:

- US Executive Order 13653 Preparing the US for the Impacts of Climate Change and the establishment of an inter-agency Council on Climate Preparedness and Resilience to provide direction and identify priorities for adaptation planning and action[25]
- Mexico's intention to incorporate adaptation criteria for public investment projects that include infrastructure and maintenance
- Singapore's Building Control Act which requires energy services to meet certain performance standards.[26]

To improve overall resilience, the energy industry and policymakers are recognising the importance of an integrated approach that uses a combination of hard and soft measures (see Table 2). For example, following Hurricane Sandy and its impacts on the eastern US, the NYS 2100 Commission investigated how to strengthen

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[25] US Environmental Protection Agency (EPA), 2015: Federal and EPA Adaptation Programs
[26] United Nations Framework Convention on Climate Change (UNFCCC), 2015: INDCs as communicated by Parties, www4.unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx

infrastructure in the face of extreme weather. This group explicitly examined both hard and soft measures to increase resilience and recommended several immediate steps to improve preparedness, and also to implement when redesigning damaged infrastructures.[27]

Table 2

Examples of hard and soft resilience measures for extreme weather

Source: World Energy Council, Marsh & McLennan Companies, Swiss Re Corporate Solutions, 2015

Hard resilience	Soft resilience
Sea and flood walls	Micro grids
Upgrading existing stock	Electricity storage
Increasing the size and strength of the infrastructure, such as raising nuclear stations above sea level	Regular updates to disaster management planning, procedures and protocols
Adding backup generators	Continual maintenance of assets
Installing shut-off valves for piping	Ongoing evaluation of vulnerability in the value chain
Vulnerability assessments done at plant level	Integration of the disaster management plan with the wider system
Relying on historical data for predicting failures	Community engagement and local empowerment
Deploying a disaster management plan for a single plant only	Financial hedging of expected energy shortages and energy efficiency measures

While hard resilience measures are needed to strengthen energy infrastructure, soft resilience measures may reduce the cost of adaptation by shifting from expensive protection solutions to systems that are more flexible. The following section provides an overview of the adaptive measures the energy industry can take to increase the resilience of energy assets.

Energy supply

Oil and gas

Oil and gas represent the majority share of existing energy assets and are expected to continue to do so until 2050.[28] Oil and gas are at high risk from extreme weather patterns, including climate variability, floods, sea-level rise, hurricanes and storms, permafrost thawing and water availability.[29] These risks are expected to increase as oil and gas sources are more likely to come from offshore, deep water and Arctic fields. Weather events have an impact on equipment but also on production rates as crews and supply vessels are evacuated, oil production stops and drilling rigs must move out of the projected storm path.

Offshore developments

Offshore oil and gas platforms, coastal refineries, ports and pipelines are highly vulnerable to extreme weather. The number of offshore locations and coastal infrastructures has increased over the past few years. For North America, the Gulf of

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[27] New York State, "Governor Cuomo announces commissions to improve New York State's emergency preparedness and response capabilities, and strengthen the state's infrastructure to withstand natural disasters", 15 November 2012, www.governor.ny.gov/news/governor-cuomo-announces-commissions-improve-new-york-states-emergency-preparedness-and

[28] World Energy Council, 2013: World Energy Scenarios: Composing energy futures to 2050

[29] International Petroleum Industry Environmental Conservation Association (IPIECA), 2013: Addressing adaptation in the oil and gas industry

Mexico is one of the fastest growing offshore markets with potential for crude oil drilling. As of May 2015, there were 213 offshore rigs in the Gulf of Mexico. Asia is another region that is especially prone to changing weather patterns and exploration and production facilities – more than 300 offshore rigs were operating as of May 2015 in Southeast and Far East Asia – are vulnerable. New offshore oil and gas projects are underway in many other regions of the world, including eastern and western Africa, Latin America, and Europe.[30]

Offshore facilities face even greater exposure the further they are from shore. Deeper waters result in more difficult reconstruction and operation management. If the facilities themselves are damaged, it can take weeks or months to return to operation.

For example, hurricanes Katrina and Rita in the US shut down 46% of large-scale energy infrastructures in the affected areas, with 112 oil platforms significantly damaged. Overall, the energy industry lost an estimated $15bn in 2005 alone, not including the cost of restoration and recovery. In addition, hurricanes caused more than 400 offshore spills which led to over 30.2 million litres of fuel lost and additional millions in lost future earnings, as well as environmental damages and related costs.[31]

While the damage caused by both hurricanes was huge, they have led to improved standards in operation and site development. These improvements have enhanced the resilience of North American deep water operations and could be replicated in other regions of the world.

Onshore developments

Onshore platforms also require resilience measures against extreme weather. Scenarios on the uncertainty of weather patterns are needed to quantify potential impacts on the current operating environments and the identification of efficient adaptation measures.

Typical hardening measures have traditionally included purchasing and leasing large-scale portable generators to provide electricity to critical facilities during outages. However, these options are expensive. A typical 2 MW trailer-mounted unit costs approximately US$1 million or more, including accessories and financing.[32] Instead, companies need to provide smaller generators to service stations along evacuation routes to provide emergency power for the reopening of the plant.

Storage tanks and tank farms are another area of concern, as Hurricane Katrina showed. Tanks floated up in a storm surge, ripping the connecting pipes and destroying the facility. The released oil affected approximately 1,700 homes in adjacent residential neighbourhoods.[33] Balancing the tanks out according to a pre-prepared emergency response plan would have avoided that loss. Increasing the use of soft resilience helps improve the resilience of individual assets.

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[30] Statista: The Statistics Portal, 2015: Number of offshore rigs worldwide as of 2015, by region, www.statista.com/statistics/279100/number-of-offshore-rigs-worldwide-by-region

[31] The Chartered Insurance Institute, 2009: Coping with Climate Change: Risks and opportunities for insurers

[32] US Department of Energy, Office of Electricity Delivery and Energy Reliability, Infrastructure Security and Energy Restoration, 2010: Hardening and Resiliency: US energy industry response to recent hurricane seasons, www.oe.netl.doe.gov/docs/HR-Report-final-081710.pdf

[33] Pine J, 2006: “Hurricane Katrina and Oil Spills: Impact on coastal and ocean environments”, Oceanography, June 2006, 38

When looking at resilience in the oil and gas sector, energy companies play a major role in identifying the best methods of evolving infrastructure designs. Governments also have an important role to play. They must develop and protect the public infrastructure that energy facilities rely on. Zoning and land use that locates critical facilities outside exposed areas is another beneficial approach. Finally, promoting research to enhance climate understanding and engineering solutions that strengthen observation networks for weather and climate variations will be a key activity to strengthen resilience.

Electricity generation

Extreme weather can significantly affect the various electricity generation options such as fossil fuels, nuclear power, hydropower and renewable energy. For example, plants located near coastal areas are at risk from more intense storms and sea-level rise. The impacts can be on the plant equipment itself as well as on the demand side with associated impacts on revenue. Hot days increase the demand for power for air conditioning while also potentially diminishing the supply of cooling water for power plants and around the distribution network. In this case an increase in demand coincides with a decrease in supply, threatening grid stability.

Nuclear power

Nuclear power generation is an abundant low-carbon source of energy and its expanded use can be viewed as an important climate change mitigation response. However, it is susceptible to the impacts of extreme weather and particularly heat and rising water temperatures. For example, because of extreme hot weather during the summer of 2015, nuclear power plants in Switzerland had to reduce generation in order to not overheat the rivers used for cooling the plants. Similarly, in July 2009 due to a long-lasting heat wave, about 20 GW of France's overall 63 GW nuclear power capacities had to be shut down.[34]

Major storms, hurricanes or extreme flooding can lead to the release of radioactive elements to the environment, and related disturbances in the regional electric grid. Both soft and hard resilience measures are needed to manage the risks that stem from the need to provide continuous electrical power to cooling water pumps, even when the reactor is shut down, to dissipate the heat which the fuel elements continue to produce. These measures include enhanced safety regulations and standards, improved risk analysis tools, highly trained reactor operators and emergency response personnel stationed at the plants throughout an extreme weather event. A reactor should shut down at least two hours before the onset of hurricane-force winds at the site, typically between 70 and 75 miles per hour. To provide electrical power to plant safety systems in case there is a loss of off-site power during or following an extreme weather event, emergency backup generators should begin operating. These must be in protected environments fit for extreme floods or other perils. It should be noted that no 'nuclear' damage has ever been caused by extreme weather.[35]

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[34] Kamps K, 2011: "Far from 'Solving global warming' N-Power too risky in destabilized climate", Nuclear Monitor Issue, 28 July 2011

[35] The incident at the Fukushima Daiichi nuclear power plant on 11 March 2011 was the result of a devastating earthquake and subsequent tsunami. While considered natural disasters, neither earthquakes nor tsunamis are extreme weather events.

Hydropower

Hydropower is a low-carbon energy source that also provides irrigation and water supply services. However, hydropower is highly vulnerable to the impacts of extreme weather events, including drought and an excess of rain or floods. While drought diminishes power supplies, excess rain can lead to overtopping and damage to installations. For example, in 2009 a drought led to two months of power rationing in Kenya (more than 30% of electricity generation came from hydropower at the time).[36] Subsequently, the government sought up to US$1bn from international bond markets to finance geothermal and wind energy projects.[37] Many other countries in Africa, Latin America, Asia and also regions in the US, where hydropower plays a dominant role in electricity generation, are prone to the impacts extreme weather events have on hydroelectric generation (see Box 4).

Box 4: Managing the recurrence of droughts in Brazil

Brazil, the world's second largest producer of hydraulic energy, recently faced the worst drought in 40 years. As a result, hydropower consumption in Brazil fell by 7% in 2013, and an additional 5.5% in 2014.[38] As of December 2014, the biggest dams in Brazil were only at 16.1% capacity.[39] Although El Niño[40] was expected to increase the amount of rainfall over the 2014–2015 winter, changing weather patterns shifted its path, missing the points in Brazil where hydraulic dams need filling the most. As a result, the ministry removed restrictions on the transfer of electricity from the northern to southern regions, and also put in place control measures to reduce the supply of electricity to the grid. It was also necessary to increase production from more costly thermoelectric plants and import additional energy from Argentina to avoid blackout, the first time Brazil had needed to import energy since 2010. Industrial customers signing for energy contracts in 2015 are facing prices that are more than double the retail price of January 2014. Brazil will continue to focus on energy supply diversification as a key strategy for resilience, with increasing investments in renewable energy – for example, wind power.[41]

Careful attention needs to be paid to the level of water in a reservoir; the operator's inclination will be to conserve as much water as possible, since it represents potential energy and revenue. However, a flash flood can mean water needs to be discharged quickly, causing downstream damage. The maximum water level permitted may need to be reviewed and revised as the hydrology of the catchment area evolves. Modelling

[36] US EIA, 2012: International Energy Statistics (2009)
[37] Circle of Blue, "Drought, climate change jeopardize global hydropower policies", 22 February 2010, www.circleofblue.org/waternews/2010/world/africa/drought-climate-change-jeopardize-and-complicate-hydropower-policies-around-the-world
[38] BP, 2015: Statistical Review of World Energy 2015
[39] Morales A, 2014: "Drought in US and Brazil linked to hottest year ever", Bloomberg New Energy Finance, 3 December 2014
[40] The El Niño Southern Oscillation (ENS) refers to the effects of a band of sea surface temperatures that are warm or cold for long periods of time. This develops off the western coast of South America and causes climatic changes across the tropics and subtropics. The 'Southern Oscillation' refers to variations in the temperature of the surface of the tropical eastern Pacific Ocean, with warming known as El Niño and cooling known as La Niña, and in air surface pressure in the tropical western Pacific.
[41] Cascione S, 2015: "Brazil to import electricity from Argentina, Uruguay", Reuters, 26 March 2015

rainfall and inflow are factors to be considered in the design and siting of future plants. Site location and project planning should include water-runs, upstream and downstream water flows to maximise the predictability in the stability of the grid as well as local geomorphology.

Box 5: Capacity building to strengthen the climate resilience of hydropower assets and operations in Tajikistan

Tajikistan is one of the countries most vulnerable to changes in hydrologic patterns and cycles. This is due to the extreme sensitivity of the country's glacial hydrology, which is critical for energy generation and agricultural irrigation, and for the livelihoods and wellbeing of the population.

Environmental models predict significant changes in precipitation, snowmelt and the dynamics of Tajik glaciers. As hydropower provides 98% of Tajikistan's electricity supply, the entire energy sector is highly sensitive to climatic variability. This vulnerability is compounded by prolonged underinvestment, over-reliance on ageing hydropower assets, policy failures and weak corporate governance. Upgrades are needed urgently to avoid the risk of major technical failure that would jeopardise the supply of electricity to all customers and cause enormous damage to Tajikistan's economy. To address the changes in hydrologic patterns and cycles, the European Bank for Reconstruction and Development (EBRD) has integrated a detailed impact analysis into the preparation and design of a major investment in the modernisation of Qairokkum Hydropower Plant, a strategically important part of Tajikistan’s energy system, being the only power generation facility in the north of the country. The project team modelled projected hydrology patterns under a range of scenarios. This provided a basis for selecting the most suitable design, based on the projects that would have the most sound future water inflows. As part of the US$75 million investment package for the modernisation of the plant, EBRD is also providing a technical assistance package that will help the power utility that owns and manages the plant to mainstream climate resilience into the overall operational management of hydropower assets. In this way, the appropriate solution was identified as a sound investment.

Renewable sources

New renewable energy, in particular solar and wind, is also affected by extreme weather events. Because of their reliance on weather to optimise energy production, renewable projects naturally consider weather patterns. However, increased weather variability makes it difficult to rely on the accuracy of historical weather patterns. In the instance of an extreme weather event, such as high-velocity winds or a hurricane, solar panels need to be able to endure a great deal of stress on the exposed equipment. While most high-quality solar panels are designed and tested to withstand high-velocity winds, harsh equatorial sunshine, or hailstones, proper mounting and racking is critical to increase their resilience.

Wind turbines face similar problems in terms of continuity and storage. However, compared to solar photovoltaic, wind turbines are still less resilient to the stress of an extreme weather event. While events such as onshore wind turbines catching fire, collapsing or blades flying off in a storm can occur, offshore wind parks appear to have an additional benefit as they can reduce the strength of hurricanes rather than be destroyed by them.[42] A number of technological innovations have increased the resilience of this technology. For example, special storm control features slow the turbines down to avoid shutdown and loss of generation and storm-related damage. Hydraulic towers used in wind turbines help to maintain equipment and can be used to lay down a turbine in a storm.

Distributed generation

The greater use of distributed generation systems – systems that generate electricity on-site – may improve overall system resilience. Generating power on-site usually features flexible technologies, such as small hydro, solar, wind, or geothermal power installations. While the capacity of these systems is comparatively low – typically they deliver around 10 MW of energy or less – they can function separately from the main grid and can do so during, or in the aftermath of, an extreme weather event.

The use of generators is likely to be stimulated by new technology innovation, such as in-battery storage which is lowering the cost for many consumers and small businesses. These innovations may increase grid resilience but may decrease the sustainability of current utility business models. With revenue models under stress, utilities may not be able to make the investments necessary to update and adapt equipment and infrastructure. Under the traditional pricing model, with the increase in distributed generation, the cost of providing electricity services (generation, transmission, distribution and maintenance of equipment) will be carried by a smaller number of consumers, while the size and cost of the existing infrastructure remains largely unchanged. To reflect changes in energy supply and technology, the energy sector (in particular utilities) will need to work with regulators to apply technical and financial expertise to develop effective tariff and pricing models.

Box 6: Advancements in battery technology

For renewables to reach large-scale deployment, technologies are needed for storing power from renewable energy sources such as solar and wind so it can be distributed when it is needed, no matter what the weather patterns are. Recent developments, such as the newly launched Tesla Powerwall in-home battery pack, show that progress is being made.[43] However, upfront costs remain a large barrier for widespread residential use, particularly in Africa where renewable energy could be very useful for replacing traditional wood-burning energy methods. Currently, a 7 kWh capacity battery costs about US$3,000 upfront, not including the costs of installation. This is a huge sum for many potential users in developing countries, and a considerable fee for

[42] Jacobson M, Archer C, and Kempton W, "Taming hurricanes with arrays of offshore wind turbines", Nature Climate Change (Letters), 26 February 2014
[43] Liedtke M and Fahey J, "Tesla CEO plugs into new market with home battery system", The Associated Press, 1 May 2015

homeowners in developed countries. For example, in California, the cost of the renewable energy would be US$0.30 per kWh, compared to the cost of US$0.10 per kWh for electricity.[44]

Mobile-pay-as-you-go solar services can also be an option for developing countries. Users pay a one-off installation fee of around US$10 for a solar panel that can power two lamps. This also comes with a phone-charging device. However, for developed countries the key remains cooperation between corporate and government entities whose pooled funds can reduce the upfront capital costs and help to deploy large-scale storage methods. For example, a utility in Spokane, Washington, in the US has launched an energy storage project of a 1 MW, 3.2 MWh large-scale battery system that connects to the electrical grid and offers backup for intermittent renewable energy generation. The US$7 million project was funded by a US$3.2 million grant, with US$3.8 million matched funds from the utility, which saw the project as a useful way to retain customer support by reducing power outages.[45]

Energy transport

Transmission, distribution, grid stability

Conventional power stations, coal-fired, gas and nuclear power plants as well as hydroelectric dams and large-scale solar power – or centralised systems – typically require electricity transmission over a long distance. This leaves power lines and substations vulnerable to extreme weather such as strong winds, ice storms, wildfires in drought conditions, tornados and flooding. Occasionally, electrical arcing from high-voltage power cables can trigger wildfires and spawn large liability claims against energy utilities.[46] The T&D grid itself is also highly vulnerable to the impact of extreme weather events. For example, in August 2015 Typhoon Soudelor caused power outages for more than 3.22 million households in Taiwan, the biggest power loss ever to result from a typhoon in Taiwan's history.[47] In the 2013 ice storm in the north-east US, parts of the Central Great Plains and Canada led to power outages in more than 1.5 million households, also due to downed power lines.[48] In December 2013, the UK was severely hit by stormy weather and flooding, leaving some 50,000 homes across the country without electricity.[49]

To increase the resilience of T&D systems in areas that are prone to severe storms, one hard resilience measure could include moving the system underground, rerouting power lines away from high-risk areas, or increased technical standards that would enforce appropriate adaptation measures. However, the cost could be much higher

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[44] McMahon J, "National lab director on Tesla battery: 'This Is The Future, Now'", Forbes, 9 June 2015
[45] Oliver Wyman, 2015: Tesla Electricity Storage Battery Could Cut Utility Revenue by Billions
[46] This is a particularly large issue in California where strict liability has been enforced by courts and energy utilities have been required to pay billions of dollars in liability claims for wildfires started by power lines. Energy driven wildfires in California are often caused by a confluence of weather factors – drought or seasonal dryness combined with 'Santa Ana winds' that can topple power lines.
[47] Yi-yu T and Low YF, "Typhoon Soudelor leaves record number of households without power", Focus Taiwan, 8 August 2015
[48] Office of the Premier, Ontario, "Latest update on Ontario's response to the ice storm", 24 December 2014, http://news.ontario.ca/opo/en/2013/12/latest-update-on-ontarios-response-to-the-ice-storm.html
[49] BBC, "Thousands hit by floods and power cuts at Christmas", 25 December 2013

than restoring the damages to the existing system. It is estimated that it would cost one Canadian city CA$15bn to bury regional T&D assets to prevent damage from further ice storms.[50] Also, burying lines could create new vulnerabilities. For example, salt accumulation in soils and increased dryness and hardness of soils surrounding underground T&D cables can cause corrosion problems and increase transmission losses.

Box 7: The Philippines recovery plan

The Philippines face extensive reconstruction of the energy system following the devastating Typhoon Haiyan (also known as Typhoon Yolanda) in 2013, in both costs and emergency procurement processes for energy supplies. Haiyan, the strongest tropical cyclone ever to make landfall anywhere in the world in recorded history, crippled critical energy infrastructure. With an average of eight or nine typhoons making landfall in the Philippines each year,[51] the Philippine government has prioritised the need for clear standards in coordination of information, transportation and fuels to be in place before beginning the rebuilding process. In addition, a vulnerability assessment will identify which areas of action will need cross-industry and transnational cooperation for recovery. Overall, resilience for the Philippines is not only building new, but building better and smarter solutions, such as underground cabling for energy T&D, and adopting new technologies.

Micro grids

Micro grids are localised grids that can disconnect from the traditional grid to operate autonomously. They are considered key in adaptation and mitigation strategies. Similar to distributed generation systems, these grids can help to mitigate grid disturbances and strengthen grid resilience. They are able to continue operating while the main grid is down and can function as a grid resource for faster system response and recovery.

Micro grids also support a flexible and efficient electric grid. They do this by enabling the integration of renewable energy (such as solar and wind) with other distributed energy resources (such as combined heat and power, energy storage, and demand response through reducing or shifting electricity usage). The use of local sources of energy to serve local loads helps reduce energy losses in T&D, further increasing efficiency of the electric delivery system.[52] For example, during and following Hurricane Sandy in New York City, a 40 MW combined heat and power plant (local co-generation plant) kept the lights on for more than 60,000 people in one residential development.[53]

Fuel transport

The transport of fuels via pipelines, sea tankers, rail and road also has a new set of challenges. Energy transport infrastructures may increasingly encounter problems

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[50] McGillivray D, Conway S and Marchionda S, 2014: Extreme Weather and Urban Energy, George Vari Engineering and Computing Centre, Ryerson University
[51] Whiteman, H, "Philippines gets more than its share of disasters", CNN, 5 December 2014
[52] US DOE, 2015: The role of microgrids in helping to advance the nation's energy system
[53] Pentland W, "Lessons from where the lights stayed on during Sandy", Forbes, 31 October 2012

during heat waves, in cold climes from thawing permafrost, increased number of severe storms, increased snowfall or more intense rainfall. These extreme weather events may lead to surface water and river flooding, damage from wave action, groundwater flooding, landslides, and even sink holes. For example, flood-caused erosion or exposure of pipelines after floodwater scrapes several feet of soil and gravel off a river bed can lead to their rupture. Flooding alone is likely to cost millions of dollars in damage worldwide.[54]

Both soft and hard resilience measures and significant upgrades and maintenance projects are required for transport infrastructure to become more resilient. Changing regulatory requirements – for example, on how deep a pipeline must be buried, new land zoning codes, or improved design and construction standards – can help to increase the resilience of energy transport infrastructure. Considering the effects (individually and combined) of extreme temperatures, wind, and precipitation events on pavements, piers and abutment protection, may require flexible or adaptive design concepts into project design, such as shorter design lives and easily replaceable parts.

The adaptation of energy transport to extreme weather events is often not effectively incorporated into business planning and operation, or assessments may be based on only current or historical weather event patterns. Resilience measures should ensure that new and existing means of energy transport consider future weather patterns over their estimated lifetime. However, this can incur costs – for example, to prevent thawing of permafrost from transport of heated oil in the Trans-Alaska pipeline, 400 miles of pipeline were elevated on thermosyphon (refrigerated) piles at an additional cost of US$800 million.[55]

[54] European Commission, 2013: Analysis of Natech Risk for Pipelines: A review
[55] Götz R, “Russia and global warming – Implications for the energy industry”, Russian Analytical Digest, 23 November 2013

3. Financing resilient energy infrastructures

The US$48–$53trn in cumulative global investment needed in energy infrastructure by 2035 does not include estimates for the cost of adapting to the effects of extreme weather events – now and in the future.[56] Financing soft and hard resilience measures, plus the general financing challenges of energy infrastructure, must be addressed to ensure that all the elements of the energy trilemma – energy security, energy equity and environmental sustainability – are met. Without the necessary adaptation measures, balancing the energy trilemma is at risk now and increasingly in the future.

Given the scale of investments required, the private sector has a crucial role to play in financing energy infrastructure to fund large-scale energy projects and also small-scale decentralised infrastructures. New investors, such as municipalities, small businesses, households, but also large non-energy companies – including some companies from the Fortune 100 list – are already entering the market.[57]

Policy frameworks need to support broader private sector involvement through traditional corporative methods (such as public−private partnerships), but also by incentivising the creation of new financial vehicles that address the shift in market dynamics. Specifically tailored funds that embrace the changing nature of the industry can help to address and reduce the high upfront capital costs that are often associated with critical technologies needed for resilient energy systems.

While the benefits are clear, assessing the economic losses caused by extreme weather events is more difficult. Often there is no systematic collection of data and the impact of an event stretches far beyond the energy sector, impacting on how people get to work, whether companies and shops are able to open, and so on. Given the expansive costs of energy system failures, policymakers must ensure that investors are provided with appropriate incentives to invest in system-wide resilience.

This could be achieved by more demanding operating standards or by providing monetary incentives to procure investments to meet the desired level of resilience. For example, in the UK, recent legislation (the Energy Act 2013) includes provisions for

[56] IEA, 2014: World Energy Investment Outlook
[57] World Energy Council and Oliver Wyman, 2014: World Energy Trilemma: Time to get real – the myths and realities of financing energy systems

policymakers to secure funds to provide energy resilience services. Energy is viewed as key to maintaining overall economic stability. By considering the systemic benefits of energy as well as the impact of interruptions to energy supply on other economic activities, countries can be better prepared for unpredictable disruptions.

While recognising the benefits of increased investments in resilience to extreme weather, there is a point where additional resilience may not be justified by the costs involved. For example, burying T&D lines underground increases their protection against ice storms and wind damage. However, there are estimates that underground power lines can cost 5 to 10 times more than overhead lines, and they are more vulnerable to flooding and costlier repairs.[58] At nuclear power stations, modifying cooling water inlets at coastal locations to allow use of cooler, deeper water and continued high levels of efficiency for stations, may cost up to US$133 million.[59] Surveys also show that customers are reluctant to pay higher rates for electricity to cover the costs of improving resilience. Determining the ‘right' level of resilience and the most cost-effective and effective adaptation measures will require the energy sector and regulators to engage with stakeholders, shareholders and customers to build support for greater resilience.[60] It is therefore critical that all stakeholders involved in developing new or operating existing energy infrastructure projects understand the benefits of investing in resilience compared with the costs.

Box 8: Calculating the cost-benefit of resilience

Cost-benefit analyses for increasing resilience currently have varied methodologies. There are many issues around the ability to quantify and integrate non-monetary impacts. Cost-effectiveness approaches may prove useful in showing the benefits of accounting for resilience. When calculating the cost-benefit analysis, costs can include achieving a given target for key services or standards. Other innovative methods include using a risk-based approach, where policies that achieve an accepted risk level are selected. Lastly, policymakers or community leaders may adopt a multi-criteria methodology where distributed effects are taken into account to ensure that adaptation benefits the most vulnerable communities and groups. Clearly identifying inter-sectorial linkages and benefits can stimulate efforts to improve resilience.

The challenge of financing adaptation measures

There is a growing recognition of the need to develop finance for the adaptation of current energy infrastructures. Unlike mitigation measures, adaptation measures often lack regulatory guidance about what is necessary to increase resilience. There is currently no agreed goal or metric for adaptation or specific responses to extreme weather. Nor is there agreement on how much resilience is sufficient and how

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[58] McGillivray D, Conway S and Marchionda S: op. cit.
[59] European Commission, 2010: Investment Needs for Future Adaptation Measures in EU Nuclear Power Plants and Other Electricity Generation Technologies Due to Effects of Climate Change: Final report
[60] McGillivray D, Conway S and Marchionda S: op. cit.

increased resilience can be related to an existing or new revenue stream and so become attractive for the investor.

Without these metrics, many problems arise for project developers and financiers. Project developers are left with inaccurate or insufficient standards to plan and construct and, as a result, there is the risk of an inaccurate project risk profile. This can reduce the attractiveness of the project for investors, whether that is a public or private financial institution. Subsequently, this becomes a problem for project financiers who are looking for projects that provide an accurate, stable return on investment.

Where projects become financed based on an inaccurate risk profile, financiers can face the increased risk of a failing investment. This may further deter private investors from contributing to projects that are critical for maintaining economic and social stability. There is a clear need for governments to intervene in funding important projects, yet often they cannot.

As discussed in the introduction, liquidity is often not available or may already be stretched. Governments become increasingly worried that public funds may be wasted and so they do not develop projects if the risk profiles appear inaccurate.

However, addressing adaptation measures with the same diligence that mitigation measures have received can help to ensure energy security, affordability and accessibility, as well as environmental sustainability. Finding synergies between infrastructure and climate finance may help in the long term to fulfil the huge investment needed (see Figure 5).

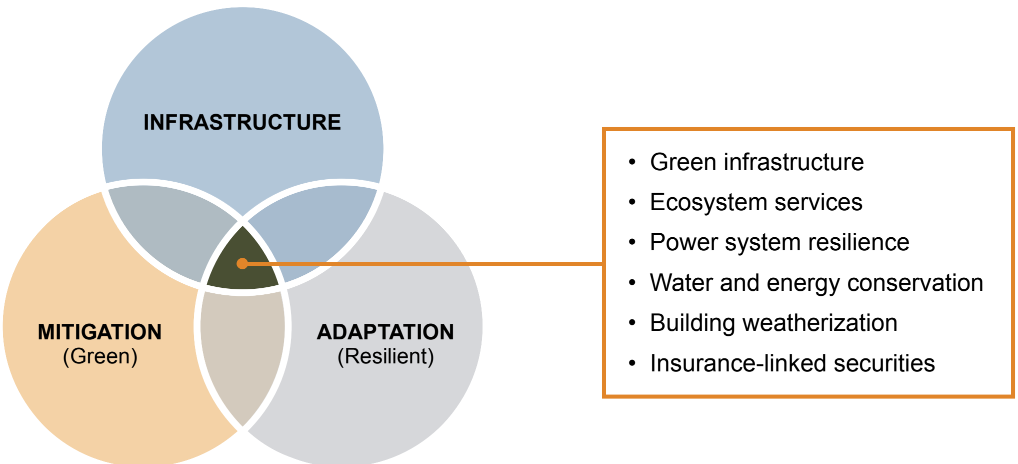
By setting clear standards for newly built systems, further encouraging the incorporation of environmental standards, and developing uniquely tailored financial instruments for addressing extreme weather, governments and the private sector can work together to provide and maintain the current and future energy infrastructures that are the backbone of any economy.

The following section provides recommendations on how to stimulate the financing needed for adaptation measures to increase the resilience of energy infrastructures.

Figure 5

Finding synergies between infrastructure and climate finance

Source: Mercer, 2015



Adapted from http://ccap.org/connecting-the-dots-adaptation-mitigation-synergies/

Providing signals for resilience – the role of energy markets

Projects to increase resilience need to have a return on investment to attract private investors. Investors must be able to identify tangible returns, reduce business interruption and enhance profitability.

In countries where energy sectors have been liberalised, markets can play an important role in financing resilient infrastructure. Market prices provide signals to investors to stimulate investment in areas where it is needed. In well-functioning energy markets, extreme weather events will trigger price changes that provide investment opportunities. In the case of electricity, changing demand patterns would be reflected in changes in prices. These in turn will provide investors with an incentive to invest in generation capacity to meet changing needs.

Similarly, increased frequency of disruptive extreme weather events can be expected to lead to increased frequency in spikes in energy prices. Market participants will have incentives to mitigate their exposure to such volatility. For example, energy companies dependent on fuel supplies that are prone to disruptions will have incentives to invest in resilience measures such as storage infrastructure.

In recent decades, the liberalisation of energy sectors across different countries has seen sophisticated energy markets emerge. Such markets include spot markets[61] for different forms of energy, and a range of secondary markets and transaction forms that allow market participants to hedge their exposure to risks. For example, well-functioning electricity markets include a broad range of market transactions and exchange platforms that cover different time horizons (the length of time over which an investment is held before it is liquidated). To hedge against price volatility – which can be particularly significant for electricity since it cannot be cost-effectively stored at large scale – market participants will use different types of contracts and products. The risks posed by extreme weather will lead market participants to seek ways to hedge their exposure, which will provide opportunities for investors to finance resilience solutions.

The liberalising of energy sectors and the fostering of markets can play an important role in making energy systems more resilient. Policymakers have an important role in liberalising energy sectors, which have historically been dominated by state entities. Many countries have embarked on this process and policymakers can draw on these experiences.

For infrastructure that depends on revenues through regulated tariffs – for example, regulated natural monopolies such as T&D infrastructure – regulators will need to reflect the cost of resilience investments in tariffs to ensure that these are viable. As with deregulated infrastructure, assessing the case for such investments requires the benefits of resilience to extreme weather risks to be well understood. Regulators rely on well-established tools to assess the case for investments in regulated industries. The understanding of emerging risks such as extreme weather, however, continues to evolve, and regulators will need to incorporate such risks in their established frameworks.

[61] A spot market or cash market is a public financial market in which financial instruments or commodities are traded for immediate delivery.

Box 9: Principles for Responsible Investment

The Principles for Responsible Investment is a United Nations-led initiative, which seeks to incorporate sustainability into investment decision making. In mid-2015, close to 1,400 signatories, including asset owners, investment managers and service providers, worked together to put six agreed principles for responsible investment into practice. Signatories recognise the importance of environmental, social and governance factors, and the long-term health and stability of the market as a whole in the generation of sustainable returns. Once considered a sustainability initiative, these standards are now seen as a means of ensuring that investors take into consideration the many risks that may arise from neglecting to incorporate environmental dimensions into risk-management practices.[62]

Ensuring project 'bankability' by increasing modelling capacity

Developing 'bankable' projects and identifying necessary risk management measures in the future will depend on identifying, quantifying, and assessing extreme weather risks for individual projects.[63] This analysis must strive to address all extreme weather risks, including those emerging from shifts in long-lasting weather patterns as well as extreme weather incidents. For example, developing better models that allow quantification of outage costs for renewable energy assets. Improving modelling would help to make a cost-benefit analysis of resilience measures and create the foundation for mechanisms, such as insurance products, that can reduce the risk of exposure.

To date, much research has explored how rising temperatures, changes in weather patterns and an increase in extreme weather events will have an impact on energy infrastructures. There has been less focus on how this research and information can be applied in financial analysis and risk assessment of specific energy infrastructure projects.

Forward-looking extreme weather and climate risk assessments are not a universally accepted part of infrastructure financing. They are generally limited to specific subsets of projects depending on project size and other factors, left to the discretion of the investment bank involved. However, pressure from the market may lead to all weather risks being incorporated into new infrastructure financing.

A degree of weather risk quantification is already taking place for new infrastructure financing. For example, wind projects may involve an assessment of historical wind patterns, while projects in coastal areas may benefit from analysis through catastrophe modelling that involve site-specific extreme weather risk assessments, such as hurricane risks. However, a robust market for site-specific risk analysis does not yet exist, and in many cases, investors are left with a range of substandard options to estimate risk.

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[62] UN Principles for Responsible Investment, 2015: www.unpri.org
[63] For further discussion on the importance of bankable projects, please refer to World Energy Council and Oliver Wyman, 2014: World Energy Trilemma: Time to get real – the myths and realities of financing energy systems.

Box 10: Incorporating natural catastrophe modelling and assessments of climate risks into the project growth and investment trajectory

The US Gulf Coast is an area of critical importance to international energy supplies. The area is increasingly vulnerable to environmental risks with over US$350bn of losses expected by 2030. To build resilience in this region, energy firms partnered with academics, government officials, industry experts and non-governmental organisations. They developed a framework and fact base to inform decision-makers when building a portfolio of economically suitable adaptation measures to benefit all stakeholders in the region. By including natural catastrophe modelling and climate risk assessments in the projected growth and investment trajectory, investors were able to understand which projects (for example, wetlands restoration, refinery levees, higher design specifications for offshore production) would provide the most stable return on investment. The methodology looked at the vulnerabilities in projects and assessed:

1. the impact of changes in hydrologic patterns and cycles on the considered hydropower dam
2. the cost-effectiveness of measures to adapt
3. the ability to gain alignment and develop capacity needed to overcome future obstacles.

The recommendations included improved construction codes and wetlands restoration as critical components of project rehabilitation. These options showed that investing approximately US$50bn over the next 20 years in measures with a cost-benefit ratio of less than one would lead to approximately US$135bn in averted losses over the lifetime of the assets. The analysis also helped to identify where risk transfer may be more cost-efficient than physical measures in providing financial coverage for low-frequency events. This study illustrates how a focus on adaptation measures by policymakers would help to drive the coordination needed across individual players and sectors to truly embed resilience.[64]

The role for improved insurance products

Insurance stabilises revenue streams and helps to attract the investments needed to build resilient energy infrastructure projects. In the past, classical extreme weather coverage focused on the effects of storms or floods. In the last decade, insurance coverage has increased to provide protection along the whole energy value chain.

Weather-related natural catastrophes such as floods and storms constitute key risks in property insurance. Understanding natural catastrophe risks and their impact is critical to assess the insurance industry's property business accurately and to structure sound

[64] Entergy, America's Energy Coast and America's Wetlands Foundation, 2010: Building a Resilient Energy Gulf Coast: Executive report

risk-transfer solutions. Improved risk assessments could help identify potential adaptation opportunities and unlock crucial investments by facilitating cost-benefit analysis.

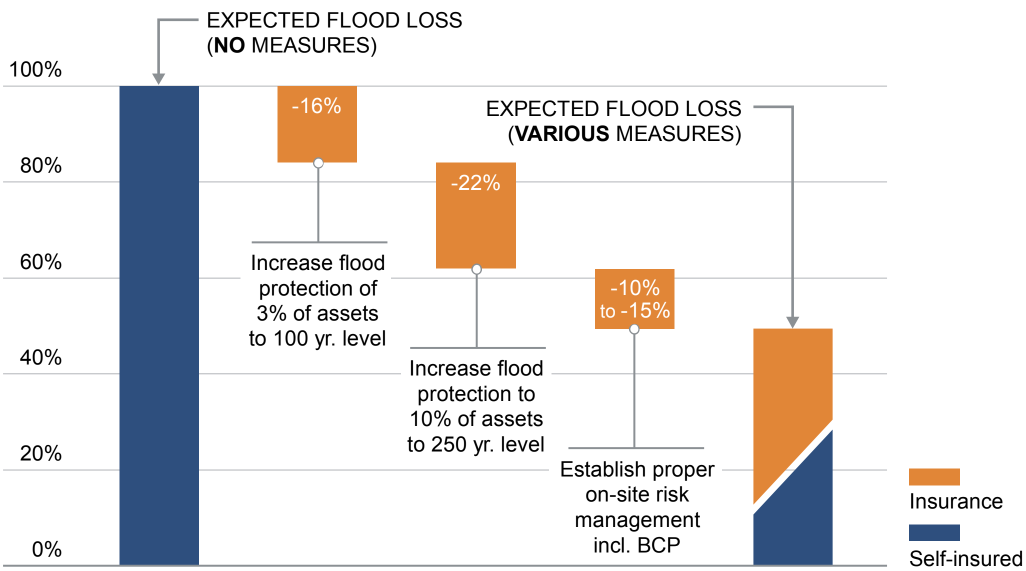
Risk assessments often start with risk-engineering services from insurance and consulting companies working with corporate clients to discuss the effectiveness of mitigation measures and improved capacity to recover from severe weather events.

Residual financial risks stemming from extreme events can be transferred to insurance companies once appropriate hard and soft resilience measures are in place. For example, financial flood-risk management entails investments in protection and includes risk-management culture and insurance. The combined impact of risk management and insurance – for example, flood protection measures – can reduce the expected losses caused by extreme weather events. Figure 6 shows the combined impact of risk management and insurance in reducing the expected flood losses for 12 industrial companies, either from the power sector or with production processes heavily dependent on power use.

Figure 6

Combined impact of risk management and insurance in reducing expected flood losses

Source: Swiss Re Corporate Solutions



Insurance provides financial coverage for risks across the whole value chain of the energy industry. These risks can be physical damages to production facilities or other influences, such as man-made damages, liability issues, and so on. Insurers charge a premium which is paid upfront and commensurate with the risk.

Insurers and those from the financial services industry also offer solutions to ensure a company's expected revenue and cash flow. Investments in infrastructure are attractive to long-term investors if steady returns are assured. Delays in start-ups of installations or underperformance in production of renewable energy installations due to extreme weather negatively affect cash flows. Insurance can address these risks and improve the attractiveness of the investment.

Box 11: How insurance reduces the financial impact of extreme weather risks

A changing climate leads to two different types of risk, which are at the core of insurers' concerns. The first is that an extreme weather event causes some physical damage to the energy asset which stops it from working for a period. The second is that changing global average temperatures damage the ability to operate, and damage the financial return.

The first type could be a flooded power station, or a wind turbine damaged by a hurricane. The damage, as well as the revenue loss while the damage is being fixed, will normally be insurable, so the project does not generally need to consider the economic loss, but just consider the cost of the insurance premium. However, the problem is not solved forever: the insurance market will evaluate the chance of a negative event occurring, and how much damage it will cause. The evaluation will always be based on extrapolations of past events and past experience. The challenge arises if an event with a probability of recurring every 100 years becomes more frequent as a result of rising global average temperatures, for example, every 50 years, or 20 years. The insurance market will apply higher premiums at first; however, at some point, the risk may become uninsurable. The insurer can recalibrate his underwriting criteria frequently – annually if necessary – and the project may become unviable during its planned lifespan. This is why mitigating climate change is important.

The second type of loss has no damage to the asset, but only to the operational capability. A dam without water due to changing hydrological patterns and cycles, a thermal power station with inadequate cooling water, a wind farm with too little or too much wind. Conventional insurance will not address this risk, but derivative-like parametric cover may be available to mitigate the risk. As in the first category of risk, this cover will only be available as long as the insurers are asked to respond to deviations from ‘normal’. If an increase in global average temperatures redefines ‘normal’ during the project lifespan, the project can become unviable.

New financial instruments

New financial instruments to address adverse weather impacts, weather-related volume exposures and electricity price volatility, combined with unplanned power outages, are being offered by the financial services and insurance industries. These products allow weather risks to be hedged, income volatility to be stabilised and risks for investors to be reduced. For example, reduced electricity consumption due to warmer winter seasons does not depend on accidental loss events. Often this is determined by indexes – so-called parametric covers.[65] For example, for hydroelectric companies facing drought and high fossil fuel prices, a weather contingent commodity price hedge (‘quanto’) comes from the basic assumption of ‘normal weather and prices’ and hedges out adverse combinations of actual weather and commodity price (see Figure 7). Investors and lenders can consider such products to mitigate the

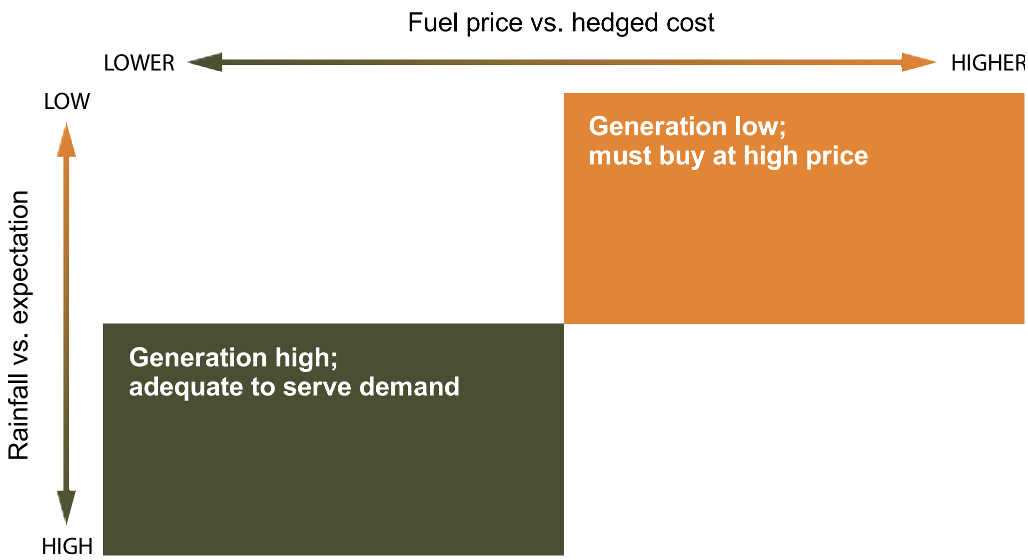
[65] CRO Forum, 2011: Power Blackout Risks − Risk Management Options

impact of extreme weather events on investment profitability. They can also become comfortable with the ability of their contract partners to cover the debt service of outstanding loans.

Figure 7

Weather contingent commodity price hedge ('quanto')

Source: Swiss Re Corporate Solutions, 2015



Box 12: Protecting Uruguay against loss of hydropower in times of drought

Weather risk has increasingly become a burden to many governments, reducing generation from renewable energy sources and forcing the government to substitute lost hydropower with costly fossil fuel generated power in case of a drought. For example, Uruguay relies largely on rainfall for its hydroelectric plants to produce enough electricity, and dry conditions can lead to increased energy imports at uncertain costs. In a 2012 drought, this climate variability pushed the government into a budget deficit when Uruguay had to buy electricity on the international spot market. To help decrease this financial exposure, Uruguay's Ministry of Finance entered into a US$450 million weather coverage deal with the World Bank Treasury from 1 January 2014. This transaction uses rainfall data and oil prices for settlement, and compensates the government for the combined risk of drought conditions and an increase in the price of energy, thereby reducing a major source of budget uncertainty each year.[66]

[66] World Bank, "The World Bank partners with Uruguay to execute largest public weather and oil price insurance transaction", 19 December 2013

Cash flow of infrastructure operators like natural gas distributors depends on the quantities transported and supplied and is sensitive to unseasonal warm or cold temperatures. For example, abnormally cool temperatures across Europe in early 2013 had a positive impact on energy sales for many companies. However, comparison of this unusually cold 2013 winter with 'normal temperatures' in the same period in 2014 would deteriorate the net income of a natural gas distributor by €236 million.[67] A quanto would hedge out daily cash flows (deviations from seasonal temperature affecting demand and expected gas prices).

Similarly, the profitability of merchant power generators and retail electric providers can be affected in mild summers, through a combination of reduced sales and low power prices. A cooling degree day option (a weather derivative price with an index based on the number of days when temperatures rise above the average when people start to use air conditioning) would protect against this. Assuming that the power market always absorbs the generator's production, a weather contingent power price derivative is appropriate. It hedges the daily cash flows against warm winter, potentially in combination with a hedge against low power prices.

Unplanned power outages, especially in a period of high power prices that allow the generator to profit, can create a difficult situation for a power generator. In case the power is already sold forward, replacement power has to be bought on the market at an unfavourable price. An outage insurance solution would cover the cost of replacement power or dispatching generated power for a profit. Due to its contingent nature, solutions are available at an affordable price, typically cheaper than keeping a generator in reserve.

Insurance Linked Securities (ILS) complement traditional reinsurance solutions and provide additional benefits to issuers such as fully collateralised protection for both peak risks and multi-year protection at a fixed price. These ILS products essentially function as derivatives, but have not achieved widespread acknowledgement. A small, yet highly scalable and willing, market for energy and catastrophic risk transfer is ready to be tapped into, particularly in pension funds and other long-term investments. The ILS offers compelling alternative returns that are largely uncorrelated from the broader investment market.

Within ILS, catastrophe bonds, often referred to as cat bonds, typically transfer peak risks to the capital markets. In sponsoring a transaction, an insurer can potentially improve both the risk and capital management effectiveness and flexibility. ILS such as catastrophe bonds can provide benefits to institutional investors as well. Investors are able to gain access to risks that help to diversify their current holdings and benefit their overall asset allocation strategies.[68] Usually catastrophe bonds run for only few years and can be renewed. Their pay-outs are usually linked to pre-defined triggers – for example, for a windstorm the trigger is related to the lowest air pressure measurement as a key indicator for hurricane strength − and are independent from physical loss assessments (see Box 13).

[67] Kepler Chevreux ESG Sustainability Research, 2013: Climate Change – Demystifying climate effects
[68] Swiss Re, "Experts on MultiCat Mexico", April 2012

Box 13: Catastrophe bonds in Asia Pacific

The Asia Pacific region, faced with high levels of extreme weather and other natural disaster exposure and a significant gap between insured and economic losses, is in desperate need of strengthening resilience to disasters. To improve catastrophe management and access to reinsurance or risk capital for protection against losses, catastrophe bonds or other insurance-linked securities (ILS) and collateralised reinsurance products are expected to feature increasingly as regional insurers leverage alternative sources of risk capital. While there is awareness of the need to increase resilience, there are limitations on the availability and quality of data and the regulatory and operating landscape. Improved data is expected to enhance the ability to use risk transfer options, grow the levels of education on risk transfer and ILS options, and help stimulate the use of instruments such as catastrophe bonds and the diversification of risk capital in the Asia Pacific region.

While risk transfer options are established in Japan, with typhoon and earthquake risks most commonly transferred to the capital markets, other countries are slowly following. For example, the first China catastrophe bond, Panda Re Ltd. (Series 2015-1), is covering China Re for US$50m of its earthquake risks.[69] With the increase in extreme weather events, catastrophe bonds' coverage of weather risks will become more important in the future.

Gaps in the energy insurance market

Traditional insurance mechanisms protect investments against hurricane risks, flood risks and other weather events. However, key gaps exist; for example, T&D networks are generally excluded by insurance policies, with utilities generally preferring to recoup losses through rate increases. Other gaps in the marketplace are being addressed, including failure to hedge demand and supply risk due to longer extreme weather phases like droughts or heat waves, as well as widespread under-insurance of contingent and direct business interruption.

In the absence of insurance to protect against the impact of extreme weather risks, well-formulated contracts can provide energy companies with interim solutions. For example, low hydropower production can be addressed by designing contracts to protect against low precipitation or stream flow and the need to purchase fuel to maintain electricity production. Similarly, contracts can protect against low temperatures in summer to hedge against decreased revenue due to lower-than-expected consumer demand for energy. Disruption to supply or business interruption from a storm can be addressed through contracts protecting against high wind speeds. In the oil industry, weather-triggered supply interruption is often covered by buffer stocks, such as stored oil. These have an asset value, which can be used as a financing option.

While the impact of rising global mean temperatures, including an increase in extreme weather events, will manifest itself over the coming decades, most of the industry's

[69] Artemis, "Catastrophe bond issuance in Asia Pacific to increase: Fitch", 21 August 2015; Intelligent Insurer, "Cat bonds to catch on in Asia-Pacific, says Fitch", Intelligent Insurer, 21 August 2015

business renews annually. Cover usually lasts for 12 months for insurance policies and up to five years for catastrophe bonds. Therefore, insurance premiums do not reflect long-term expected loss trends. Instead, for underwriting and risk management purposes, the models provide an estimate of today's risk, mainly based on historical information. However, as natural catastrophe losses continue to rise, risk models will gradually reflect this trend as the historical record is updated.[70]

There is a role for insurers, reinsurers and the ILS market to make available the products and capacity required to help offset the growing exposure, providing a significant opportunity to the market in new capacity.[71] The energy, banking and investment sectors must seize the opportunity and exercise such products appropriately as a means of bridging the gaps in the traditional insurance market and reducing the risk of energy infrastructure investments.

Several key steps are necessary to close the finance gap. Education efforts should take place within the energy finance market, helping to spread the message that the insurance and reinsurance industries have the ability to assess and transfer this type of risk. Additionally, further research and development is needed to enable more forward-looking catastrophe and risk analysis.

Extreme weather adaptation bonds

While it may be difficult to immediately collect the weather information for a specific site or market, adaptation bonds can be issued as a way to quickly raise private finance. Many institutional investors have expressed an interest in investment products for adaptation. Specifically, pension funds, insurance firms, and banks can purchase bonds as a low-risk component of energy investments. There are many ways private and public sector finance can be used to deploy adaptation means. For example, development banks can issue generic bonds or direct project lending and credit lines.

However, it is important to consider the exposure of emerging economies and their attractiveness for investment. Micro finance projects should be created and backed by development banks and multilateral institutions to ensure that funds go towards the most vulnerable nations. Products that specially address the soft resilience measures (see Introduction) can reduce the exposure to extreme weather. Also, measures aimed at poverty reduction, education, the maintenance of local ecosystems, and energy supply diversification can all help to address the adaptation gap.

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[70] Swiss Re, 2014: Sigma No 1/2014: Natural catastrophes and man-made disasters in 2013

[71] Artemis, "Climate change a trillion-dollar threat. Re/insurance & ILS can help", 4 August 2015; Economist Intelligence Unit, 2015: The Cost of Inaction: Recognising the value at risk from climate change

Conclusions

The frequency, severity and exposure of energy systems to extreme weather events is changing. The number of extreme weather events increased more than 4 times from 38 in 1980 to 174 events in 2014.[72] Severe convective storms' contribution to overall insured losses (last 5 years compared to last 20 years) alone has increased to over 40%.[73] Economic costs have increased and extreme weather events are challenging the financial stability of the energy industry.

Evolving infrastructure design

The energy system as a whole, individual energy infrastructure assets, as well as energy production and companies' earnings are at risk. There is a growing focus on the need to adapt energy infrastructures to improve resilience to the impact of extreme weather events.

In the past 'fail-safe', impact-resistant structures were built, but there is a shift towards having energy infrastructures now operating under the assumption that 'safe-fail' – smarter, not stronger – is necessary. In many cases soft adaptation measures now complement hard adaptation measures. Innovation is happening in many energy fields. In addition to smarter designs, the energy industry is adapting with greater flexibility. Along with more modular designs and decentralised solutions, local empowerment is becoming a key issue in the proposal, construction, and operation phases. Sharing information on the impact of an event, design recommendations and emergency response strategies among the various stakeholders can help improve energy infrastructure resilience in an increasingly uncertain and complex world.

Financing resilience

Financing energy infrastructure resilience comes at a cost – whether resilience is factored in from the beginning of a project or later. To increase the bankability of a project and reduce costs, financial models should incorporate the risks of extreme weather and changing climate patterns right from the start of project planning. Given the already huge amount of investment needed over the next 20 years, resilience is a prerequisite to unlock funds from public and private investors.

Investors are looking for reliable and stable returns. Every hard and soft resilience measure implemented will contribute to this reliability. Cost-benefit analysis can help to minimise the cost of resilience. Also, new financial instruments are able to hedge weather risks, smooth income volatility and help to stabilise earnings certainty by lowering the cost of finance or improving returns on equity.

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[72] Swiss Re Economic Research and Consulting, 2015: Sigma world insurance database (last accessed 10 September 2015)
[73] Swiss Re, 2015: Sigma Report No. 2/2015 – Natural catastrophes and man-made disasters in 2014: Convective and winter storms generate most losses

Residual financial risks stemming from extreme events can be transferred to insurance companies, by using products such as catastrophe bonds or other insurance-linked securities and collateralised reinsurance products as alternative sources of risk capital. In the absence of insurance to protect against the impact of extreme weather risks, well-formulated contracts can provide energy companies with interim solutions.

Financial markets have an important role to play in unlocking investments:

1. Insurance and brokers can assess extreme weather risk.
2. Insurance and banks can provide risk transfer instruments, including new ones such as green bonds, catastrophe bonds, weather and weather-triggered commodity price options and swaps.
3. Insurers, banks, pension funds, and new sources of capital can provide investment.

If financial models can move to identify risks related to changing weather patterns, these risks can be better transferred to the financial and insurance markets, and the energy infrastructure project itself becomes easier to finance. Guiding principles that help to enforce this, such as environmental, social and governance standards can help to incorporate a variety of environmental risks, specifically extreme weather and climate risk. Such principles can foster mitigation as well as adaptation. Mitigation could include environmental standards related to emissions, tax and other incentives for resilience measures to be implemented. Adaptation could include reliability standards, building codes, or safety codes.

Regulating resilience

To build resilience, all energy stakeholders must understand the impact of extreme weather events on energy infrastructure. This means that energy companies and project developers, banks, insurance companies, long-term investors, governments, and regulators must collaborate. Better coordination will enable innovation, technological standards, appropriate financial and risk transfer instruments, and a regulatory framework to provide the necessary guidance for resilience and market regulation. The energy industry and financing sector should work with regulators and governments to adapt regulation to make it more viable for a greater variety of long-term investors, in particular large institutional investors such as insurers, reinsurers and pension funds to invest in energy assets.[74]

Call to action

Together and individually, stakeholders have a role in ensuring that current and future energy supply is secure and reliable. The full recommendations are set out in Table 3 and summarised as:

- Energy companies and project developers must consider extreme weather in their planning, operation and maintenance, and implement adequate soft/hard resilience measures.
- Regulators must provide regulatory guidance for resilience and market regulation, and must open energy infrastructure to all investors.
- The financial services industry must develop models that fully reflect extreme weather risks and include soft/hard resilience in cost-benefit analysis.

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[74] Swiss Re, 2014: Infrastructure investing. It matters.

- Insurance companies and banks must create additional risk transfer options for residual risks.
- Long-term and institutional investors must collaborate with other stakeholders to overcome investment barriers.

Table 3

A call to action – ensuring secure and reliable energy supply

Source: World Energy Council, Marsh & McLennan Companies, Swiss Re Corporate Solutions, 2015

Stakeholder	Responsibility	Goals	Alternatives	Greatest obstacles
Energy companies	Consider extreme weather in planning, operation and maintenance; implement soft/hard resilience measures.	No disruption to supply/business interruption, low income volatility, guaranteed cash flows and profits, no damage to equipment.	Solutions/insurance to cover physical damage and ensure revenue and cash flow.	Absence of clear regulatory guidance. Costs of adaptation measures. Risk transfer options for residual risk.
Project developers	Consider extreme weather in planning, operation and maintenance; implement soft/hard resilience measures.	Projects guaranteeing stable returns are easier to sell.	Solutions/insurance to cover physical damage and ensure revenue and cash flow.	Absence of clear regulatory guidance. Risk transfer options for residual risk. Lack of models that fully reflect extreme weather risks and include soft/hard resilience in cost-benefit analysis. Limited range in diversity of investors for providing capital. Costs of adaptation measures.
Long-term/ institutional investors*	Investment in resilient energy infrastructure.	Stable and adequate long-term returns.	Investment in alternative assets.	Current regulation does not allow all institutional investors to invest in energy infrastructure. Risk transfer options for residual risk.
Banks and insurance institutions (as 'risk takers')	Develop models that fully reflect extreme weather risks and include soft/hard resilience in cost-benefit analysis. Provide risk transfer instruments.	Outlook to write profitable business.	N/A	The modelling challenge – all stakeholders must cooperate and share information and data. Regulations may restrict institutions from investing in energy infrastructure.
Regulators (governments)	Set clear guidance (requirements) for the development of resilient energy infrastructure by defining clear adaptation needs. Ensure fair competition.	Ensure energy services are accessible and affordable for all consumers.	Decrease in reliability of energy supply. Public investment in energy infrastructure.	All stakeholders must cooperate and share information and data to increase understanding of what is needed. Large upfront capital costs needed for critical infrastructure projects.

*including insurance companies as long-term investors

Appendix A: Project participation

The project team would like to thank the individuals who informed the project's approach, supplied information, provided ideas, and reviewed drafts. Their support and insights have made a major contribution to the development of the report.

World Energy Council Knowledge Network – Principal Contributors
Frank Balas, Canada; Will Sutherland, Canada; Jia Yu, China; Jean-Eudes Moncomble, France; Rob Youngmann, France; Matti Goldberg, Germany; Frank Holtrup, Germany; Marc Muff, Germany; Ushma Shah, Germany; Christoph M. Stolz, Germany; Stefan Ulreich, Germany; Christoph Wüstemeyer, Germany; VK Garg, India; Rajeeva Srivastava, India; Stefano Buschi, Italy; Claudio Dicembrino, Italy; Francesco Giorgianni, Italy; Takahiro Kato, Japan; Minoru Muranaka, Japan; Tarek Atallah, Lebanon; Martin Berg, Luxembourg; Christopher Knowles, Luxembourg; Roland Schulze, Luxembourg; Laxman Neupane, Nepal; Tim Henshaw, New Zealand; Baltz Tribunal, Philippines; Mariusz Krupa, Poland; Karen Sinclair, Qatar; Dudley Baylis, South Africa; Ronald Chauke, South Africa; Johannes Horstmann, South Africa; Jason Schäffler, South Africa; Nirvan Sookay, South Africa; Beatriz Mayor Rodriguez, Spain; James Marshall, Switzerland; Stephanie Teufel, Switzerland; Ali Al-Shafar, United Arab Emirates; Raimund Bleischwitz, United Kingdom; Peter Charville-Mort, United Kingdom; Simon Jackmann, United Kingdom; Victoria Melvin, United Kingdom; Filipe Mota Pinto da Silva, United Kingdom; Daniel Westerman, United Kingdom; Noel Bakhtian, United States; Hank Courtright, United States; John J. Easton, Jr, United States; Peter Evans, United States; Lawrence E. Jones, United States; Ian Lloyd, United States; Scott MacArthur, United States; Austin Montgomery, United States; Onyeka Obasi, United States; Diego Juan Rodriguez, United States; Georges Sassine, United States; Guodong Sun, United States; Xiaoping Wang, United States.

Philippe Joubert (Executive Chair, Global Electricity Initiative, World Energy Council); Florence Mazzone (Head of Communications, World Energy Council); Stuart Neil (Senior Director, External Affairs and Communications, World Energy Council).

World Energy Council Study Group – Observers
Jorge Bacher, Argentina; Sue Brown, Australia; Maxx Diley, Australia; Steve Hatfield-Dodds, Australia; Warwick McDonald, Australia; Lisa Brennan McKellar, Australia; Alberto Troccoli, Australia; William D'haeseleer, Belgium; Felipe Dias, Brazil; Joao Carlos de Luca, Brazil; Lauro Valdir de Souza, Brazil; Andrew Claerhourt, Canada; Ian Philp, Canada; Padma Tata, Canada; Rodrigo Violic, Chile; Mario Luna, Colombia; Benjamin Court, France; Eva Sass Lauritsen, Denmark; Leif Sonderberg Petersen, Denmark; Nazre Adum, Ecuador; Anne Crepin, France; Cesar Ortiz, France; Tristan Zipfel, France; Prajwal Baral, India; Ashraf Yahya Gheni, Iraq; Paolo D'Ermo, Italy; Chris Schmelter, Germany; Samir Ibrahim, Kenya; Suzanna Samstag Oh, Korea; Sheehama Andreas, Namibia; Iyaloo Andre, Namibia; Justine Hauala, Namibia; Mir Yahya Ismail, Pakistan; Maria Carvalho, Portugal; Virgil Musatescu, Romania; Noura Mansouri, Saudi Arabia; Desnei Leaf-Camp, South Africa; Dave Wright, South Africa; Elena Lopez-Gunn, Spain; Ibon Zugasti, Spain; Charles Breitenfellner, Switzerland; George Scott, Switzerland; Somjait Sudprasert, Thailand; Eren Ergene, Turkey; Belinda Scott, United Arab Emirates; Ben Caldecott, United Kingdom; Nick Eyre, United Kingdom; Elaine Hawes, United Kingdom; Cameron Hepburn, United Kingdom;

Chris Llewellyn Smith, United Kingdom; Simon Mills, United Kingdom; Jan Peter Onstwedder, United Kingdom; Phil Sivell, United Kingdom; John Achenbach, United States; Paul Loeffelman, United States.

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Project Team

Christoph Frei (Secretary General, World Energy Council); Juerg Trueb (Managing Director, Head Environmental Commodities and Markets, Swiss Re Corporate Solutions); Alex Wittenberg (Executive Director, Global Risk Center, Marsh & McLennan Companies).

Authors/Project Management

Adil Hanif (Principal Banker, Policy & Technical Cooperation, Energy & Natural Resources, EBRD); Katrina Kelly (Project Manager, Financing Resilient Energy Infrastructure, World Energy Council); Lucy Nottingham (Director, Global Risk Center, Marsh & McLennan Companies); Oliver Schelske (Vice President, Swiss Re Centre for Global Dialogue, Group Strategy): Bernd Wilke (Vice President, Swiss Re Branding & Public Affairs); Sandra Winkler (Director, Policies & Member Services, World Energy Council).

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Further details at **www.worldenergy.org** and **@WECouncil**

World Energy Council
62-64 Cornhill
London EC3V 3NH United Kingdom
T (+44) 20 7734 5996
F (+44) 20 7734 5926
E info@worldenergy.org
www.worldenergy.org

For sustainable energy.
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