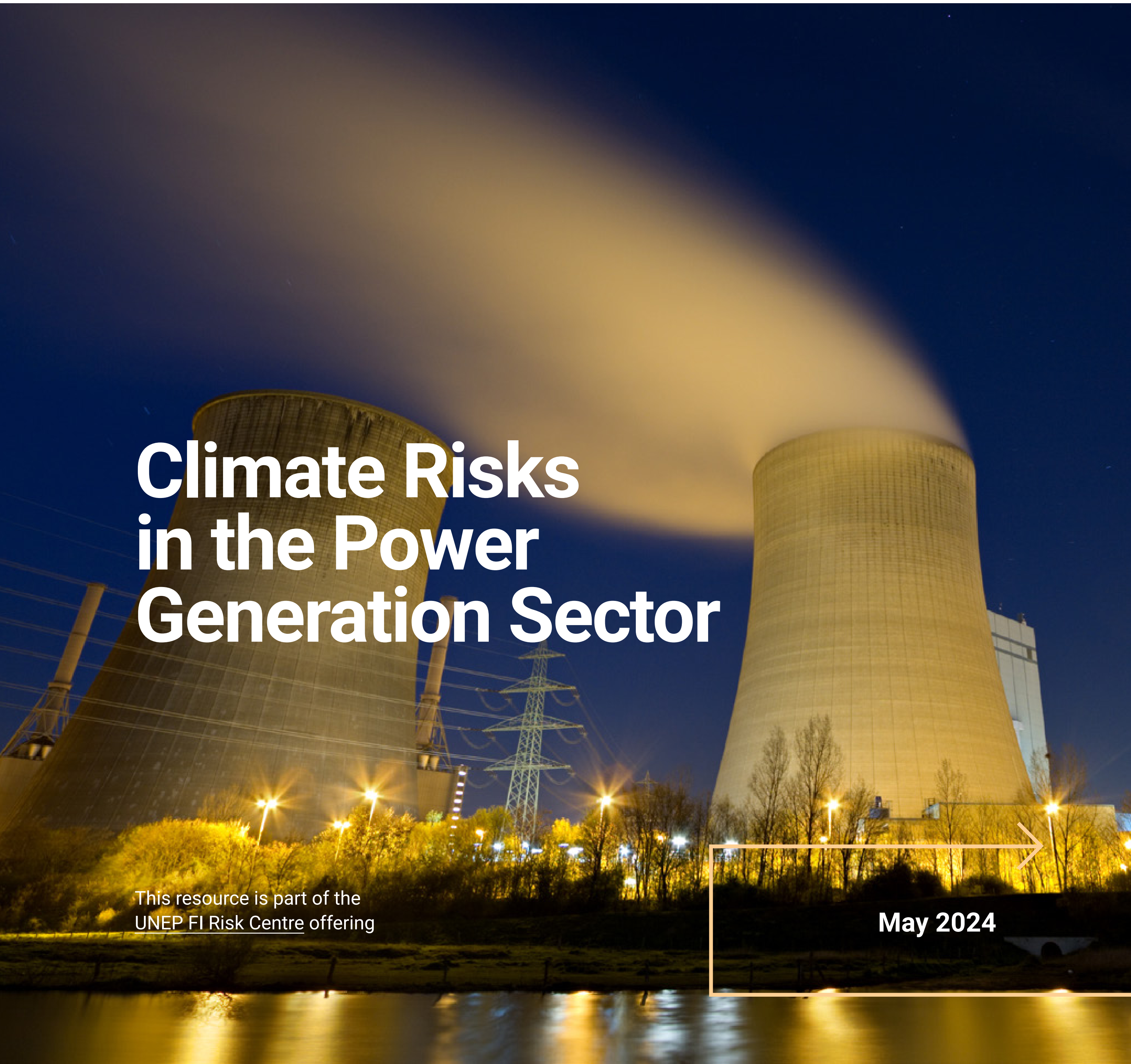
Sectoral Risk Briefings:
Insights for Financial Institutions

UN environment programme finance initiative



Climate Risks in the Power Generation Sector

This resource is part of the UNEP FI Risk Centre offering

May 2024

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Suggested citation: United Nations Environment Programme (2024). Climate Risks in the Power Generation Sector. Geneva.

Production: United Nations Environment Programme Finance Initiative.

Cover image: elements.envato.com/power-plant-at-night-D2PAXB8

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The authors would specifically like to acknowledge the contributions, inputs, and supporting research that have enabled the completion of this report:

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Project management

The project was set up, managed, and coordinated by the UN Environment Programme Finance Initiative, specifically: Remco Fischer (kai.fischer@un.org) and David Carlin (david.carlin@un.org).

The project has been supported by the following financial institutions as members of the UNEP FI convened Climate Risk and Taskforce on Climate-related Financial Disclosures Programme:

ABN-AMRO
Access Bank
AIB
Bank of Ireland
Banorte
BBVA
Bradesco
CIBC
Citibanamex
Danske Bank
Desjardins
DNB
EBRD
Farm Credit Canada
Goldman Sachs
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Itau
KBC
Lloyds
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NIB
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Standard Bank
TSKB

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Purpose of this document

This detailed briefing note explores relevant climate risks for the sector, supported by illustrative examples from firms in the form of case studies featured in the main text. These case studies showcase how firms in the sector are recognising and confronting climate risks through disclosure examples from their annual reports.

It is important to note that this brief specifically delves into the potential impacts of climate change on the sector. Therefore, exploring the reverse—how the sector impacts climate change—is not the primary purpose of this document. Additionally, the scope of this brief is narrowed to focus solely on climate risks, excluding a broader examination of potential environmental and social risks for the sector. A future series may incorporate these other important risks and considerations of double materiality.

This brief also provides guidance and recommendations aimed at assisting financial institutions in effectively managing both their own risks and those of their clients, with the aim of accelerating a sustainable financial and economic system.

Introduction

In the past few years, the global economy has been lashed by the COVID-19 pandemic,-geopolitical conflict, supply chain disruptions, an energy crisis, and high inflation. These challenges are occurring against the backdrop of the mounting planetary emergency of climate change. Climate change can exacerbate all other challenges, increasing geopolitical conflicts over resources, crippling infrastructure and supply chains, extending the range of dangerous pathogens, and collapsing the natural systems upon which we depend. As the US Pentagon presciently stated: "climate change is a threat multiplier". While the transition to a sustainable, net-zero future is critical, it demands fundamental shifts in nearly all economic sectors. These shifts are not without risk for companies and communities impacted by them.

Financial institutions face an array of risks from this rapidly changing, and often chaotic, world. Their clients are exposed to physical hazards as well as transition risks, which can have major credit, market, and operational implications. The prudent financial institution will explore these climate-related risks and prepare strategies to meet them. Future resiliency and success are contingent on thoughtful planning and good decisions today. UNEP FI has been working at the intersection of sustainability and finance for over 30 years. Its programmes for financial institutions develop the tools and practices necessary to positively address the most pressing environmental challenges of our time. UNEP FI's Climate Risk and TCFD Programme has now worked with over 100 financial institutions to explore physical and transition risks posed by climate change. Through this work, a need has been identified to provide financial institutions with a baseline understanding of climate-related risks and their manifestations across different sectors.

This brief is part of a series of notes that cover major economic sectors and their associated climate risks.[1] Each brief also provides specific guidance and recommendations for financial institutions to enable them to more effectively manage their risks and those of their clients. UNEP FI intends for the resources and perspectives included within these notes to empower financial colleagues to communicate these risks throughout their institutions and across the financial sector more generally. The hope is that the communication process will not only enhance awareness of climate risks, but also begin conversations that will lead to tangible changes in strategy and operations. It is the integration of the insights that will be the truest test of the effectiveness of this series. This particular brief covers the physical and transition risks facing the power generation sector.

1 Previously published climate risk sector briefs by UNEP FI cover Agriculture, Real Estate, Oil & Gas and Industrials.

Sector overview

Power generation is the generation of electricity from primary energy sources.[2] In 2022, electricity from fossil fuels generated 40% of the total global carbon emissions (Liu *et al.*, 2023). In 2021, the power generation sector witnessed the greatest increase in carbon dioxide (CO_2) emissions across all sectors globally, with the sector accounting for 46% of the rise in emissions (IEA, 2022a). The sector faces high transition and physical risks as a result of its contribution to CO_2 emissions. The power generation sector is therefore one of the pivotal sectors that must undergo rapid decarbonisation to mitigate global warming.

Despite rapid growth in renewable energy, fossil fuels account for 82% of the global energy mix (S&P Global, 2023a). In 2020, the global power generation mix was primarily comprised of fossil fuels—namely, coal and natural gas (IEA, 2020a). However, the global energy mix is expected to shift significantly in the coming decades. The International Energy Agency's (IEA) updated roadmap to net zero by 2050 shows global electricity generation rising by 3.5% annually from 2022 to 2050. This is due to electrification of end-uses, such as electric vehicles (EVs) and industrial processes, coupled with economic development and population growth. In the pathway, less carbon-intensive energy sources (such as renewables, nuclear and hydrogen) outcompete unabated fossil fuels after 2025. These account for 71% of total electricity generation by 2030, double the share in 2022 (Figure 1) (IEA, 2023a). Therefore, this sector risk brief will focus on both power generation from fossil fuels and low-emissions alternatives.

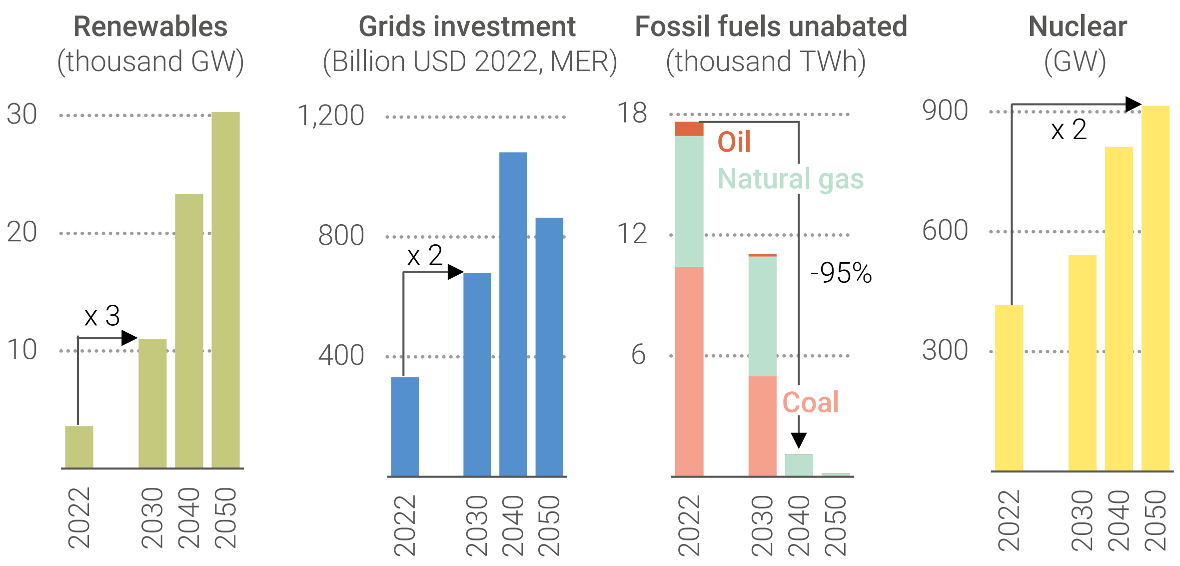


Figure 1: Changes in electricity generation in the IEA's Net Zero Scenario (IEA, 2023a)

2 Energy available in its resource form before it has been transformed.

The power generation sector faces vulnerabilities from physical risks owing to the increased frequency and severity of extreme physical hazards caused by climate change. For example, the combination of stronger storms and rising sea levels threaten to flood energy production facilities. Similarly, wildfires can cause significant damage to facilities or even destroy them. Greater uncertainty in physical conditions will lead to decreased performance and reliability of power-producing assets, causing greater risks of down-time and blackouts as well as higher capital and insurance costs for firms in the sector.

As nations ramp up their transition to a low-carbon economy in efforts to meet net-zero pledges, the highly reliant fossil fuels power generation sector will face exposure to transition risks, especially through the implementation of carbon prices and other types of policy restrictions. The increasing availability of alternative energy sources and their decreasing costs will also impact the market share of traditional power generation companies. Other types of transition risks can range widely from shifts in consumer and investor preferences to increasing legal and reputational risks as awareness of climate change and the sector's role grows among societies.

Below, we explore in depth the key transition and physical risks faced by the power generation sector (Table 1).

Table 1: Key climate risks for the power generation sector

Risk		Summary
Transition risks	**Increasing carbon prices**	As a major contributor to global emissions, the sector will be significantly impacted by the implementation of carbon pricing schemes. Carbon prices will increase the cost of emissions, raising production costs for firms and moving energy prices. Higher energy prices raises concerns about the affordability of electricity for households.
	Other public policy shifts	An increasing number of countries have pledged to stop power generation from coal and reduce fossil fuel subsidies. Such government actions threaten the ability of power producers reliant on coal to operate and generate profits.
	Rise in low-carbon technologies and technological risks	Advancements in low-carbon technologies have resulted in greater capacity and lowered costs of fossil fuel alternatives, such as renewables, thus increasing competition for traditional power generation firms.
	Consumer and societal pressure	Increased awareness of climate change and its impacts is driving a shift in consumer preferences from fossil fuels to alternative energy sources, potentially causing a decrease in demand for fossil fuel-based power generation.
	Market risk and asset stranding	To limit warming to 1.5°C, newly developed and existing plants must be retired. As a result, owners will be at high risk of stranded assets.

Risk		Summary
Transition risks cont...	**Shifting investor preferences**	Investors are increasingly taking climate change into consideration for decision-making. Many financial institutions have announced disinvestment policies for coal financing. As a result, firms in the sector could face greater difficulties in receiving financing for carbon-intensive projects.
	Reputational risk	Power generation companies face increased scrutiny by the public due to the emissions produced from their operations.
	Emerging legal risks	Firms in the sector are growing increasingly susceptible to lawsuits from activists and governments on climate-related issues.
Physical Risks	**Rising temperatures**	Higher temperatures reduce the operational capacity of power plants, while adding extra pressure on the sector to meet rising energy demand.
	Droughts and water stress	Power generation, especially hydropower, requires large amounts of water and is threatened by rising drought conditions and water scarcity.
	Wildfires	Wildfires can damage power infrastructure and can decrease the efficiency of solar power generation. Furthermore, power lines and other equipment have frequently contributed to wildfires for which power generation firms have been held accountable.
	Intensifying storms and floods	Increased frequency and severity of extreme storms and flooding can increase operational costs of firms in the sector due to damage to infrastructure and constraint supplies of raw materials.
	Rising sea levels	Power plants located along coasts are exposed to rising sea levels, which threaten power plant infrastructure, including damaging electrical and cooling systems. Such damages will increase maintenance and repair costs for firms.

SECTION A:

Transition risks

Due to its heavy reliance on fossil fuels for power generation, the sector has become a focus for governments, climate activists, and consumers. As a result, the sector will encounter significant transition risks in the form of climate policies, technological advancements, and shifting investor sentiment. The pathway to limiting warming to 1.5°C requires the majority of coal, oil, and gas reserves to remain un-burned. According to researchers, to limit warming to 1.5°C, 60% of oil and gas and 90% of coal will need to remain unextracted (Figure 2) Welsby et al., 2021). However, many power generation firms have invested heavily in the infrastructure and equipment needed to generate power from fossil fuels. As the impacts of climate change worsen, power generation firms that contribute high levels of emissions will also be susceptible to reputational damage due to their contribution to climate change and due to lawsuits by governments, non-governmental organisations, communities, and individuals.

The transition risks facing the power generation sector also pose a risk for workers and communities that rely on the sector for jobs and income. It is therefore important to align financing with a just transition approach that considers the impact of the transition on groups at risk to operations in the power generation sector, including workers, Indigenous Peoples and local communities.

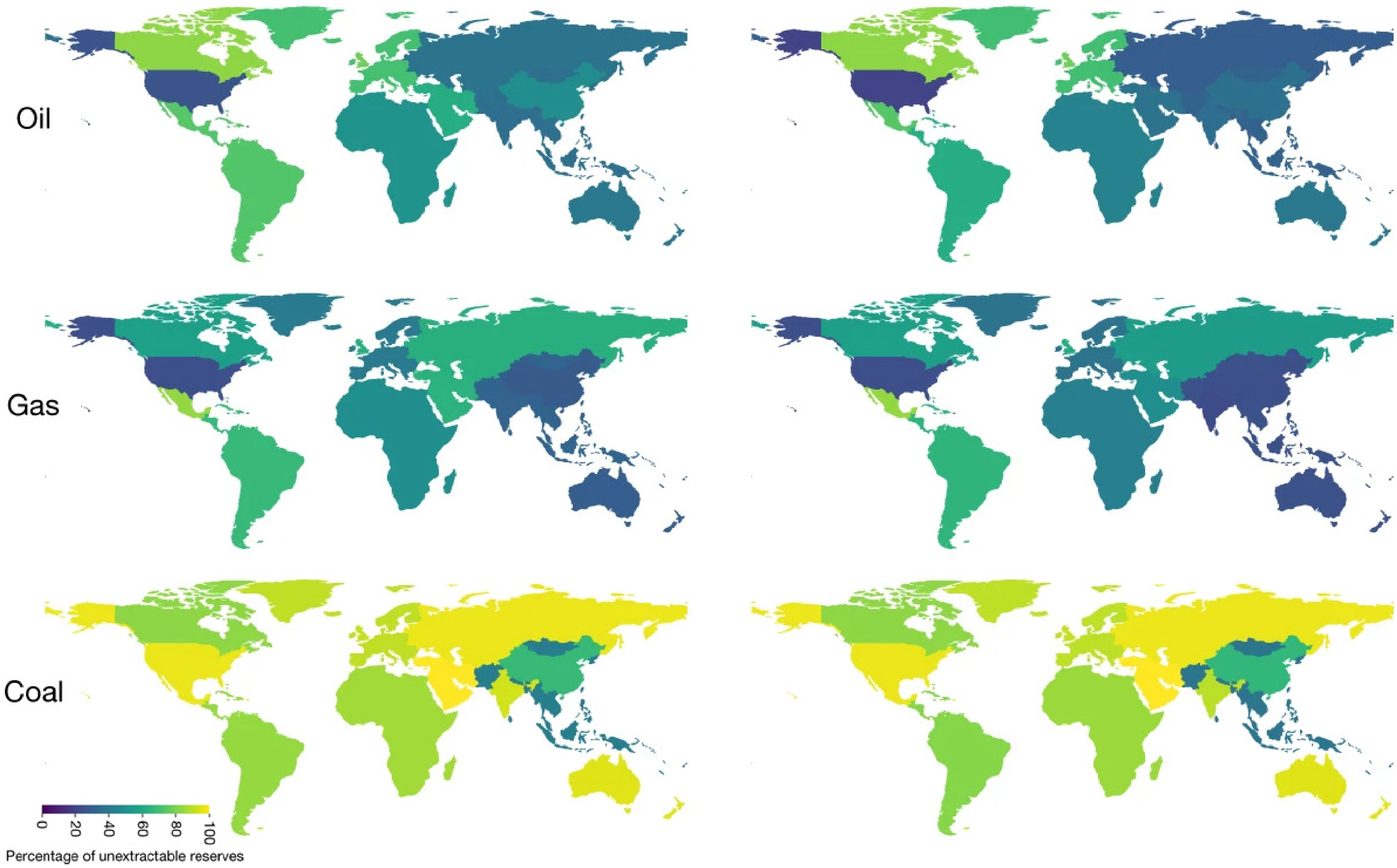
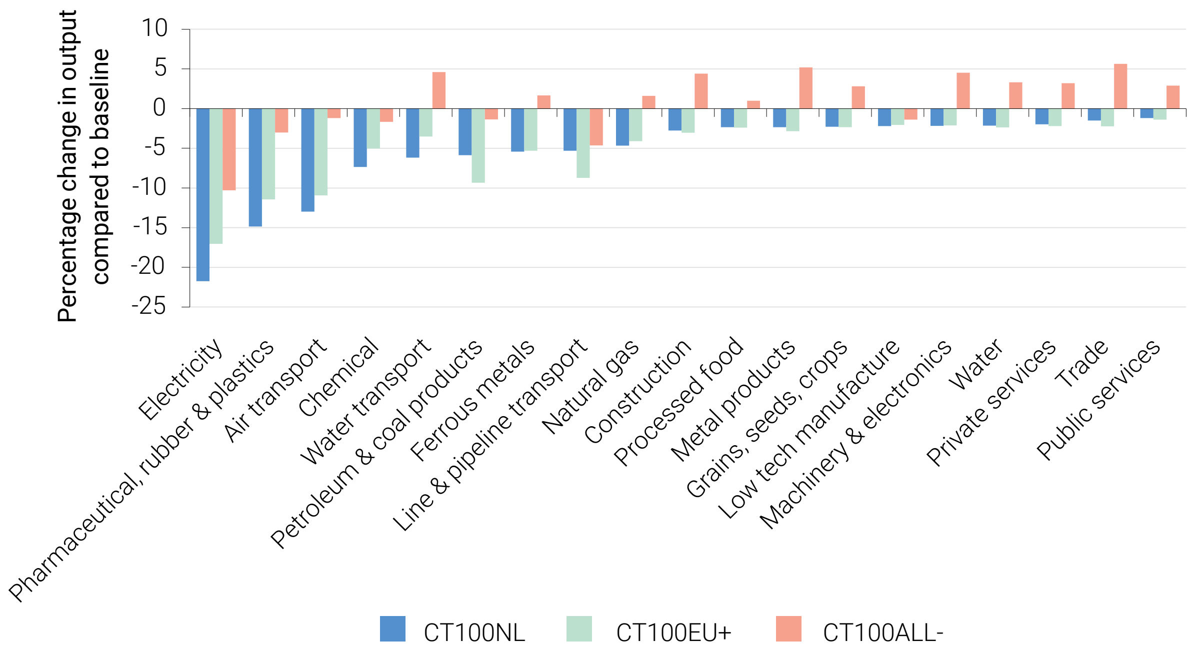


Figure 2: Unextractable reserves of fossil fuels by region in 2050 and 2100 under a 1.5°C scenario (Welsby et al., 2021)

1. Increasing carbon prices

To decarbonise and limit warming to 1.5ºC, governments worldwide are implementing measures to reduce CO_2 emissions. One key mechanism that is being used is the implementation of carbon prices. A carbon price raises the cost of emissions in order to discourage firms from carbon-intensive activities by raising the cost of operations. As a high-emitting sector, power generation will be one of the hardest hit by a carbon price. A study by De Nederlandsche Bank (DNB), the Dutch central bank, showed that the imposition of a carbon tax of USD 100 would cause the greatest decrease in output in the power generation sector[3] out of all the Dutch sectors (Figure 3) (DNB, 2022).



Source: GTAP database, Rabobank simulations

Figure 3: Impact of a carbon tax of USD 100/tCO_2 on sectors in the Netherlands (DNB, 2022)

Countries are implementing a carbon price mechanism through a carbon tax or an emissions trading scheme (ETS). As part of a carbon tax, the government decides a price that an emitter will pay for each ton of emission they generate (C2ES, 2018). An ETS, also known as a 'cap and trade' system, works where a limit or cap is placed on the right to emit specified pollutants. Firms can trade the permits allocated to them, establishing a carbon price (World Economic Forum, 2022). By 2022, 46 countries had implemented carbon price mechanism, such as a carbon tax or an emissions trading

3 If substitution with renewables is not possible

scheme, with prices rising as high as USD 90/tCO_2 (IMF, 2022a). In 2023, revenues from carbon pricing reached a record high of USD 95 billion through 73 different pricing schemes (World Bank, 2023).

Globally, the power generation sector has been the main target of many carbon pricing schemes. For example, as part of the European Union (EU) ETS, all European electricity producers must buy CO_2 emissions' allowances for each ton of their emissions. In the fourth quarter of 2023, the carbon price in Europe was EUR 85.48/ton (Ember, 2023a). South Korea, where the power generation sector accounts for 54% of emissions (IEA, 2020b), has an emissions trading system in place since 2015. The average auction price in 2022 was almost USD 18 (International Carbon Action Partnership, 2023a). In 2021, China implemented its national ETS, which regulates 2,000 companies from the power generation sector (International Carbon Action Partnership, 2023b). Switzerland implanted its ETS in 2008. This now covers many sectors, including electricity generation. It had a market auction price of USD 80, as of 2022 (International Carbon Action Partnership, 2023c). Although the United States does not have a nationwide ETS, some regional initiatives require power generation firms to purchase emission permits, linking their cap-and-trade system to that of Quebec. Other regions, such as New Zealand and the United Kingdom, operate emissions trading systems that cover emissions from the power generation sector.

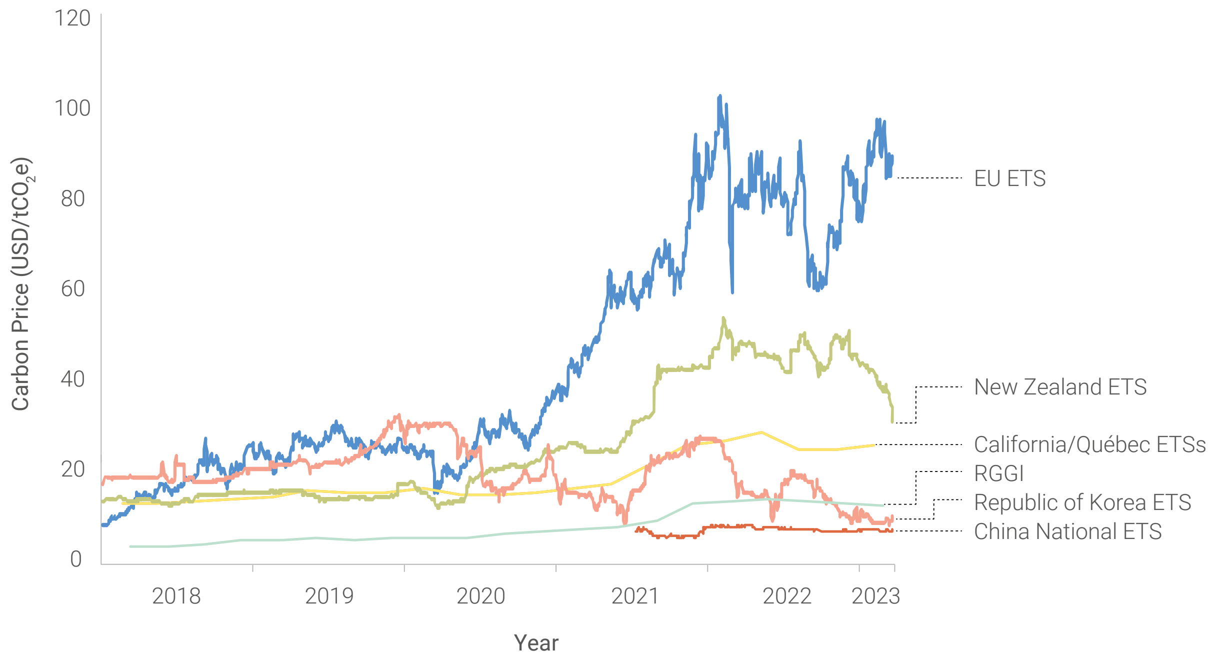


Figure 4: Examples of various ETSs from 2018–2023 (World Bank, 2023)

Coal

In the pathway to reach net zero, the Network for Greening the Financial System (NGFS) Net Zero 2050 scenario (REMIND-MAgPIE model) shows carbon price increasing from less than USD 10 per ton of CO_2 (/tCO_2) in 2020 to USD 115/tCO_2 in 2030 and USD 451/tCO_2 in 2050 (Figure 5). As the carbon price increases, the scenario also shows a rapid and significant decrease in electricity generation from fossil fuels. Electricity generation from coal decreases by more than 80% in 2030 from 2021 levels. By 2050, electricity generation from coal decreases by 100% (Figure 6).

As coal is more carbon-intensive than oil and gas, coal power plants are particularly more vulnerable to rising carbon prices. According to economic analysis, the imposition of a carbon price of USD 30/tCO_2 would drive a shift in power generation from coal to gas in multiple countries. This shift is driven by increased operating costs for coal power plants, making them less economically competitive compared to natural gas alternatives. In order to mitigate these costs, some coal plants may explore strategies like retrofitting, repurposing, or early retirement. In the case of Thailand, for example, the declining costs of wind and solar energy suggest that these energy sources could become cost-competitive with coal as early as 2025 (IEA, 2021a). Similarly, a study conducted on Indonesia's power generation sector revealed that a carbon price exceeding USD 35/tCO_2 could significantly alter the country's energy mix, resulting in a reduction in coal-based power generation (Kamandika and Dhakal, 2023). In Germany, the EU ETS is driving a transition from coal to natural gas for electricity generation. In 2021, the cost of emission permits surged by 28% compared to 2020. This increase in permit costs led to higher operational costs for coal power plants, subsequently reducing their profitability. To adapt, some power generators made the switch to natural gas. It is important to note that some of the costs could be passed along to consumers (Reuters, 2021a).

Firms in the sector that rely on coal for power generation will face increased costs from carbon prices. A carbon price of USD 7 tCO_2 could increase the operating cost of an average coal plant by USD 7 per megawatt-hour (MWh), whereas a carbon price of USD 50/tCO_2 could increase the operating cost of an average coal by USD 50/MWh (Resources for the Future, n.d). Analysis on carbon taxation by the National Institute for Economic and Social Research (NIESR) found that a carbon tax of USD 100/tCO_2 would quadruple the price of coal relative to the price of renewable energy. The rise in costs could cause demand for coal to decrease by 35% globally (NIESR, 2022). High costs can also impact the lifetime of power plants. For example, in one study, a carbon price of USD 7/tCO_2 could reduce the average residual lifetime of Chinese coal plants by 5.43 years (Mo et al., 2021).

Oil and Gas

In a pathway to reach net zero emissions, the carbon price increases from less than USD 10/tCO_2 in 2020 to USD 115/tCO_2 in 2030 and USD 451/tCO_2 in 2050 in the NGFS Net Zero 2050 scenario (REMIND-MAgPIE model) to mitigate emissions (Figure 5), electricity generation from oil decreases by almost 80% in 2030 from 2021 levels. In 2030, electricity generation from gas decreases by 20% of 2021 levels. By 2050, meanwhile, there is a full reduction where gas is not responsible for generating electricity (Figure 6).

Firms in the sector that rely on oil and gas for power generation will face increased costs from carbon prices. A carbon price of USD 7/tCO_2 could increase the operating cost of an average natural gas plant by USD 3/MWh, whereas a carbon price of USD 50/tCO_2 could increase the operating cost of an average natural gas plant by USD 20/MWh (Resources for the Future, n.d). Analysis by NIESR found that a carbon tax of USD 100/tCO_2 would increase the price of oil and gas by 60 to 70% relative to the price of renewables. The price increase could overall cause energy demand to decrease by 15% (NIESR, 2022).

As mentioned above, carbon pricing could lead producers switching from coal to gas power generation due to the cost competitiveness of gas in comparison to coal under a carbon tax. For example, since the introduction of a carbon tax in the United Kingdom, electricity generation from coal decreased by almost 93% and was replaced by less emission-intensive sources, including gas (UCL, 2020). In the United States, the shift from coal to natural gas is already taking place without the implementation of a carbon tax. Between 2005 and 2019, for example, the share of coal in the country's electricity generation mix decreased from 50% to 23%, while the share of natural gas increased from 19% to 38% (EIA, 2021a).

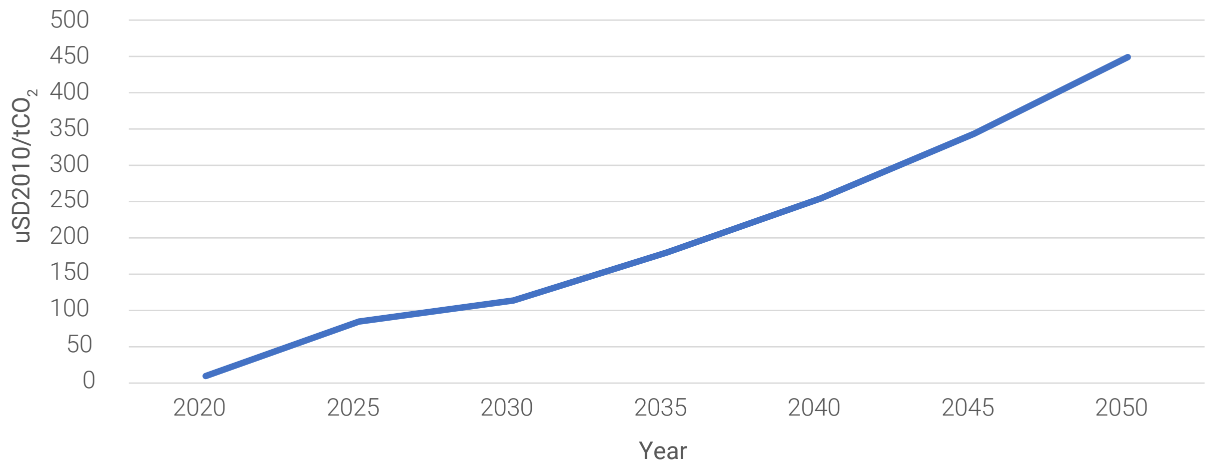


Figure 5: Global carbon price shown in the NGFS Net Zero 2050 scenario (REMIND-MAgPIE model)

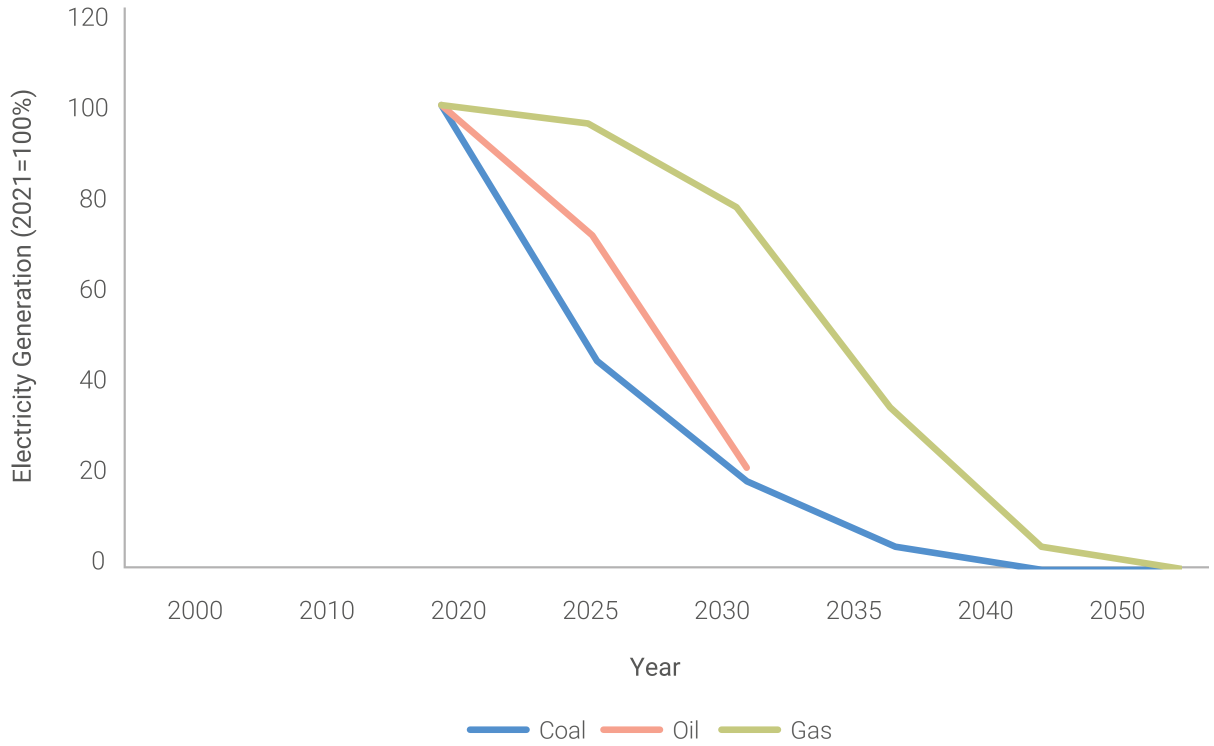


Figure 6: Electricity generation from coal, oil, and gas as a percentage of 2021 levels in the NGFS Net Zero 2050 scenario (REMIND-MAgPIE model) (BNEF Energy Outlooks Comparison, 2023a)

For power generation by fossil fuels as whole, DNB finds that a carbon tax of EUR 50/tCO_2 increases production costs on average by 0.7% in the short term. However, for the power generation sector, including electricity and gas, production costs increase by 8% on average in the EU and 18% in the trading bloc's Central and Eastern European member states (DNB, 2021). The increase in costs became a crucial concern for firms in the sector in 2023 when the price of the EU ETS reached EUR 100/tCO_2. Carbon price for the sector can also cause an increase in electricity prices for consumers (Resources for the Future, n.d.). In areas where power plants are chosen based on market forces, a carbon price can lead to higher operating costs for these plants. This, in turn, can raise the overall electricity prices that consumers pay, especially if these power generators set the market prices themselves. In situations where power companies earn a fixed, regulated profit on their investments, the costs linked to carbon pricing may cause these companies to increase electricity rates for consumers so as to protect their profit margins (Resources for the Future, n.d.). This occurred in 2021 after natural gas prices rose sharply. While it is important to note that this increase in prices was primarily driven by a combination of Russia's invasion of Ukraine and heightened demand, it is important to note that the EU ETS price at the time had more than doubled compared to 2020. This suggests that carbon pricing also had an impact on energy costs. In the Nordic region, wholesale electricity prices were almost seven times higher in the fourth quarter of 2021 than the same period in 2020. This reflects a complex interplay of various factors, including geopolitical events and the influence of carbon pricing (IEA, 2022b). Energy prices in Europe could have been even higher if it were not for the presence of existing renewable energy infrastructure, which played a role in mitigating the potential impact on costs.

The affordability of energy for households remains a just transition concern, with carbon prices comprising one of the notable factors of the transition that could potentially negatively impact consumers.

Case study 1: Carbon price risk

Capital Power Climate Change Disclosure 2022

Canadian power producer

Transition risk mapping and corresponding mitigation pathways
Key assumptions:

- Carbon pricing remains a central mechanism of climate policy in Canada; prices rise over time while performance benchmarks are increased; complementary pricing and regulatory mechanisms are implemented and strengthened.
- Carbon pricing is gradually adopted and expanded across the United States; pricing is implemented in the long term with material escalation of prices.
- Stimulus spending by governments is increasingly focused on energy and green infrastructure.
- Demand growth accelerates globally from recent levels due to increasing levels of electrification in industry as a way to reduce emissions.
- Carbon markets continue to expand across North America.

Risks

- **Short term**
  - Changes in governments create uncertainty with respect to future climate change-related policy.
  - Current portfolio is exposed to carbon pricing; as prices rise, this may result in higher compliance obligations and reduced margins for existing facilities.
  - Unexpected variation in carbon prices and regulation may lead to material variances compared to expectations.

- **Mitigation**
    - Capital Power actively participates in industry groups to monitor and engage with government officials on emerging policy development relating to climate change and carbon pricing.
    - Carbon costs are passed through to counterparties on select power purchase agreements and are also partly reflected in wholesale merchant power market prices, thereby minimising exposure to carbon price.
    - Capital Power actively manages compliance costs through participation in environmental commodity markets and through continuous investments in operational efficiencies and enhancements to reduce emissions at our generating facilities.
    - Scenarios and sensitivity analysis relating to carbon prices and regulation is embedded in all commercial decision making and due diligence to ensure appropriate consideration of climate change-related risks.
- **Long term**
    - Accelerated decarbonisation of the power sector is being considered by governments in Canada and the United States
    - Adoption and escalation in carbon prices continues in response to increasing pressure to reduce emissions through market mechanisms; prices rise well above current levels, while performance benchmarks are made more stringent.
- **Mitigation**
    - Unmitigated thermal assets are increasingly expensive to operate; Capital Power actively pursues Carbon Capture, Utilisation, and Storage (CCUS), direct air capture (DAC), and hydrogen blending to minimise exposure to carbon pricing, with a target of being net zero by 2045.
    - Capital Power continues to actively manage compliance costs through participation in carbon markets and investments in operational efficiencies and enhancements that reduce emissions at its facilities.
    - Over the longer term, Capital Power will pursue abatement at source, where feasible, and negative abatement where emissions cannot be reduced at source.
    - Carbon costs are passed through to counterparties on select power purchase agreements, minimising exposure to carbon price.
    - The costs and risks associated with emissions abatement from thermal assets are considered in all commercial decision making and due diligence; capital allocation decisions may favour assets and technologies that minimise potential exposure.

2. Other public policy shifts

The power generation sector, especially power generation from coal, is also vulnerable to policy risk from growing government restrictions. One of the biggest threats to the sector is countries' commitments to phase out coal power. Over 200 parties at COP 28 called for a transitioning away from fossil fuels. The first ever 'global stocktake', which aims to accelerate climate action by 2030, also took place at the conference in Dubai. The global stocktake calls for the phase down of unabated coal power generation and the phase out of inefficient fossil fuel subsidies (UNFCCC, 2023; Greenpeace, 2023). Prior to this, some countries had already set out ambition plans to phase out coal, including Mauritius and North Macedonia's pledges to phase out coal by 2030. Aligning with this international shift, Montenegro, the Czech Republic, Ukraine, and Bulgaria have committed to the same goal by 2040 (Energy Monitor, 2023).

Countries are also establishing renewable energy targets, creating further risks for fossil fuel power producers. Notable cases in point include:

- Germany, which has set a target to achieve 80% renewable power by 2030 and 100% by 2035 (Table 2).
- New Zealand, which has a goal to derive 100% of its electricity from renewables by 2030.
- The United Kingdom, which plans to decarbonise its power generation sector by 2035 (Climate Council, 2022).

Traditional power producers that fail to adapt to such targets could face decreased demand, resulting in losses and forced closures. For example, in 2021, 16 of 31 provinces in China implemented electricity rationing to meet their annual emissions target (SCMP, 2021).

After meeting its target of 50% renewable energy a full eight years early, Sweden is on track to rely 100% on renewable sources by 2040 (Climate Council, 2022). In 2020, the Nordic country was able to shut down its last coal power plant, Värtaverket, two years early. This was partly due to changes in tax rules that made coal use for heating less profitable. The plant, owned by Stockholm Exergi, had been operating since 1989, when Sweden was dependent on fossil fuels for energy. The plant will be replaced by a plant for capturing CO_2 emissions from burning biofuels (Smart City Sweden, 2020).

Table 2: Germany's energy transition targets[4] (French Institute for International Relations, 2023)

	Target stated by the former coalition	Target set in 2021	Target set in 2022	Stand in January 2022
Share of RES in the power mix	65% by 2030	80% by 2030	80% by 2030	46.4%
Onshore wind	75 GW by 2030	Around 100 GW by 2030	115 GW by 2030	57 GW
Offshore wind	20 GW by 2030	30 GW by 2030	30 GW by 2030, 40 GW by 2035, 70 GW by 2045	8 GW
Solar	100 GW by 2030	200 GW by 2030	215 GW by 2030	63 GW
Electrolyzers	5 GW	10 GW	10 GW	-

The removal of fossil fuel subsidies for power generation is also becoming a threatening reality for the sector. There are many ways in which fossil fuels are currently subsidised. On the supply side, governments have various options at their disposal. One common measure is to transfer funds directly to power companies via lower taxes. On the demand side, consumer subsidies can lower the taxes on fuels or electricity or set lower prices for consumers (IMF, 2019). Figure 7 illustrates various types of energy subsidies as a percentage of global GDP.

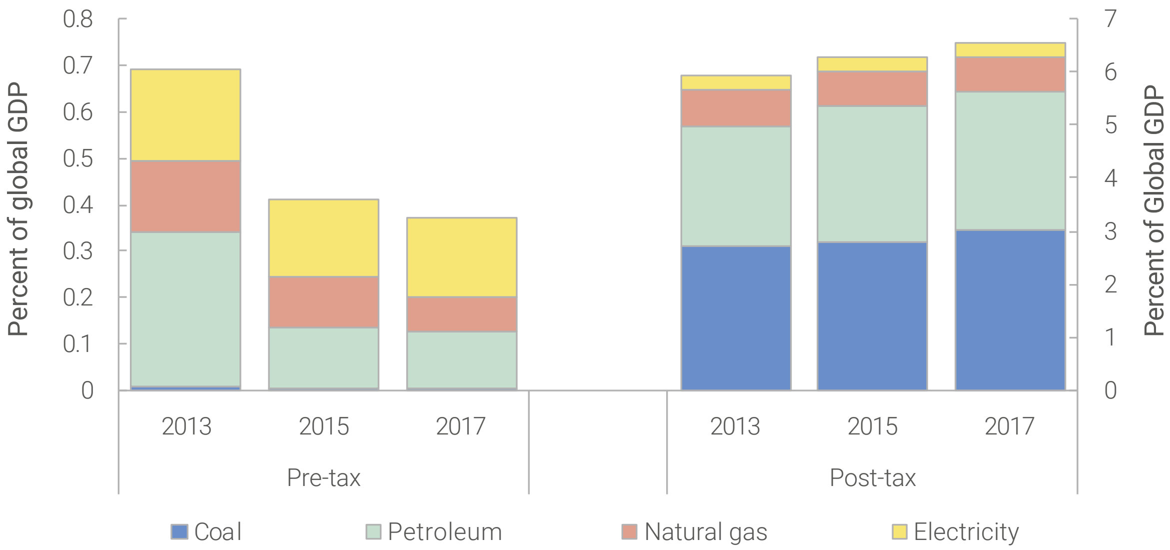


Figure 7: Types of energy subsidies as percentage of global GDP (IMF, 2019)

In 2021, 197 countries agreed to renew efforts to phase out fossil fuel subsidies at COP26 (IMF, 2022). Some countries have already begun to take steps to remove explicit subsidies, such as India, Morocco, Saudi Arabia, and Ukraine (IMF, 2022). In India, coal subsidies have decreased from about USD 2.8 billion in 2014 to USD 1.6 billion in 2021

4 'Stand in January 2022' refers to levels measured in 2022 for the targets set.

(Climate Scorecard, 2023). Removing subsidies can significantly impact consumers and firms due to increased energy costs. The impact on costs for firms can be compared to the impact of a carbon price, and therefore the removal of subsidies on fossil fuels can be a huge incentive to switch to the use of cheaper renewable energy.

The Energy Community Treaty creates a common energy market between the EU and nine Contracting Parties: namely, Albania, Bosnia and Herzegovina, Georgia, Kosovo, North Macedonia, Moldova, Montenegro, Serbia, and Ukraine. Despite the EU's goal to decarbonise its energy sector by 2050, annual subsidies for coal within the Energy Community amount to EUR 2.4 billion. Between 2015 and 2017, total direct subsidies by the Contracting Parties added up to EUR 400 million annually, while hidden subsidies reached an estimated EUR 1.9 billion (Figure 8). Without any subsidies on electricity generated from coal, the price of electricity could increase from 15% in the case of Montenegro and North Macedonia right up to 52% in the case of Serbia. Table 3 shows the percentage increase that end-users, households, and industry could witness from the removal subsidy assuming that domestic power generation was sold to domestic consumers. In Bosnia and Herzegovina, for example, the removal of coal subsidies for electricity production could result in a price increase of 37% for households and 29% for industry (Energy Community Secretariat, 2019).

As the phase-out of fossil fuels progresses, policymakers will need to carefully address the challenge of minimising the impact of this transition on electricity prices and affordability, addressing the concerns related to a just transition.

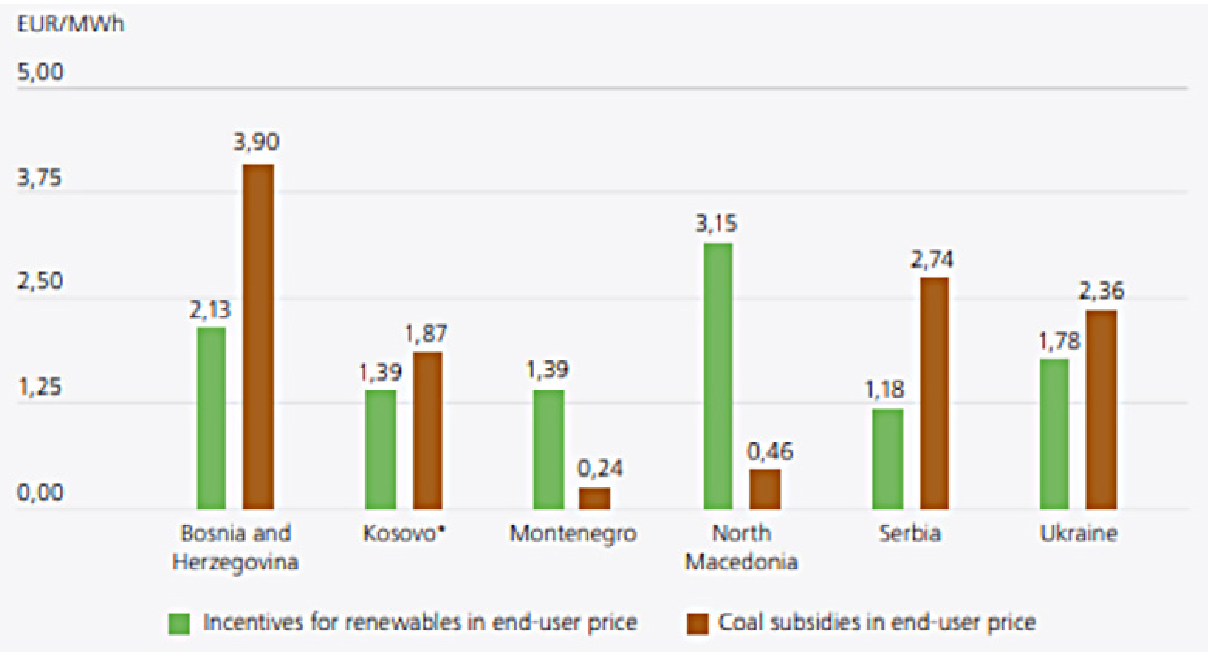


Figure 8: Incentives for renewables compared to subsidies for coal-fired electricity in 2017 as end-user prices (Energy Community Secretariat, 2019)

Table 3: Estimated change in end-user prices without coal subsidies (Energy Community Secretariat, 2019)

in EUR/MWh						
Contracting Party	End users prices for households			End user prices for industry		
	Charged in 2018	Price adjusted for subsidies	Change in %	Charged in 2018	Price adjusted for subsidies	Change in %
Bosnia and Herzegovina	74,40	102,20	37%	65,30	84,30	29%
Kosovo (under United Nations Security Council Resolution 1244/99)	59,10	78,70	33%	73,30	70,00	-5%
Montenegro	84,80	97,50	15%	80,50	90,40	12%
North Macedonia	66,70	80,50	21%	67,50	76,80	14%
Serbia	59,10	89,80	52%	71,90	80,40	12%
Ukraine	34,20	n/a		61,80	n/a	

Case study 2: Public policy risk

Enel Integrated Annual Report 2022

An Italian multinational energy corporation

Policy implications on business
Enel group operates in regulated markets and changes in the operating rules of the various systems, as well as the prescriptions and obligations characterizing them, impact the operations and performance of the Parent.

Mitigation measures
Accordingly, Enel closely monitors legislative and regulatory developments, such as:

- periodic revisions of regulation in the distribution segment;
- the liberalization of electricity markets, with special attention being paid to the acceleration provided for in Italy and expected developments in South America;
- developments in capacity payment mechanisms in the generation segment;
- regulatory measures to shield users from impact of price developments
- In order to manage the risks associated with these developments, Enel has intensified its relationships with local governance and regulatory bodies, adopting a transparent, collaborative and proactive approach in addressing and eliminating sources of instability in the legislative and regulatory framework.

3. Rise in low-carbon technologies and technological risks

Renewable energy

Advancements in renewable technologies have allowed for a rapid expansion in power generation from renewable sources as these technologies become cost competitive. This creates increasing competition for traditional companies in the sector with business models reliant on power generation from fossil fuels. However, these technological advancements can create business opportunities for those willing to diversify their operations and adapt their business models.

Technological innovations are improving storage capacity, such as through advancements in battery technology, which are helping overcome the obstacle of intermittency. Large-scale energy storage systems have improved grid stability and enabled greater integration of renewable energy. According to McKinsey, more than USD 5 billion was invested in Battery Energy Storage Systems (BESS) in 2022, three times the amount invested in 2021. By 2030, it is estimated that between USD 130 and USD 150 billion will be invested in the global BESS market (McKinsey, 2023). According to BNEF, Bloomberg's primary research service, energy storage capacity reached a record high in 2022, with 35 gigawatt hours (GWh) of capacity being added to the grid, an increase of 68% from 2021. Improvements in battery storage are expected to continue, with estimates suggesting storage additions to reach 278GWh annually by 2030 (BNEF, 2023b). The development of smart grid technologies has also improved the integration of renewable energy sources into the grid, enabling better control, demand response, and efficient distribution (Department of Energy U.S, n.d). Advances in materials and manufacturing processes of solar have improved the efficiency of solar power generation significantly, while innovative turbine designs have increased wind energy generation. In both cases, this has helped to reduce costs (Dada & Popoola, 2023). Such advancements in renewable technologies are being driven by a significant rise in investments, with financing for renewables doubling in 2022 compared to 2010 levels (IEA, 2023b). According to IEA's World Energy Investment 2023 report, investment in solar power generation in 2023 was predicted to be seven times higher than that for coal power and gas power generation (see Figure 9 below) (IEA, 2023c).

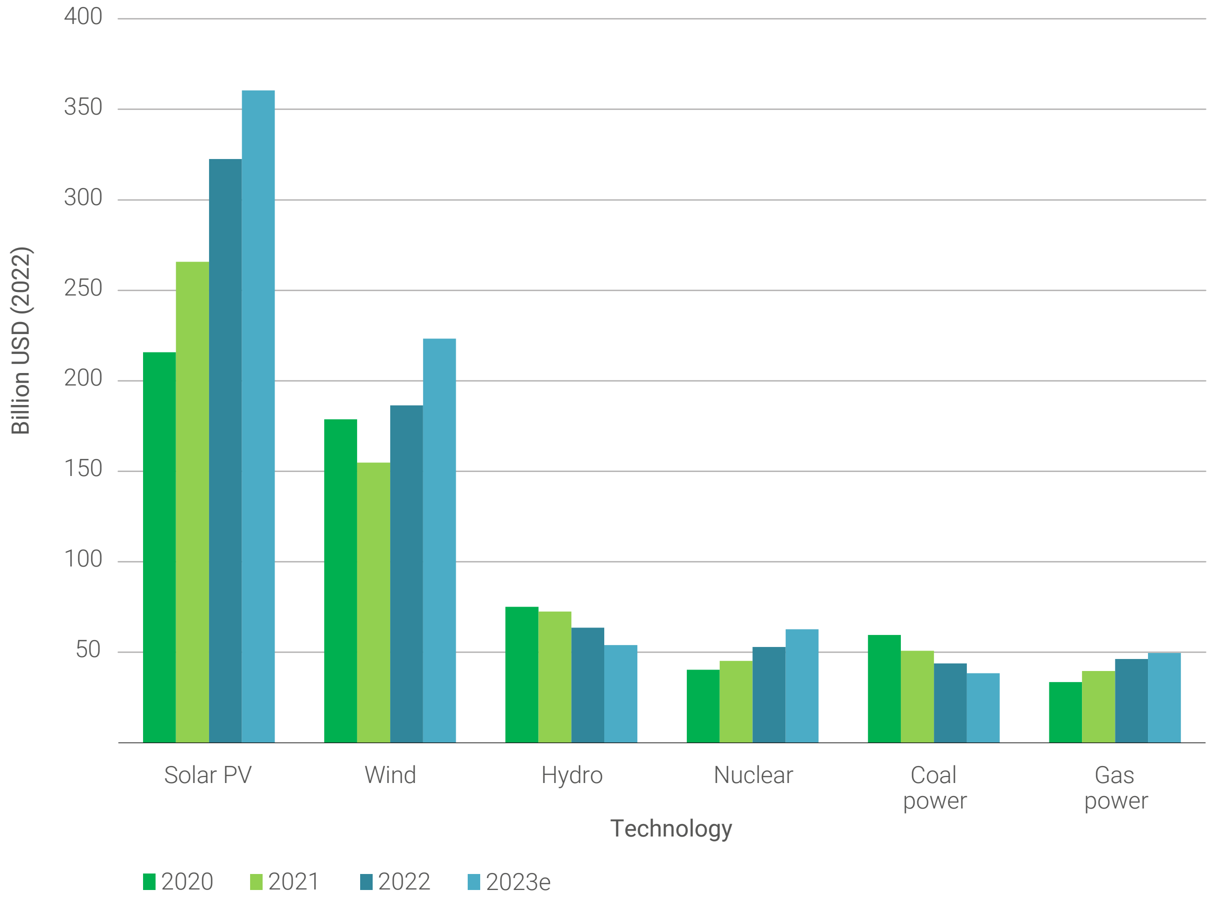
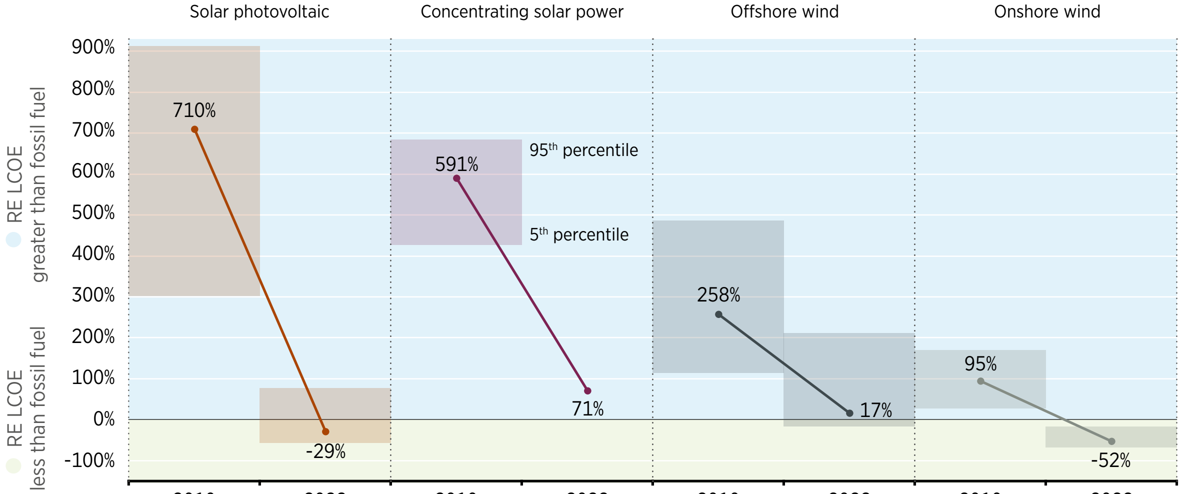


Figure 9: Global annual investment in the power generation by selected technology, 2020–2023e (IEA, 2023c)

Over the last few decades, the costs of renewable technologies such as solar and wind have significantly decreased, becoming increasingly more competitive with fossil fuels (IRENA, 2023). The spike in fossil fuel prices caused by the Russian invasion of Ukraine made power generation from renewable energy even more competitive. The falling costs and increased availability of renewable technologies create increasing competition for power producers in the sector that rely on fossil fuels. The coal power sub-sector is especially vulnerable to decreasing costs of renewables. Indeed, in some cases, it is now cheaper to build renewable energy plants than operating existing coal power plants (Auger et al., 2021).

According to the International Renewable Energy Agency (IRENA), the global weighted average cost of electricity from new utility-scale solar PV, onshore wind, geothermal, bioenergy and concentrating solar power (CSP) all decreased in 2022. The global weighted average levelized cost of energy (LCOE) for new onshore wind projects fell by 5% between 2021 and 2022. In 2010, the LCOE for onshore wind was 95% higher than the lowest fossil fuel-fired cost. In 2022, meanwhile, the LCOE of new onshore wind projects was 52% lower than the cheapest fossil fuel solution. Similarly, solar PV was 710% more expensive than the cheapest fossil fuel solution in 2010; by 2022, this cost differential had reversed, with solar PV becoming 29% less expensive than the cheapest fossil fuel solution (Figure 10)[5] (IRENA, 2023). Due to the falling prices of renewable energy and the increased demand for cleaner energy sources, technology in the renewable energy market is being developed rapidly to accommodate and accelerate this shift. The economic competitiveness of renewable technologies is also being further enabled by rising carbon prices for fossil fuel power producers.[6]



Note: The global weighted average LCOE data by technology and the fossil fuel LCOE data used to derive this chart is presented in detail in Chapter 1; RE = renewable energy.

Figure 10: Change in LCOE of solar and wind in comparison to fossil fuels from 2010 to 2022 (IRENA, 2023)

5 Despite record low costs of renewable energy, price inequality among countries still remains as some countries and investors face greater costs in deploying renewable technologies. Such inequalities can hinder the transition (University of Oxford, 2023).

6 The transition from fossil fuels to renewable energy for power generation will be complex, with headwinds slowing down new renewable projects. Headwinds such as policy uncertainties, volatile prices, interest rates, shortages of raw materials, and the need for grid integration can pause project bids, increase bid prices, restructure long-term agreements, and increase project development timelines (Wood Mackenzie, 2022; Kearney, 2023).

Case Study 3: Expansion of solar power energy in Egypt

As part of its Energy Strategy 2035, Egypt is increasing its reliance on renewable energy. According to IRENA's Renewable Energy Statistics 2022, Egypt's total renewable energy production stood at 15,325 GWh in 2012, surging to 24,064 GWh by 2021. Specifically, solar energy production increased to 4,453 GWh in 2020, up from 504 GWh in 2012 (IRENA, 2022).

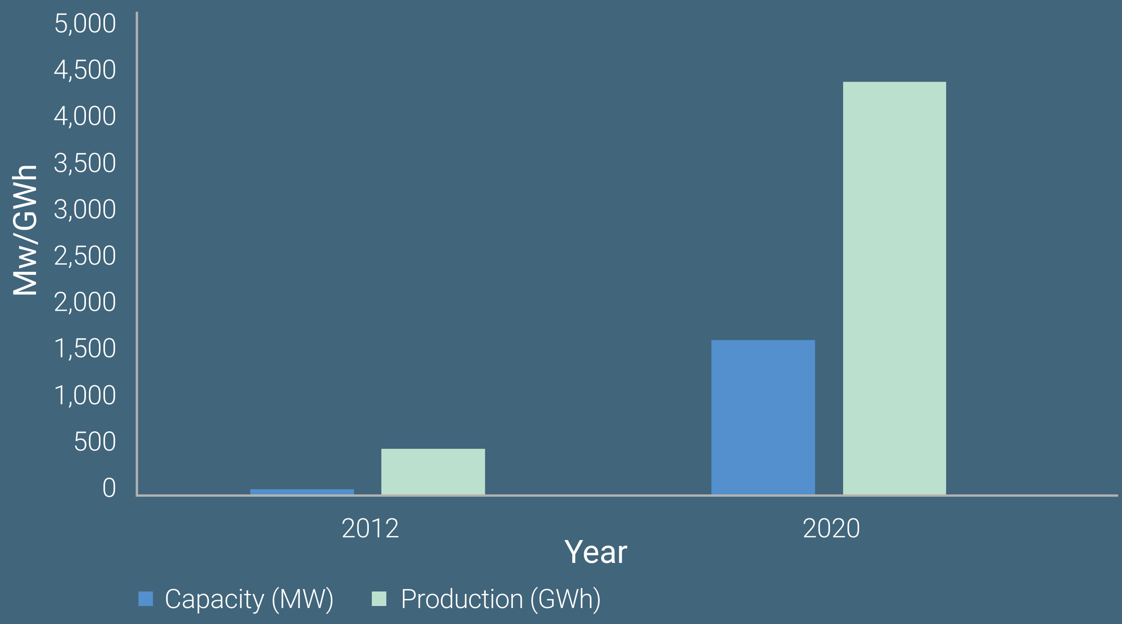


Figure 11: Solar Energy Capacity and Production in Egypt 2012–2020 (IRENA, 2022).

Egypt has set an aim to generate 42% of its energy from solar sources by 2035 and 55% by 2050. By 2035, the country is targeting for wind power to generate 14% and for solar PV to generate 21.3% of its total electricity. These targets are currently being updated to achieve 48% and 55% of electricity generation by renewables by 2025 and 2035, respectively. Renewable energy projects are expected to be delivered by the private sector (International Trade Administration, 2022). For example, the Egyptian Electricity Holding Company disclosed in its 2020/2021 annual report that installed renewable generation capacity increased from 887MWs to 3016MWs between 2016 and 2021 (Egyptian Electricity Holding Company, 2022).

As a result, it has undertaken numerous solar energy projects (Egypt Today, 2021a). Egypt is one of the largest geographical locations receiving solar brightness throughout the year, making the use of solar energy a desirable option (Egypt Today, 2022). From 2019 to 2021, the country established over 126 power stations, including Benban Solar Park, which is the largest solar energy project in the world (Egypt Today, 2021a) with 32 solar projects spanning 36 km^2 (MEI, 2020). Developed by the private sector with about USD 2 billion in investments, the park can produce an additional 2000 megawatts of electricity for the national grid (Egypt Independent, 2021). It is expected that Benban Solar Park will reduce carbon emissions by two million tons annually (MEI, 2020). The solar plant aims to ensure energy diversification and optimal use of renewable energy (Egypt Independent, 2021).

To scale up renewable energy, Egypt is offering cost incentives. In 2021, the Egyptian government decided to lower the price of renewable energy (kilowatt/hour) to attract foreign and local investments. The cost of its solar energy (2 cents kilowatt/hour) and its wind energy (3 cents kilowatt/hour) has consequently become one of the lowest globally (Egypt Today, 2021b). The government has also announced efforts to phase out electricity subsidies by 2025, as well as unveiling plans to remove subsidies for diesel and gasoline. Furthermore, the Benban Solar Park was awarded a feed-in-tariff higher than international standards. In 2021, solar PV in the country emerged as a more cost-effective option for new bulk generation when compared to other sources (Climatescope.org, 2022).

Carbon capture and storage

In a low-carbon economy, to remain operational, fossil fuel power producers will need to rely on Carbon capture and storage (CCS) technology. For example, the IEA's Net Zero Emissions by 2050 scenario shows that unabated coal-fired generation needs to reduce by about 55% by 2030 (compared to 2022) and needs to be completely phased out by 2040 to reach net zero CO_2 emissions by 2050 globally (IEA, 2023d). To get on track with this scenario, coal-fired power plants need to reduce emissions by 10% annually until 2030. To align with this scenario for gas, unabated gas-fired plant emissions need to decrease by 2% annually between now and 2030 (IEA, 2023e). As a result, CCS technology will need to be added to existing power plants to limit warming.

However, the development of CCS technology is still in its early stages and has not been widely deployed. Currently, only around 40 commercial facilities apply carbon capture, utilisation and storage (CCUS) technology across industrial processes, fuel transformation, and power generation (IEA, 2020c). Since January 2022, plans for about 50 new projects have been announced, with operating dates of 2030 or before. However, as of 2023, no new power plants with CCS installed have been developed at a commercial scale. Two major retrofit power projects have taken place in North America—Boundary Dam in Canada and Petra Nova in the United States. However, Petra Nova has since suspended operation, and both plants have performed below the target of a capture rate of 90% (IEEFA, 2023a).

Currently, CCS technology is costly and uncertain. Implementation of CCS will increase expenditures for firms given rising operating and fuel costs, as well as additional expenditure for the transportation and storage of CO_2. The LCOE for thermal power generation with CCS is estimated to be at least 1.5–2 times higher than renewable energy (Figure 12). Therefore, using CCS for power generation could significantly increase costs for firms and cause electricity prices for end-users to rise (IEEFA, 2023a). Along with higher costs, efficiency is also a significant barrier to deploying CCS technology (RFF, 2020). These barriers create substantial challenges for producers reliant on fossil fuels as the power generation sector decarbonises due to the lack of cost competitiveness of operating fossil fuel plants with CCS.

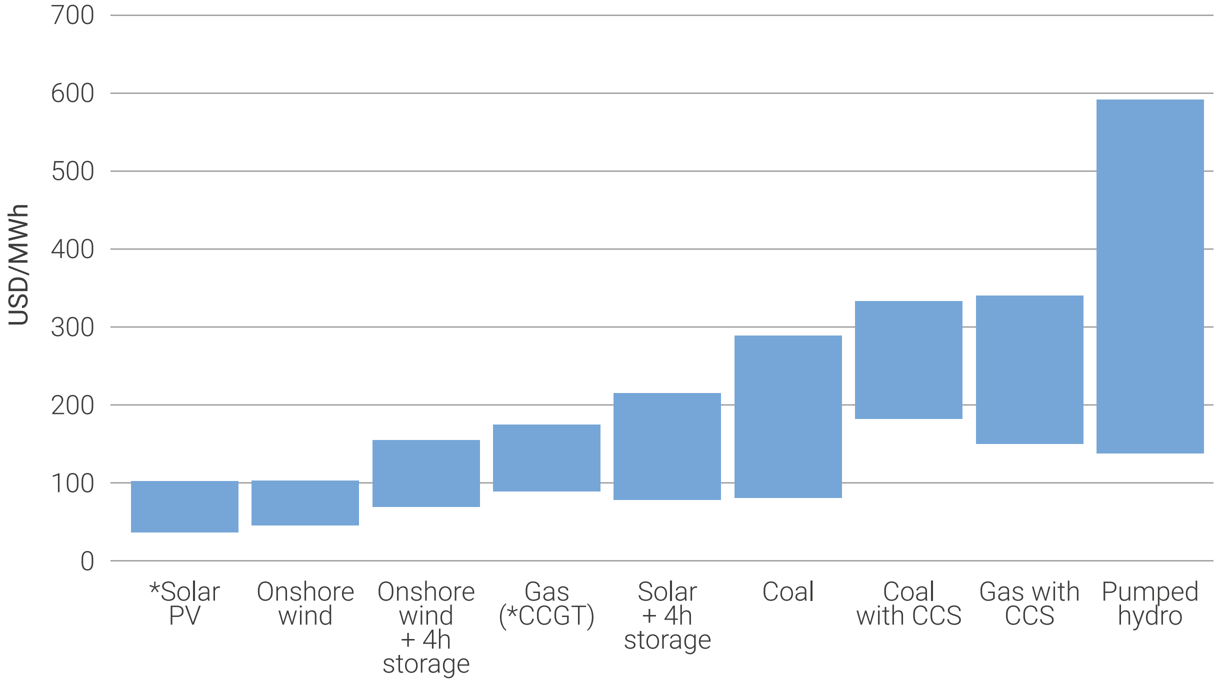


Figure 12: Comparison of power generation with CCS with other alternatives based on their LCOEs (IEEFA, 2023a)

Case Study 4: Risks linked to the rise in low-carbon technologies

EDF Universal Registration Document 2022

French electricity generation company

Risk factors

Group's long-term strategic directions are in line with the transition to a low-carbon economy. The EDF group's raison d'être, adopted in May 2020, centres on the objective of "building a CO_2-neutral energy future". The majority of the Group's investments are directed towards this low-carbon climate strategy. In this seemingly favourable and promising context, there are several significant transition risks. For example, the Group may have to deal with the emergence of new technologies or disruptive solutions that are part of the efforts to meet the transition objectives. Such situations could make it more difficult to carry out these transformations and achieve the desired objectives. These situations could directly or indirectly affect the Group's business volumes, margins, asset value, financial position, reputation and/or prospects.

Control Framework to address transition risks

- Carbon trajectory. In 2018, the Group made a commitment to significantly reduce its carbon dioxide emissions, with a target of 30 million tonnes in 2030 instead of 51 million tonnes in 2017 (a 40% reduction). The EDF group also confirmed this goal in 2020 by joining the "Business Ambition for 1.5 degrees" initiative. The EDF group has made new commitments to contribute to achieve carbon neutrality by 2050, both in direct and indirect emissions (scopes 1, 2 and 3), with milestones set for 2023 and 2030. The SBTi organisation certified this approach in 2020 as going beyond the 2°C set out in the Paris Agreement. Thus, for the first time, the EDF group has set reduction targets for its indirect emissions, covering in particular the emissions associated with the sale of gas to end customers. The EDF group undertook discussions with the SBTi organisation in 2022 in order to obtain 1.5°C labelling for its trajectory.
- Deployment of low-carbon solutions. The Group has been particularly active in the development of renewable energy in France, electric storage and low carbon electric mobility, which will make it possible to develop and promote the Group's low-carbon energy solutions, particularly for the transport sector, which still emits a very high level of carbon dioxide in France and Europe.
- As a final step in the process of contributing to achieving neutrality, the Group favours so-called "negative emission" projects to offset its residual emissions by 2050.
- Control actions for risk No. 1A concerning changes in public policies and the regulatory framework consist of: monitoring the political, legislative and regulatory context; analysing the potential consequences of legislation in preparation; dialoguing with and lobbying the public authorities.

4. Consumer and societal pressure

As consumers' awareness of the contribution of fossil fuels to climate change continues to increase, and as new alternatives continue to enter the market and their costs decrease, fossil fuel-reliant firms in the sector will face challenges from changing consumer preferences. In 2021, World Economic Forum-Ipsos Forum Climate Change and Consumer Behavior survey of 23,055 consumers in 29 countries found that 56% of respondents had changed their purchasing practices to reduce their carbon footprint (World Economic Forum, 2021).

Historically, the market for power generation has been dominated by fossil fuels. As renewables continue to become cheaper and thus more competitive, there will be a huge shift in the global power generation mix. Between 2022 and 2025, renewable and nuclear energy are likely to dominate the growth of global electricity supply, meeting an average of over 90% of additional demand, as seen in Figure 13. Growth in natural gas and coal power generation is expected to remain flat between 2022 and 2025 (IEA, 2023f).

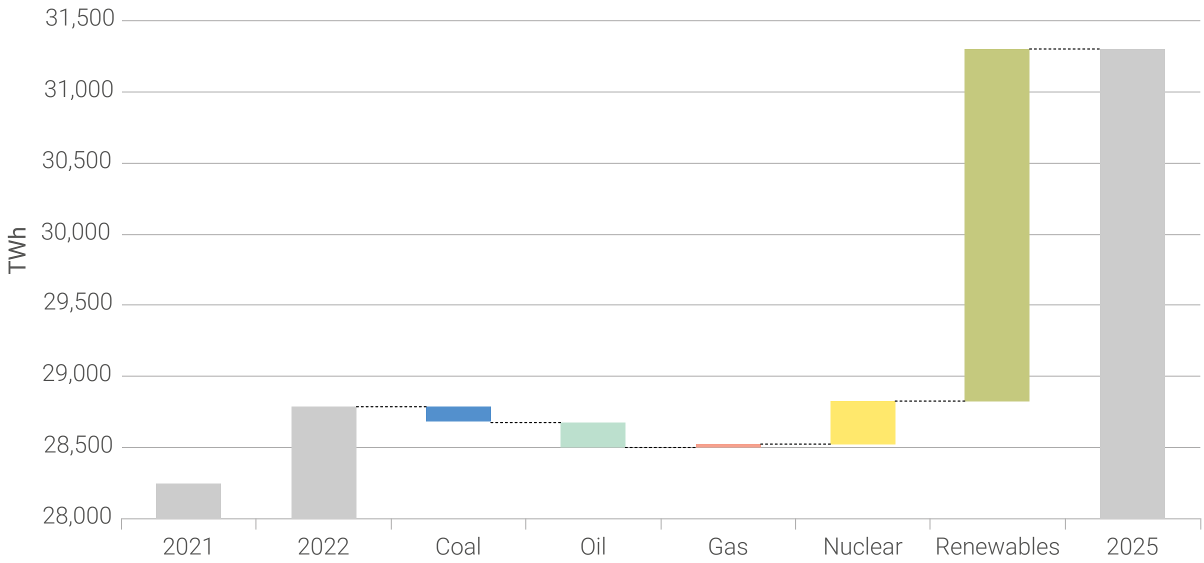


Figure 13: Changes in global electricity generation by source between 2022 and 2025 (IEA, 2023f)

Globally, society has witnessed a clear shift in the support of fossil fuels to renewable energy. For example, a study found that twice as many people in South Korea support renewable energy as those who do not (Kim et al., 2018). Similarly, a recent survey by the Pew Research Center in the United States showed that 67% of Americans would prioritise the development of renewables over new fossil fuels (Pew Research Center, 2023). This supports a previous survey that showed 85% of Americans supporting a requirement for power generation companies to transition to renewable energy (Yale Climate Communications, 2019). As consumer preferences rise for renewable energy over fossil fuels, power generation firms that do not transition from fossil fuels will experience a loss in demand.

Along with the growing awareness of climate change, rapidly decreasing costs for renewable energy (Figure 14) can become a strong driver for a shift in consumer preference from fossil fuel-fired power generation to renewable energy. For example, solar PV now costs 29% less than the cheapest fossil fuel solution on average globally (IRENA, 2023). The impact of energy prices on energy preferences can be illustrated by the impact that Russia's invasion of Ukraine in early 2022 had on energy prices. Notably, wholesale electricity prices in in many European countries, such France and Germany, were three to four times more expensive in the first half of 2022 than in the same period of 2016–2021 (IEA, 2022b). Amidst the energy crisis, with electricity bills increasing on average by 59%, solar power installations by homeowners in the United Kingdom doubled in 2022 compared to the previous year (Department for Business, Energy & Industrial Strategy, 2023; Euronews, 2023).

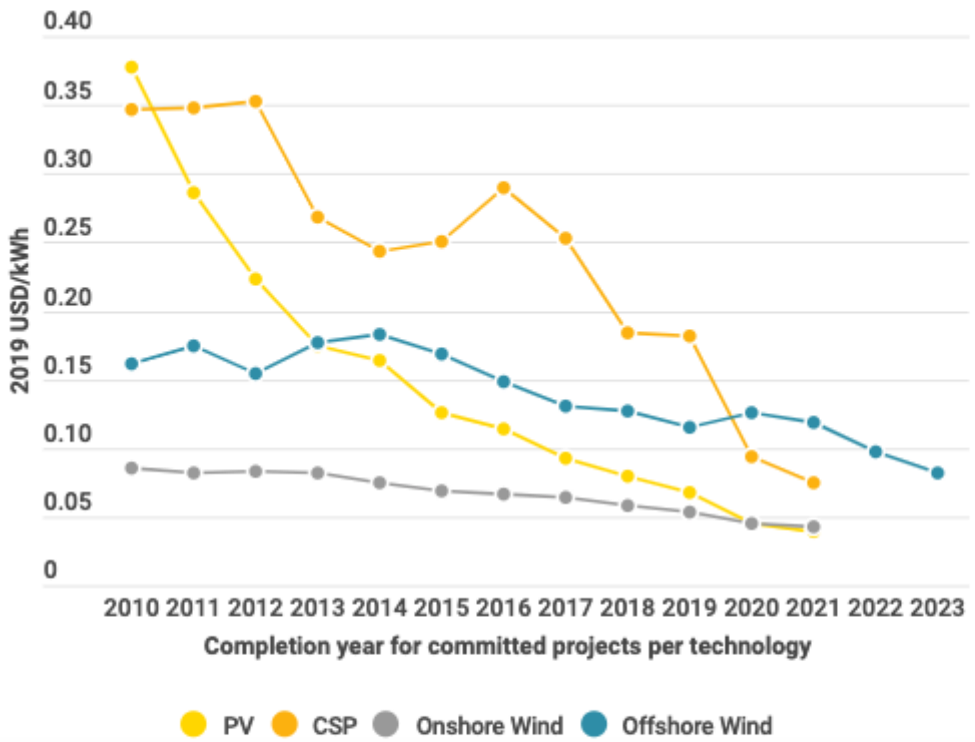


Figure 14: Decreasing power generation costs (2010–2023) (WEF, 2020)

Power generation firms will also be affected by the change in consumer preferences resulting from changes in temperatures, shifts in weather patterns and water availability, and a greater frequency of extreme weather events. Climate change is expected to influence global electricity demand, potentially leading to decreased demand for heating during cold seasons and increased demand for cooling during extreme heat events (Romitti and Wing, 2022; EPA, 2017). The unpredictability of future weather events is predicted to lead to significant performance gaps for power generation companies due to climate variations that affect both electricity demand and the reliability of the power grid during extreme weather. For example, office buildings in the Canadian cities of Quebec City, Toronto, and Vancouver could witness a decrease in annual energy demand by 8.7%, 9.1%, and 9.9% between 2056 and 2075 (Jafarpur and Berardi, 2021). Similarly, Sweden is set to experience an estimated 30% decrease in heating demand by the end of the century, relative to 1991–2010 demand levels. Peak demand for heating and cooling is projected to increase between 50% and 400% during extreme conditions (Perera et al., 2020).

One extreme example of the impact a massive change in electricity demand could have on firms in the sector was seen during the global pandemic. At the height of COVID-19, electricity demand dropped by almost 30% in some major economies (IEA, 2020d; IEA, 2021b). Low demand led to a significant drop in energy prices, which, together, led to financial losses for power generation firms as well as the delay or cancellation of new power generation plants (Congressional Research Services, 2020; IEA, 2021c). Analysis by Hartree Solutions, an energy equipment and services firm, found that between March and August 2020 the UK power sector lost USD 1.3 billion (GBP 1.1 billion) in income (Hartree Solutions, 2020). Similarly, in Bangladesh, power generation decreased by almost 17% in the two years up to May 2020 (Hasan et al., 2022). Between March and December of 2020, meanwhile, the Ministry of Power Energy and Mineral Resources predicted that the country's power generation sector would see revenues fall by USD 0.5 billion (The Business Standard, 2020). The massive changes in electricity demand that result from climate change can create similar uncertainties for power generation firms around the profitability of their current and planned projects.

5. Shifting investor preferences

Investors are growing increasingly climate-conscious and are driving financing away from fossil fuel sources to less carbon-intensive alternatives. Coal-fired plants are especially exposed to climate action by investors. Over 200 global financial institutions have announced divestment policies to restrict investment in coal-fired power projects and/or in coal mining. These financial institutions include asset managers and owners with more than USD 50 billion in assets under management (AUM), as well as banks, insurers and reinsurers, credit agencies, and multilateral development banks with more than USD 10 billion in assets (IEEFA, 2023b). Figure 15 illustrates the rapid rise of disinvestment policies at banks in recent years.

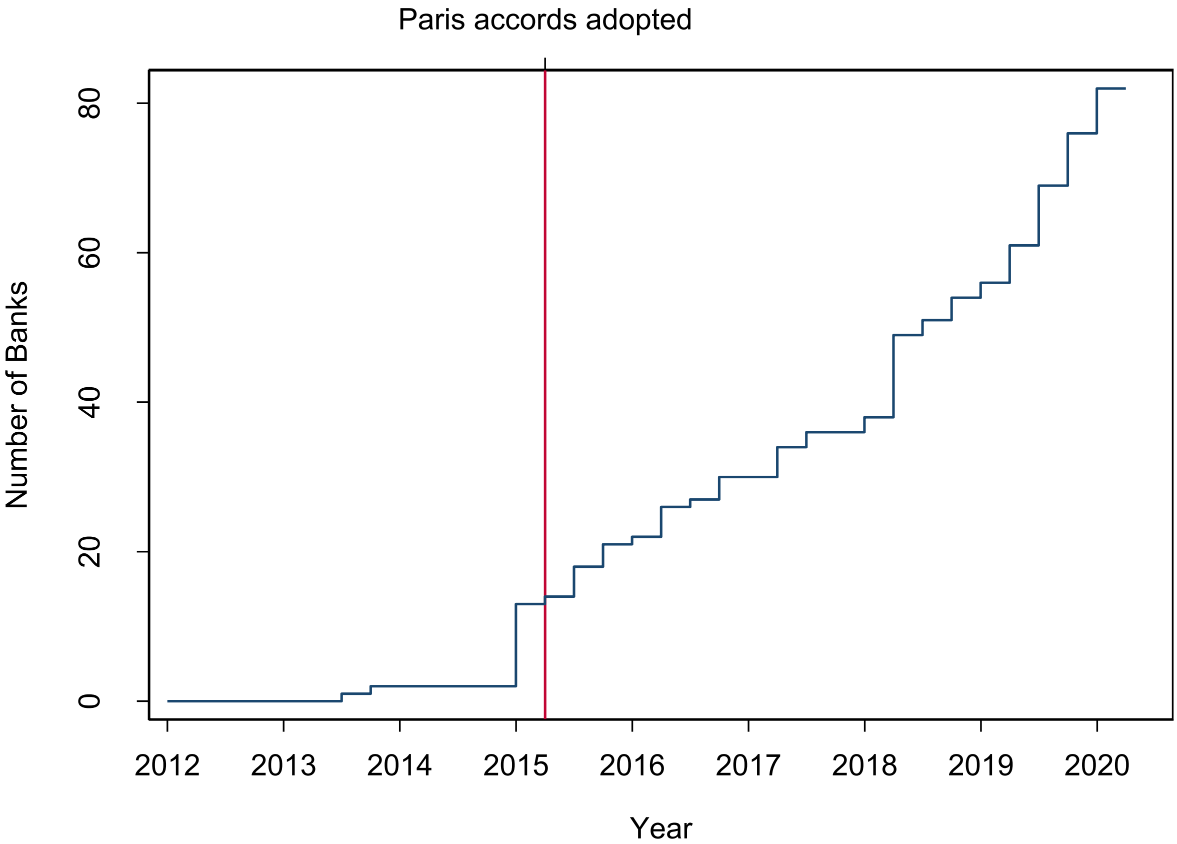


Figure 15: Number of banks with active coal policies (Green and Vallee, 2023)

For example, the EU's biggest Pension fund, ABP of the Netherlands, joined a growing number of investment managers in dumping fossil fuels in 2021. The company, under pressure from activists, customers, and the physical risks of climate change, announced it would divest EUR 15 billion by early 2023, which it has done (Bloomberg, 2023). In 2021, the European Investment Bank stopped its funding for fossil fuel projects, while

Chinese institutions did the same for overseas coal plants (BBC, 2019; The Guardian, 2021). The Bank of the Philippine Islands, the oldest bank in Southeast Asia, has also committed to stop new greenfield investments (on undeveloped land) and has pledged to completely divest from coal by 2030 (BusinessMirror, 2023).

A study has shown that companies focused on coal-fired power generation facing strong disinvestment policies from their lenders have reduced their borrowing by 25%, in comparison to coal companies that do not face the same policies. The reduction in capital could force divested companies to shut down their facilities (Green and Vallee, 2023). Outside of China, for every USD 1 lent to coal projects that were approved and funded in 2022, an additional USD 14 earmarked for other coal projects was cancelled or halted. The coal sub-sector lost an estimated USD 7.7 billion in financing for projects outside of China. The decrease in corporate lending has been due to divestment policies, as well as country commitments and other financial uncertainties. Figure 16 shows the number of coal-power projects cancelled as a result of lost financing between 2011 and 2023 (Carbon Brief, 2023). In 2022, for instance, the Japanese government withdrew financing for two coal-fired power plants in Indonesia and Bangladesh (Mongabay, 2022). Both projects were permanently shelved as a result. This follows Japan's decision the previous year to stop financing coal projects that do not have credible measures in place to reduce emissions.

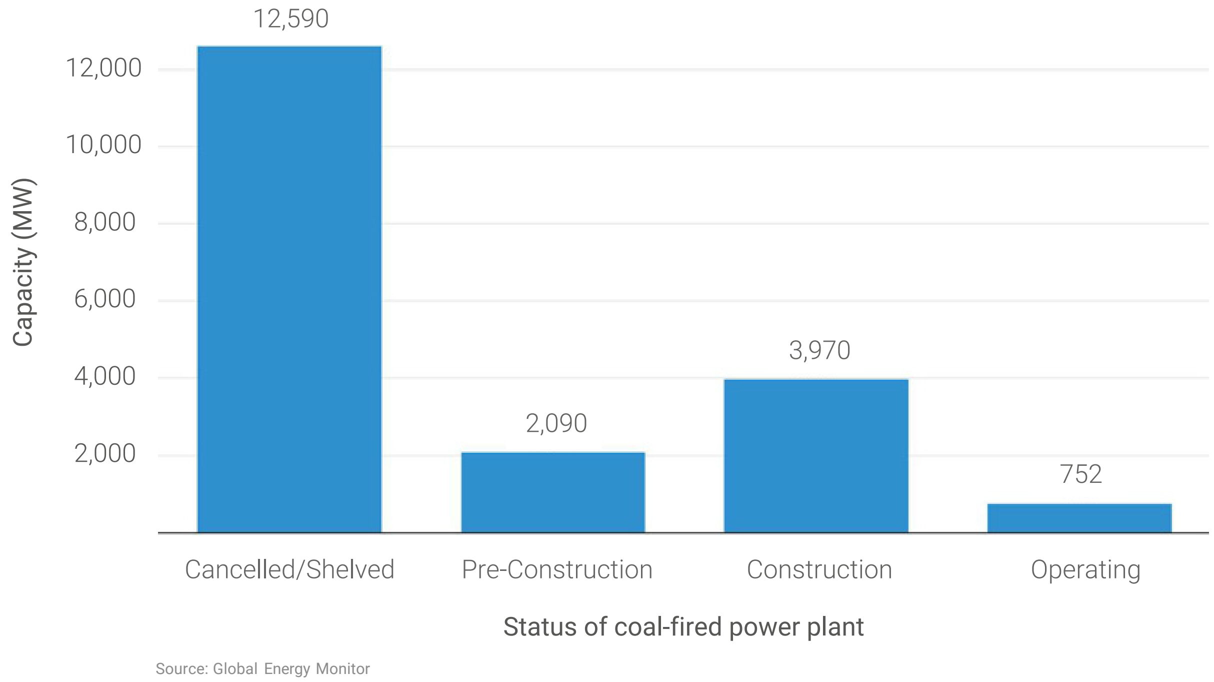
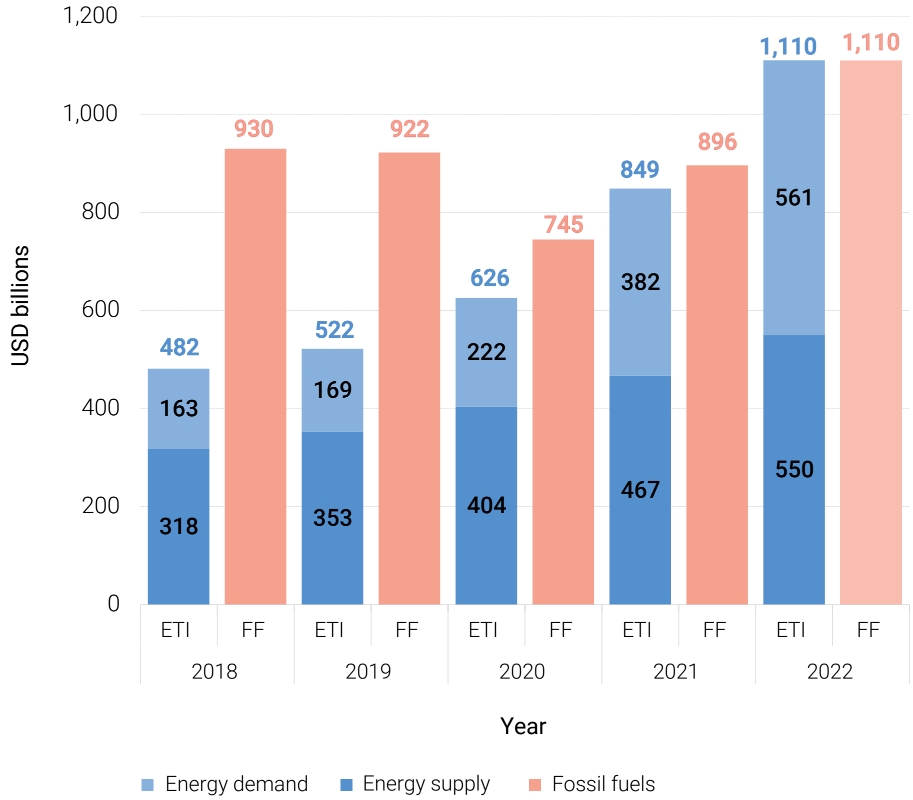


Figure 16: Status of coal-fired power plant projects as a result of lost financing from 2011 to 2023 (Carbon Brief, 2023)

Besides increasing disinvestment in coal-fired power plants, global energy transition investment has reached unprecedented levels. Investments reached USD 1.1 trillion in 2022, bringing them in line with annual investments in fossil fuels for the first time (Bloomberg NEF, 2023c). Investment in renewable power and fuel rose for the fifth consecutive year in 2022, reaching a record USD 495 billion. This achievement is complemented by a 2.4% increase in global electricity generation, partially led by solar

PV production and wind power (IEA, 2023). Moreover, renewable power installations, which account for 74% of the total amount of new power capacity investments, attracted more financing than fossil fuel or nuclear generation plants (Ren21, 2023).



Source: BloombergNEF, IEA. Note: ETI stands for Energy transition investment. FF stands for Fossil fuels. 2018-21 FF values were derived from the IEA World Energy Investment 2022 report. 2022 fossil fuel investments are BNEF estimates, and include upstream, midstream, downstream sectors and unabated fossil power generation.

Figure 17: Global clean energy investments compared to fossil fuel investments from 2018 to 2022 (Bloomberg NEF, 2023c).

6. Market risk and asset stranding

As the urgency to limit warming to 1.5°C grows, the need to phase out unabated coal is growing increasingly crucial with the need to retire newly developed plants, as well as existing ones. This puts owners of coal-fired power plants at high risk of contraction in market value and opens them up to the risk of stranded assets. To meet climate goals, coal-fired power plants will need to be retired 10–30 years earlier than before the end of their useful lives (London School of Economics, 2022). The value of global stranded assets of coal power generation between now and 2050 is estimated at between USD 1.3–2.3 trillion (MIT, 2022).

To limit warming to 1.5°C with a 50% probability, 90% of coal and 60% of oil and gas will need to remain unextracted by 2050. As a result, countries will need to reach peak production soon (Welsby et al., 2021). This has significant implications for fossil fuel power plants. An estimated 107 countries are five years or more past their peak electricity generation from fossil fuels (Ember, 2023b). A study by Edwards *et al.* assessed the changes in global stranded asset risk from coal-fired power plants over time in various regions (Edwards et al., 2022). The analysis considered a scenario in which a 1.5°C policy was in place and all coal-fired plants currently under development continued to be built. The stranded assets that would be created in such a scenario were calculated to be worth a total of USD 1.4 trillion. For a 2°C policy scenario, the figure is closer to USD 1 trillion. If all proposed projects were cancelled, on the other hand, stranded assets would decrease to USD 880 billion under a 1.5°C policy scenario and USD 573 billion under a 2°C policy scenarios. Coal plants currently in the pipeline represent 55% of stranded assets under a 1.5°C climate goal. No new financing for coal could lead to a 50% reduction in the stranding of international investments (Edwards et al., 2022).

Countries with a larger portion of newer coal-fired power plants, such as emerging economies in Asia, are much more likely to face higher stranded risks. China, India, and Southeast Asia are exposed to greater asset standing than the United States and the European Union. However, based on the location of the headquarters of companies, stranded asset risk is higher in China, the United States, Europe, South Korea and Japan (Edwards et al., 2022).

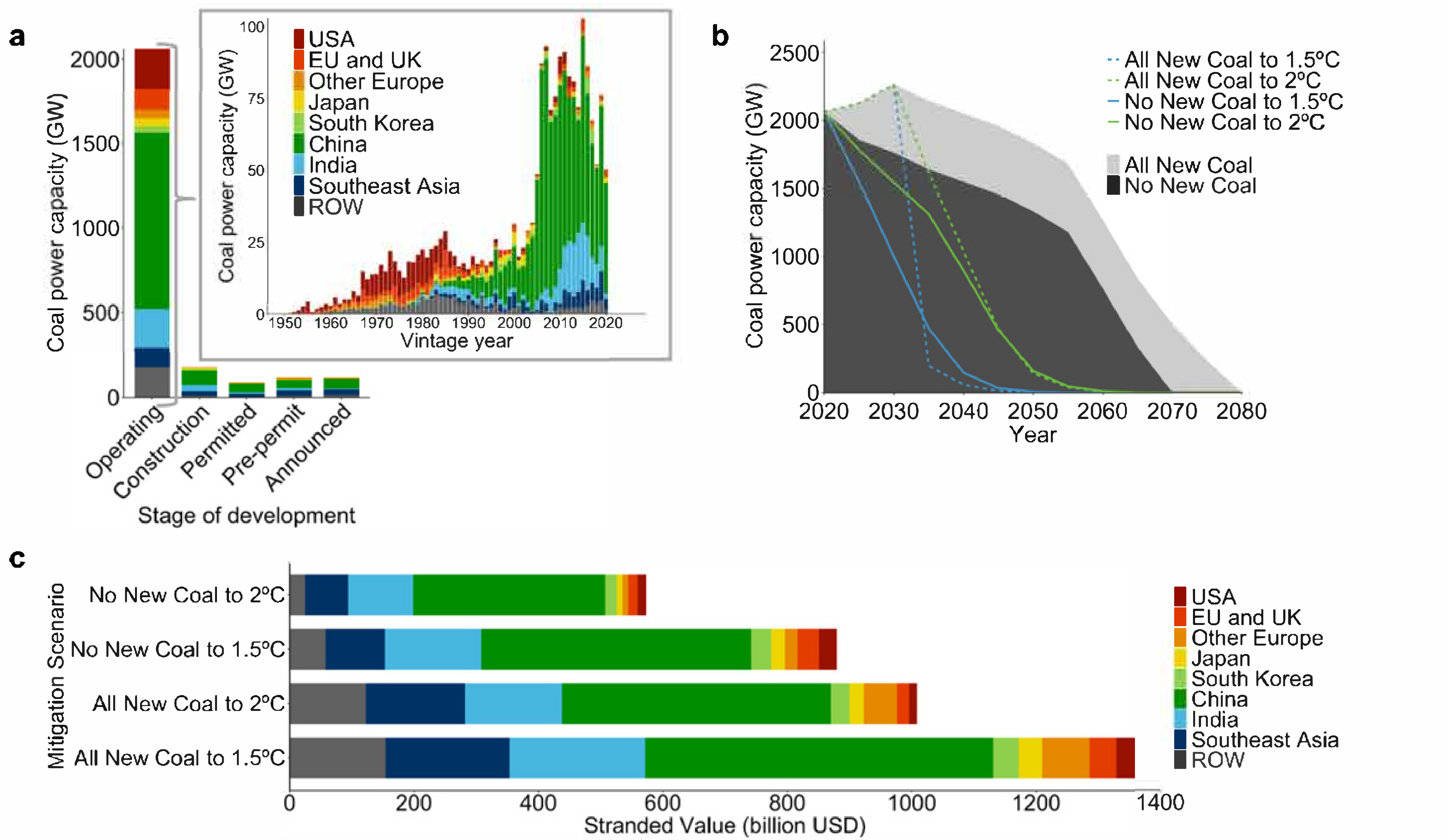


Figure 18: Pathways for global coal capacity and stranded assets: (a) coal capacity by development stage; (b) coal capacity pathways under 1.5°C and 2°C goals (lines) or if plants outlive their historical average lifetimes (shaded regions); and (c) asset stranding under 1.5°C and 2°C scenarios (Edwards et al., 2022)

7. Reputational risk

Power generation companies and governments face increased reputational scrutiny from non-governmental organisations, activists, and communities as they continue to rely on fossil fuels for power generation. For example, in Switzerland, demonstrations against fossil fuel power plants were held across eight cities in 2023. The most intense demonstrations were directed towards an emergency power plant that runs on oil and gas and a planned liquefied natural gas terminal (Swiss info, 2023). In Edinburgh, meanwhile, it was reported that a group of climate campaigners planned to march through Edinburgh in early September 2023 to protest against an oil field and against plans for a gas-fired power plant (Aberdeen Live, 2023). In the same year, protests were held close to the last active coal power plant in New England, in the United States. A large number of the protestors, who were advocating for the plant to be turned into a renewable energy plant, were arrested (WBUR, 2023). Similarly, in 2023, students chained themselves to the University of Washington's campus power plant, demanding that the university to shift from fossil fuel use to renewables (Seattle Times, 2023). Firms in the sector are also being held accountable for further exacerbating extreme climate events. In Mirditë, Albania, for instance, residents have protested new hydropower plants due to the potential for flooding or loss of power during droughts (Euractiv, 2023). Hydropower projects in Brazil have also led to flooding and displacement of families during wet years, leading to criticism (Mongabay, 2023).

Firms in the sector are also vulnerable to reputational damage caused by insufficient preparedness for extreme weather events. For example, protests broke out in 2022 in Puerto Rico after LUMA Energy, the island's main power grid operator, failed to ensure consistent access to electricity. The fact that LUMA Energy had a 15-year contract with the government increased the protestors' frustration (Reuters, 2022). In the same year, a power outage caused by Hurricane Ian in Cuba led to protests in the island nation, with hundreds of people demanding the restoration of electricity in the capital city, Havana (NPR, 2022). In 2021, meanwhile, citizens took to the streets across different cities in Iran to express their anger over electricity blackouts, which the government blamed were as a result of severe droughts in times of high demand (BBC, 2021).

8. Emerging legal risks

As of December 2022, there were more than 2,180 climate-related lawsuits in place in over 68 jurisdictions (UNEP, 2023). The power generation sector faces increasing climate-related legal risks as environmental activists, governments, and citizens grow more predisposed to pursue legal action in order to hold firms accountable for climate change. The cost of fines, climate-related damage, and legal fees arising from such litigation can be high for firms. In extreme cases, it can even lead to bankruptcy. Additional losses from reduced demand associated with reputational damage can also occur (EPA, n.d.).

In 2018, for example, families in Kobe, Japan, sought an injunction to prevent the construction and operation of a nearby coal-fired plant (Climatecasechart, 2023c). The plaintiffs claimed a violation of personal rights on the grounds that the project's construction would make climate change worse and consequently impinge on these rights (Columbia Law School, 2023). The court initially rejected these claims and also a preliminary request or injunction, but the families have since appealed the decision (Climatecasechart, 2023c). Similarly, ClientEarth, a UK-based advocacy organisation, bought shares in the Polish power company, Enea, and then sued the company over a planned coal power plant outside Warsaw. ClientEarth argued that the EUR 1.2bn coal power plant would become a stranded asset due to new climate-related regulations and market trends, including carbon pricing, the phasing out of fossil fuel subsidies, and increased competition from renewable energy. A final judgement in favour of ClientEarth was made in 2020 (The Economist, 2022; Climate Case Chart, 2023b). In the same year, a District Court in Poland ordered the owners of the Belchatow plant, Europe's biggest coal-fired power plant, to negotiate with ClientEarth in order to accelerate the closure of the plant (ClientEarth, 2020).

As part of an ongoing case, Saúl Luciano Lliuya, a Peruvian farmer, sued RWE, a German utilities company, in the District Court of Essen, Germany, for its contribution to climate change (Climate Case Chart, 2023a). The plaintiff claimed that his home is at risk from climate-induced flooding from a rapidly growing glacial lake (Germanwatch, 2022). He is arguing that RWE should pay 0.47% of the EUR 3.5 million adaptation costs to increased flooding as the firm has contributed to 0.47% of global emissions (The Guardian, 2017). A ruling is expected to take place later this year.

In South Africa, meanwhile, the Centre for Environmental Rights launched a high-profile "Cancel Coal" case in 2021 with the goal of halting government plans to expand the capacity of coal-fired power generation by 1500 MW (Earthjustice, 2021). The lawsuit argues that new coal plants are incompatible with South Africa's climate goals. Not only do they pose health and environmental threats, it is argued, they also violate the constitutional rights of children and future generations. The case is supported by young climate activists and community members affected by coal. In 2023, the applicants filed a supplementary founding affidavit emphasising that new coal-fired power is not the cheapest fuel option and that it poses health and economic risks to the population of South Africa (Ground work Environmental Justice Action, 2023). The applicants are now awaiting the government's response.

Along with firms' contribution to GHG emissions, insufficient preparation for extreme events is also leading to significant legal damage, especially to the equipment of power firms contributing to wildfires. PacifiCorp, an American power company, provides a notable illustration. In 2023, the firm was found liable for billions of dollars in damages because the electrical equipment that it kept overground was judged to have contributed to a series of major wildfires in Oregon in 2020. PacifiCorp was also found to have refused to cut power to 600,000 customers despite warnings about fires from officials during a windstorm (AP News, 2023). Beyond the outcome of litigation, the fires killed nine people and destroyed over 5,000 homes and other buildings, causing enormous reputational damage for the company. Similarly, Pacific Gas and Electric Company (PG&E), the largest utility in California, faced several lawsuits for the contribution of equipment to the deadliest wildfires in the state's history. The fires led the firm to temporarily declare bankruptcy after having to compensate victims USD 13.5 billion (ABC News, 2023). PG&E is now subject to another class action lawsuit over the health costs of another fire that its equipment started in 2022 (CBS Sacramento, 2023).

9. Transition risk guidance

This section offers guidance on how financial institutions can address transition risks within the sector and support their clients in the process.

Key transition risk questions for financial institutions to consider

1. Gathering information

- Are there any new governmental standards (on energy efficiency, on fossil fuel use, on pollution/waste) that impact assets within our portfolio's footprint?
- How rapidly is the low-carbon transition progressing across our portfolio footprint? What do energy costs, demand, and efficiency look like across our portfolio footprint?
- What have our clients disclosed in their financial, sustainability, and climate reports regarding their transition risks?
- Are any of our clients facing legal action related to industrial activities, pollution, or other environmental issues?
- How many of our clients have transition plans? Do they consider plans for phasing down or restructuring? Do they incorporate just transition considerations into these plans?
- Do we have emissions data for our clients?

2. Assessing the risks

- Have we looked at transition scenarios to see how those risks will evolve over time across the portfolio? Have we considered short-term, medium-term, and long-term risks?
- What does our exposure to higher-risk clients look like? What are the terms of our financial relationship (e.g. debt/equity, tenor)?
- How does the emissions intensity of our clients compare to industry and regional averages?
- What is the cost of production for our clients? How does that compare to industry and regional averages?
- How much are clients investing in low-carbon operations and research and development?
- Which power generation types will be the most and least impacted in the low-carbon transition?

- How much are clients investing in low-carbon power generation? How much of their revenue is derived from low-carbon sources?
- Have we considered the potential environmental and social risks that might emerge from shifts in the value chain or changes in demand resulting from transition risks?

3. Engaging with clients and updating strategy

- Do our senior leaders understand the transition risks of our clients?
- How are we helping our clients to transition to a low-carbon future? How are we supporting their efforts to advance a just transition?
- How will the transition risks identified and assessed influence our strategy in the power generation sector?
- What specific updates to risk management practices or business activities will be needed to appropriately consider these transition risks in our operations?

Recommendations for risk management

1. Determine potential stranded assets

The power generation sector, at present, is highly dependent on reserves of coal, oil, and gas. The majority of these reserves need to remain unused so as to limit warming to 1.5°C. Fossil fuel power plants are therefore at risk of being discontinued before the end of their lifetime because of government regulation on fossil fuel use, an increase in competitiveness from renewable sources, and a growth in litigation. These plants thus face the very real possibility of becoming stranded assets. As such, financial institutions with exposure to power generation clients reliant on fossil fuels must carefully assess the major assets of these clients in order to identify which assets are most likely to become stranded. Financial institutions should explore the proportion of assets likely to be stranded under different transition scenarios. They should then consider risk drivers such as costs, the emissions intensity of energy generated, and the environmental impact so as to identify assets and clients that are particularly vulnerable.

2. Evaluate transition progress

Firms in the power generation sector using fossil fuel sources will face significant challenges in the coming decades unless their current business models are updated. Firms looking ahead and recognising the potential risks to their business are developing (or have developed) transition plans. Many firms' transition will require significant investment to diversify their energy sources for power generation, shifting from fossil fuel-based production to low-carbon energy sources. However, firms that are slow to act may be able to stay competitive in the sector due to new government policies and technological advancements. Financial institutions should carefully assess whether their clients have developed, or are developing, transition plans. Where this is the case, they should compare these plans to others in the sector. A number of frameworks are publicly available for financial institutions to use in their assessment. Examples include the Assessing Carbon Transitions framework of CDP, as well as the guidance issued by the TCFD on effective transition plans. By evaluating a client's transition plan, financial institutions will be evaluating the future prospects of both the client in question and the sector overall. As a result, a financial institution's industry analysts should play an active role in working with their climate risk colleagues to assess the viability of client transition plans.

Adaptive and mitigating actions of clients

1. Diversification and transition

Firms in the power generation sector that produce energy from fossil fuel sources are highly carbon-intensive. However, some firms recognise the importance of transitioning to less carbon-intensive business practices. To do so, firms need to diversify their energy sources and expand their business portfolios, focusing on renewable power generation, especially from wind and solar energy sources. The diversification in business operations will require a large amount of investments towards new capital assets and research and development to reduce the firm's emissions intensity. To support the transition, firms should develop a transition plan to outline the shift to power generation from low-carbon energy sources and detail the various changes needed across the business to transition.

2. Environmental and social stewardship

Strong environmental and social practices are essential across all economic sectors. However, given the historical (and ongoing) environmental and social issues associated with the power generation sector, from fossil fuel power plants causing toxic air and water pollution to hydropower plants causing habitat destruction and worsening water quality, environmental and social stewardship needs to be a top priority for power generation firms. Firms in the sector should promote stricter emissions control and consider practices with mutual benefits for the surrounding communities and the environment. Environmental and social impacts should be considered early prior to constructing a new plant. Firms should support clients in the process of closing plants to ensure a just transition to protect jobs and incomes of those affected. Firms should also consider involving local communities in the planning face to identify and address any potential social and environmental issues. Power generation companies should work to ensure accessibility to power in all communities by investing in infrastructure development, focusing on extending power grids to underserved areas, and promoting renewable energy solutions. Simultaneously, addressing affordability involves optimizing operational efficiency, embracing cost-effective technologies, and collaborating with governments and communities to implement inclusive pricing models. The following box offers examples of social factors that financial institutions and their clients should take into account during the transition to clean energy.

Examples of sector-specific social considerations (UNEP FI, 2023)

Employment impacts: since investments in renewable energy generally generate more jobs than investments in fossil fuels, the low-carbon transition has the potential to generate green jobs. Workers in the sector value chains can also be vulnerable to abuses including forced labour.

Skills development is a crucial consideration in the sector since fast deployment of renewable energy has led to skill shortages in technical occupations, such as solar installers and electrical engineers. Gender equitable skills development is required to restore gender balance in the industry.

Gendered impacts: women and men tend not to have equal access to skills development and green jobs in the sector; gender gaps persist in employment, senior management, and women entrepreneurship.

Land and Indigenous peoples' rights: land is a crucial resource for the energy transition. The amount of land required to scale up wind and solar production is significant. Pressure on land and resources can have potential side-effects on the livelihoods and rights of local communities and Indigenous peoples.

Social dialogue and stakeholder engagement: consultations with the affected stakeholders and communities are required in the framework of renewable project development to address the potential impacts on rights and livelihoods and improve economic linkages with local economies.

Human rights risks and protection of rights defenders: Human rights abuses linked to the construction of renewable energy projects, especially large hydroelectric dams, are well documented. Additional attention needs to be given for human and environmental defenders, grievance mechanisms and access to remedy should be put in place, as well as ensuring that human rights are integrated in in security contracts consistent with the Voluntary Principles on Security and Human Rights.

Accessibility and affordability of clean energy technologies for low-income groups are important as 770 million people still live without access to electricity worldwide. Renewable energy sources can be an opportunity to enhance accessibility and affordability of energy.

Aligning to net zero

Financial institutions looking to manage their transition risks in the power generation sector should engage directly with clients and support client transitions. However, while necessary, this client-level approach must complement a more strategic approach to reducing the firm's financed emissions. Over the past few years, hundreds of major financial institutions have committed to net zero by 2050 across their portfolios. Most of these institutions have joined one of the industry-specific decarbonisation alliances (e.g., Net-Zero Banking Alliance, Net-Zero Asset Owner Alliance) to support them in fulfilling their climate goals. Beyond the financial sector, net-zero alignment has also gone mainstream in government policies worldwide, with nearly 90% of global emissions now covered by a net-zero commitment. Amid growing pressures on high-carbon sectors and the decarbonisation ambitions of financial and government actors, financial institutions can consider a credible and actionable net-zero commitment a way to mitigate both the systemic and idiosyncratic risks of the transition. The process of operationalising a net-zero commitment begins by assessing baseline financed emissions.

Then, institutions set targets for their portfolios and specific sectors, such as the power generation sector using science-based scenarios. After the targets are set, financial institutions develop holistic strategies to reduce their financed emissions. These processes can be explained to stakeholders in a transparent transition plan that demonstrates not only the net-zero commitment but how the firm is mitigating its transition risks.

Additional guidance

- The Equator Principle's guidance note on Climate Change Risk Assessment provides detailed information on transition risk assessment.
- The Transition Plan Taskforce's draft Power Generation Sector guidance includes detailed guidance on transition planning for the sector.
- The European Central Bank has published good practices for climate-related and environmental risk management for financial institutions.
- UNEP FI and the International Labour Organization's report on Just transition Finance includes guidance for banks and insurers on adopting a just transition lens in their banking and underwriting activities.
- UNEP FI and the Cambridge Institute for Sustainability Leadership's report on Leadership Strategies for Client Engagement: Advancing climate-related assessments provides guidance on advancing climate-related assessments and assessing client transitions for effective use in client engagement.

SECTION B:
Physical risks

The power generation sector is vulnerable to a range of physical hazards. The sector is exposed to multiple chronic physical risks, including rising temperatures, sea-level rise, and droughts. In addition, it faces acute physical risks such as more frequent and severe storms and wildfires. Environmental risk assessment specialist, S&P Trucost, for example, analysed the susceptibility of 11 different sectors to physical hazards, such as wildfires and water stress. Of the sectors surveyed, the 2021 study identified the utilities sector (which includes power generation) as the most exposed (S&P Global, 2021). One main reason is the vulnerability of physical operations of companies in the sector to physical risks (Figure 19). S&P Trucost highlighted water stress as a particularly high-risk issue for these companies (S&P Global, 2021).

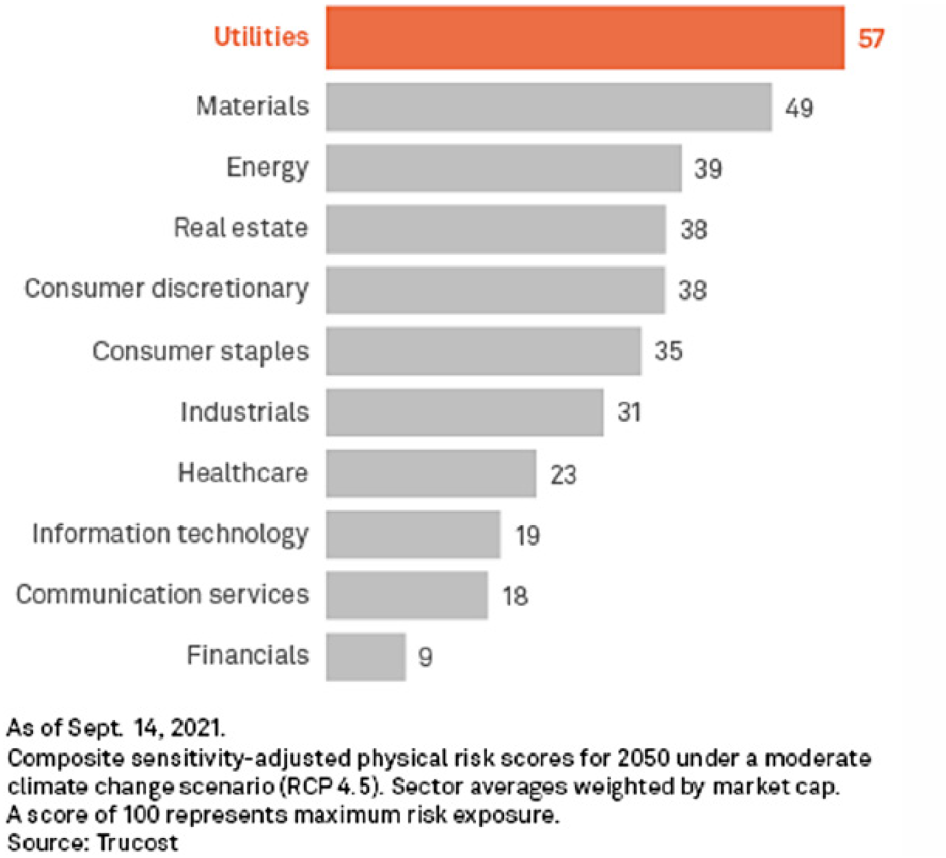


Figure 19: Exposure of various sectors to physical risks (S&P Global, 2021)

1. Rising temperatures and heat stress

Even though power plants are designed to operate in various climate conditions, an increase in global temperatures can create many challenges for firms in the sector. For example, rising global temperatures can significantly impact the power generation sector by reducing operational capacity while increasing the demand for energy. A global temperature rise of 2°C could result in a decrease of 4.5% in power plant capacity (Carbon Brief, 2021).

It has been estimated that the electricity generation capacity of power plants is maximised at a temperature of 27°C (Coffel et al., 2021). On hotter days, air and water needed to cool power plants can become too warm, which can decrease the capacity of power plants by up to 10%. For example, thermal power plants rely on water to cool steam in generators, which convert water vapor back to a liquid form. Typically, thermal power plants only store 30 to 50% of the energy in gas, coal, or other fuels to generate electricity. In contrast, the remainder of the energy (50–70%) is dissipated as heat. Such plants are therefore typically located along rivers and lakes as a means of cooling down operations. As a result, higher temperatures could decrease the efficiency of this cooling process, thereby impacting the efficiency of a plant's power generation operations as a whole (Carbon Brief, 2021). For each additional degree Celsius of global temperature rise, it is estimated that 40–60 new thermal power plants would be required to counterbalance the resulting power loss (Coffel et al., 2021).

Consider the example of French and German nuclear power plants that were severely impacted by a heatwave in 2019. As scorching temperatures raged across Europe, nuclear power plants in both countries reported substantial losses in electricity output due to high water temperatures.[7] EDF, a major power provider in France, had to follow French regulations mandating power generation to be cut when water temperatures rise above 28°C due to safety concerns (RFI, 2019). In the same year, Preussen Elektra, a German nuclear unit of the utility firm E.ON, blamed high temperatures in the Weser river as the reason for its Grohnde reactor to go offline (Reuters, 2019). As a result, two nuclear plants in France and one in Germany went offline due to high temperatures in surrounding waters (RFI, 2019). It was reported that French electricity output decreased by around 8% (5.2 gigawatts)[7] (Reuters, 2019). Similar impacts were observed during a heatwave in 2022. German power plant productivity decreased during the heatwave as the cooling effects were largely inefficient. Waterways such as German rivers used to transport coal also dried up, threatening coal deliveries to power plants (Bloomberg,

7 Decrease in power generation was also attributed to drought and low water levels. More information can be found in the sub-section, 'Droughts and Water Stress'.

2022). Half of France's nuclear power plants went offline due to maintenance. The heatwave added further pressure on energy prices that were already rising due to a decreased supply in gas from Russia. This contributed to energy prices in Germany and France reaching an all-time high, with electricity in France costing six times more than the year before (Figure 20). This could be attributed to supply and demand dislocation as the heatwave caused demand for electricity to rise but disrupted supply from power plants (Times, 2022). As global temperatures rise, events such as these that lead to disruptions in power generation are expected to become more frequent.

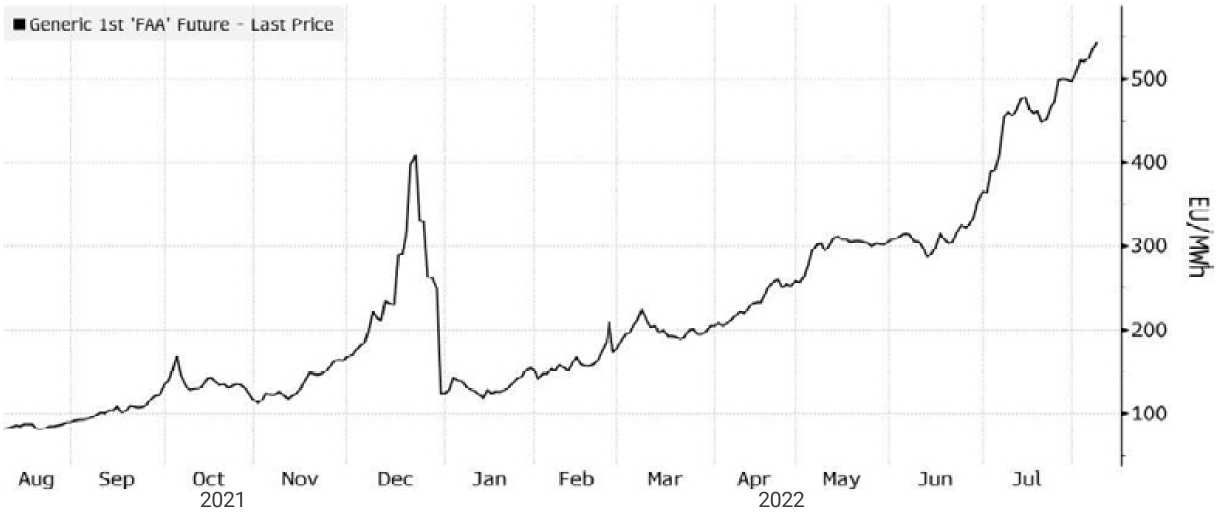


Figure 20: Electricity price hike in France after heatwave (Bloomberg, 2022)

Heatwaves are also associated with a significant decrease in the usual and expected wind levels of an area (referred to as a "wind droughts"), which can be detrimental for wind power (OECD, 2021). In 2021, many European countries witnessed wind speeds decreasing by 15% below the yearly average. In the UK, wind farms only produced 2% of the United Kingdom's total power. In comparison, in 2020, wind farms produced 18% of the total power. The country had to restart two coal plants to fill in the gap (Yale University, 2022). In order to reach net zero by 2050, the total amount of power produced from wind power will need to rise substantially. For example, to be in line with the IEA's Net Zero 2050 scenario, electricity generation will need to increase by 17% annually during this decade (IEA, 2023h). However, the potential impact of more frequent heatwaves on wind speed could threaten the scale-up. Wind droughts could also lead to price volatility. For example, low winds in 2021, coupled with the Russian invasion of Ukraine, led to gas prices rising by 450% in Europe (Yale University, 2022).

The sector will also be impacted by the changing energy needs of consumers due to higher temperatures. Demand for electricity, especially air conditioning and other cooling services, is expected to increase as the global temperature rises. A temperature increase of 3.5°C to 5°C, for instance, could increase the need for electricity by 10–20% by 2050. Meeting such an increase will require billions of dollars of investment to increase power generation capacity (EPA, n.d.). However, rising temperatures would also result in warmer winters, which can decrease the overall demand for energy for heating. In the United States, the Environment Protection Agency estimates that for every 1°C rise in temperature, 5–20% more energy would be used for cooling and only 3–15% less energy would be needed for heating (Penn State, n.d.). Under a high emissions scenario, it is estimated that the number of extreme heat days (i.e. above 35°C) experienced in the United States by 2040 will increase from 14 days to 25–40 days a year. Such an increase in the number of extreme heat days could result in demand for residential and commercial electricity increasing by 3–9% from historical levels. Expenditure on residential and commercial electricity will consequently rise by an estimated 6–18%, with a one-in-20 risk that costs will increase by 23% (Rhodium Group, 2023). Similarly, a study by Gurriaran *et al.* assessed the change in energy demand in Qatar as a result of global warming (Gurriaran et al., 2023). It determined that electricity demand would increase by 4.2%, on average, per degree of warming, and electricity demand could increase by 5–35% by 2100.

As such, the power generation sector will be confronted with the dual challenge of surging energy demand as temperatures rise, while simultaneously grappling with reduced operational capacity in power plants due to higher temperatures. Power generation companies will therefore need to make expensive investments in new energy generation and distribution to account for higher peak demand.

2. Droughts and water stress

As climate change causes precipitation patterns to change, the power generation sector is becoming highly exposed to the impacts of drought and water stress. Changes in water availability can decrease river flows and, therefore, the amount of power produced through hydroelectric sources. Reduced water availability can also disrupt oil and gas drilling, which are key energy sources, as well as operations at thermoelectric plants that need water for cooling (NCA, 2018). Furthermore, droughts and water stress can negatively affect power generation through biofuels. Biofuel feedstocks can be significantly reduced through reduced water availability and decreased soil moisture during droughts (National Integrated Drought Information System, n.d).

Water is crucial for a wide variety of power generation methods. Power generation constitutes 10% of water withdrawal worldwide (World Resources Institute, 2017). According to the World Resources Institute (WRI), 47% of the world's thermal power plants and 11% of hydroelectric power are located in highly water-stressed areas. This presents huge risks to the power generation sector as a lack of sufficient water supplies can cause power outages and increased competition for water between sectors. For example, India suffered water shortages from 2013 to 2016 that caused 14 of the 20 biggest thermal utilities in the country to close down power plants. The shutdown cost companies USD 1.4 billion and caused a loss in thermal power generation equivalent to the total annual electricity demand of Sri Lanka (WRI, 2018).

India is far from exceptional. In the United States (excluding the states of Alaska and Hawaii), for instance, projections show that 68.6% of natural gas, 73.3% of oil, 61% of nuclear, and 44.6% of coal-fired power plants are located in areas that could face medium to extremely high water stress by 2030 (S&P Global, 2020). Two-thirds (65%) of all the country's electricity comes from generators that require water for cooling Union of Concerned Scientists, 2017). Figure 21 below illustrates the amount of power plants in the United States that were exposed to droughts in 2022. Total water usage by the electric power sector in the country amounted to around 47.5 trillion gallons in 2020; the water withdrawn per unit of electricity generated was roughly 12,000 gallons/MWh (EIA, 2021b). By the 2030s, 27% of thermoelectric power plants could be significantly exposed to water stress (Ganguli et al., 2017). Compared to other thermoelectric power plants, nuclear power plants could face greater vulnerability to droughts due to their larger cooling needs. Water stress can lead to lower efficiency of nuclear power plants, as well as planned and unplanned shutdowns (OECD, 2021).

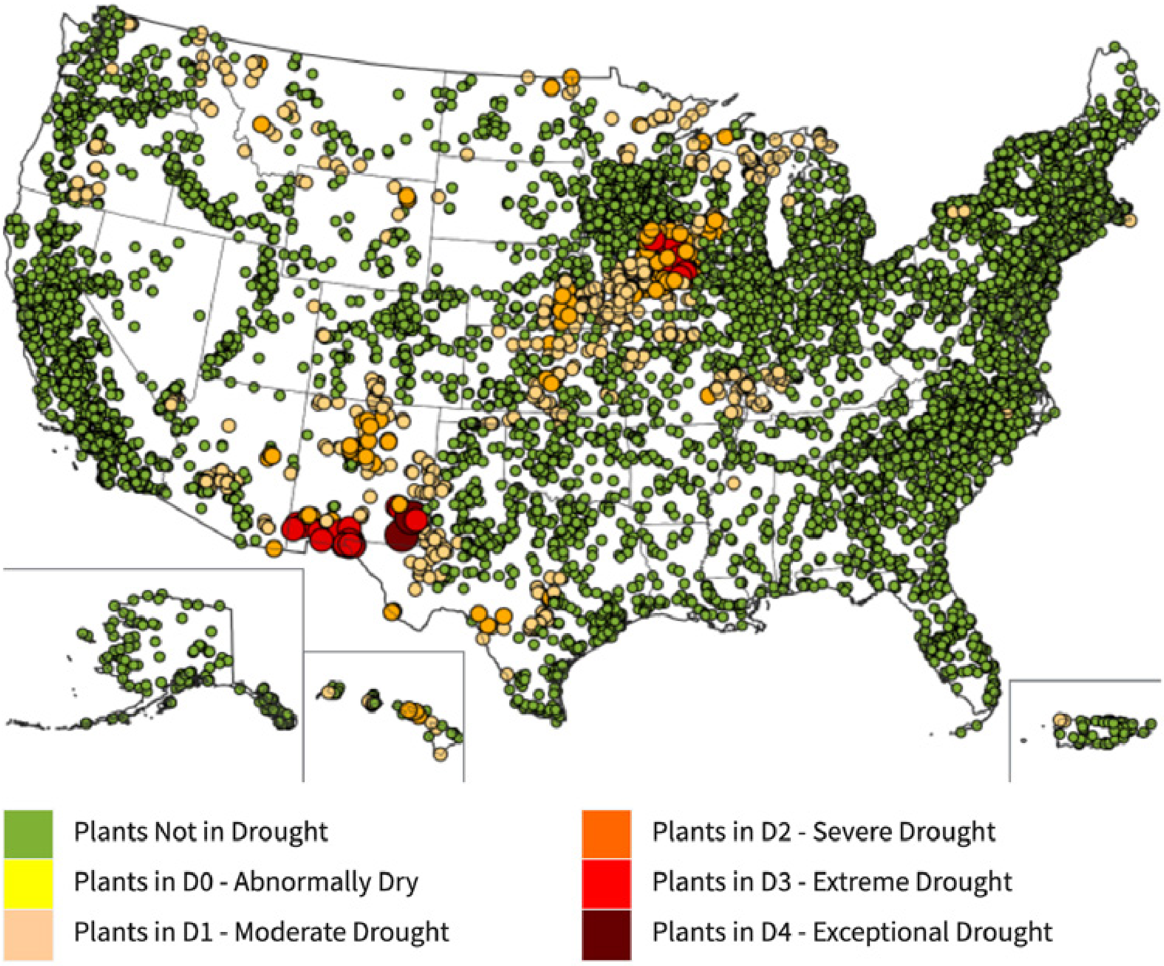


Figure 21: Map of US power plants located in drought areas (National Integrated Drought Information System, 2023)

China, the world's largest electricity producer, is another country facing major exposure to water stress. China generates 70% of its electricity from coal. A study assessing the impact of climate-related water risk on its coal-fired power plants found that 10% face water shortages between July and October, with this proportion doubling during the remaining months. The North Grid is particularly vulnerable, with 35 to 60% of its coal-fired power capacity at risk from December to June. The situation in China's northern region is expected to worsen with climate change. The country's eastern and southern grids are not without water shortage problems either. When coupled with higher demand for electricity, this could further burden coal power generation capacity in these regions (Liao et al., 2021). Similarly, fossil fuel power plants in the southern and eastern Mediterranean countries, such as Egypt, Jordan, Lebanon, Morocco and Tunisia, face vulnerability due to decreasing rainfall. Almost all (91%) of electricity generation in these countries rely on freshwater for cooling. Under all three warming levels—below 2°C, around 3°C, and above 4°C—nine in every 10 (90%) fossil fuel-fired power plants are estimated to become exposed to lower levels of water. About 32% of coal power plants, 15% of gas power plants, and 9% of oil power plants could be exposed to drier environments by 2100, higher than the global average (IEA, 2023i).

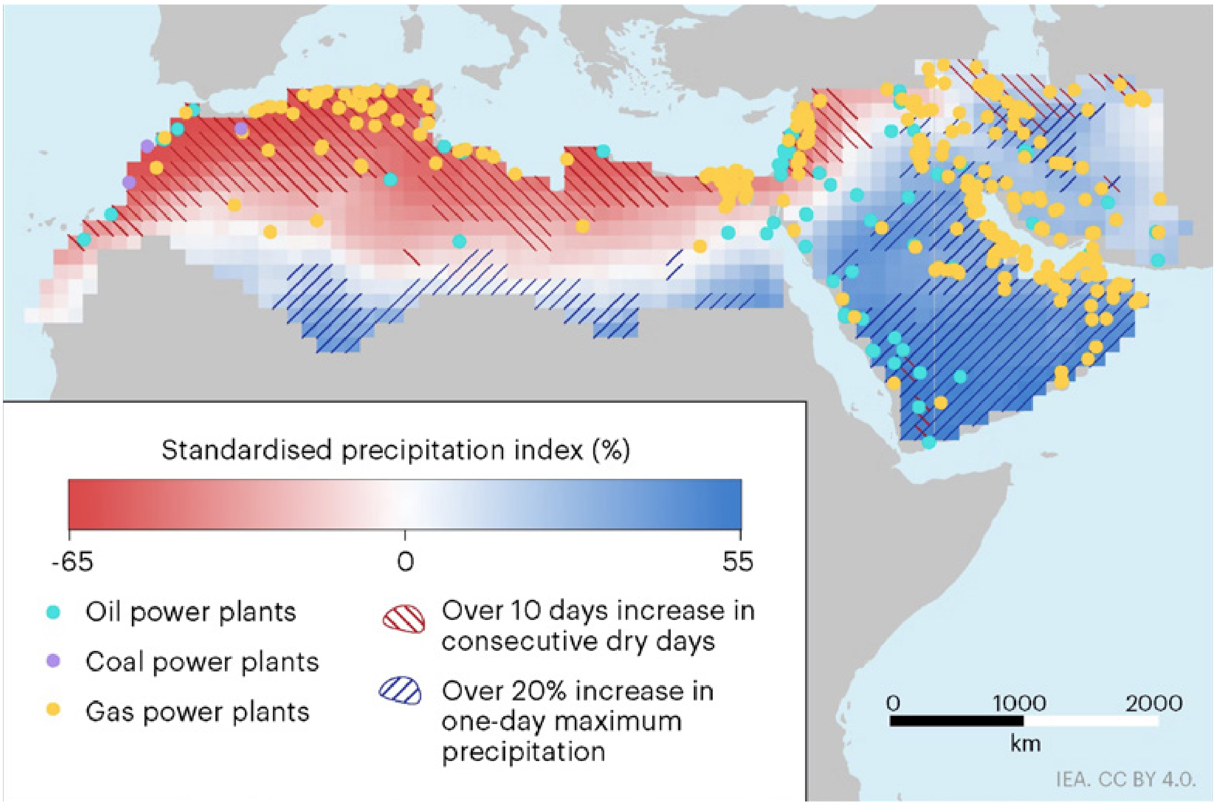


Figure 22: Changes in precipitation in the Middle East and North Africa from 2081 to 2100 under SSP2–4.5 scenario (IEA, 2023i)

Hydroelectric power generation will be especially vulnerable to rising water stress as it relies on water stored in dams. The majority of climate models project a significant decrease in hydropower generation in southern South America, for example, especially for Chile and Argentina. This is due to a decrease in rainfall in central Andes and Patagonia. In 2019, the share of hydropower for power generation was 27% and 20% for Chile and Argentina, respectively. In a below-2°C scenario, hydropower capacity in the area could decrease by 10% between 2020 and 2100. In a 4°C scenario, meanwhile, capacity could decrease by 15% between 2020 and 2060. Without any climate action, Chile's hydropower capacity could decrease by 34% by the end of the century (IEA, 2021d). Similar trends are visible in Vietnam. High temperatures in 2022 led to high energy demand in the country, while water levels in its hydropower dams remained low. The use of public lighting had to be reduced as a result, along with other energy conservation measures (Guardian, 2023).

At present, about 26% of existing hydropower dams and 23% of projected dams are located in areas of medium to very high risk of water scarcity, according to a study by Opperman *et al.* (2022). Under a 3.5°C warming scenario, these figures are expected to rise by 2050 to 32% and 20%, respectively. Countries with existing hydropower dams that are expected to be vulnerable to rising water stress include China, Jordan, Iraq, Morocco, and Syria (Figure 23a). China and Morocco are also among those countries with projected projects that are susceptible to water stress, together with Iran, Kyrgyzstan, and Uzbekistan, among others. Pakistan, India, and Turkey are also expected to be exposed to rising water scarcity by 2050 (Figure 23b). In Malawi, meanwhile, rising water stress has is already significantly impacting the power generation sector, which relies on hydroelectric power for 98% of its electricity (Grantham Institute, 2018). In 2017, the African country was only able to produce 150MW of power instead of the 300MW typically produced from hydroelectricity. As a consequence, 18 million people were left without electricity. To deal with the problem, the country imposed rolling power outages. However, these resulted in local businesses incurring substantial economic losses. They also led to an increase in mortality in hospitals as critical machinery became unavailable. Such events are expected to become more common in Sub-Saharan Africa as the region's experience of severe droughts increases in the coming decades due to climate change (Grantham Institute, 2018).

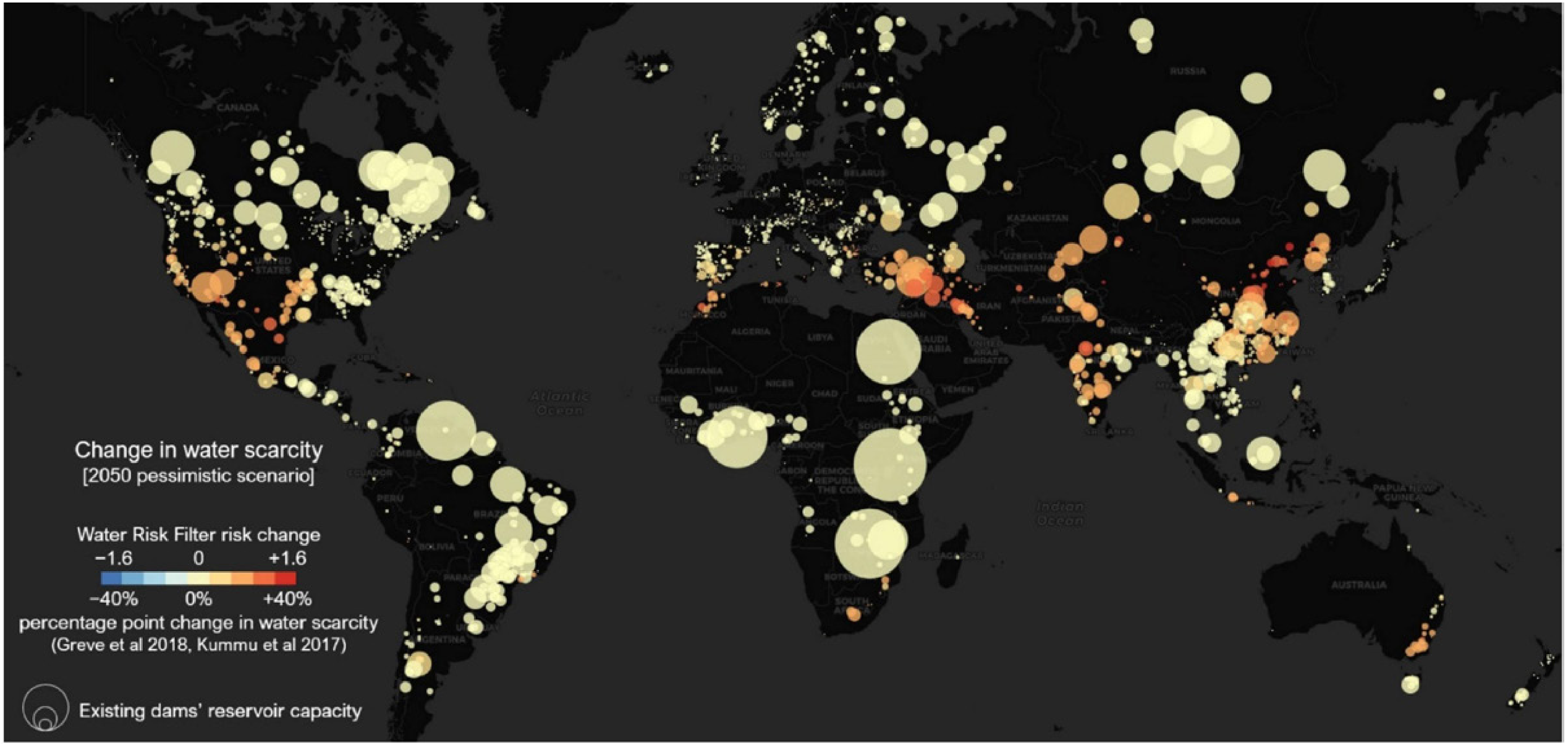


Figure 23a: Projected change in water scarcity across regions with existing dams in 2050 under a 3.5°C warming scenario (Opperman et al., 2022).

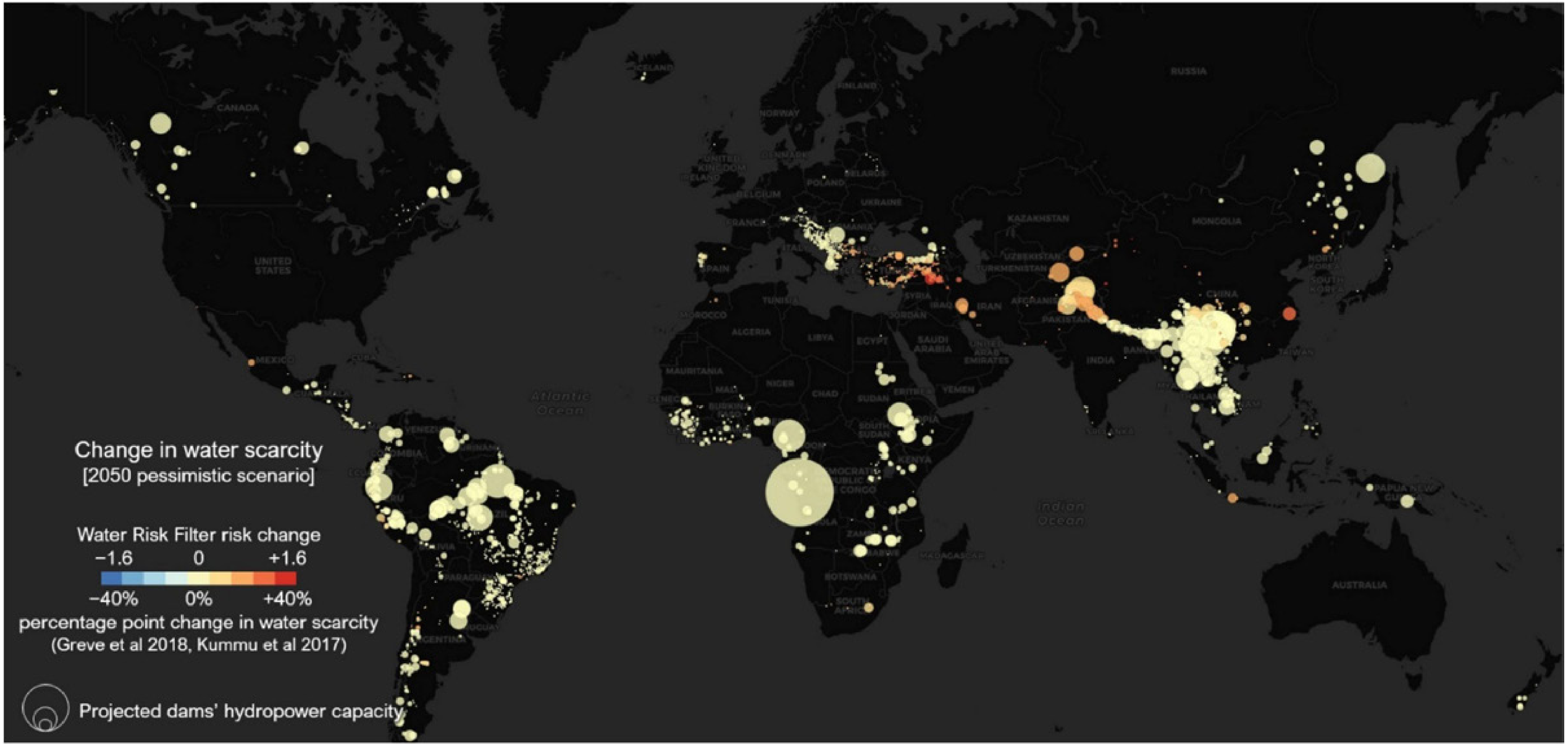


Figure 23b: Projected change in water scarcity across regions with projected dams in 2050 under a 3.5°C warming scenario ([Opperman et al., 2022](#))

Given the high reliance of the power generation sector on water availability, an increase in the frequency and severity of droughts promises to have a significant impact on firms in the sector by reducing the efficiency and generation capacity of power plants. A recent study on Britain's power supplies indicates that almost half (7GW) of freshwater thermal capacity becomes unavailable on extremely hot days. The consequent annual cumulative costs on electricity prices run from GBP 29 million to as much as GBP 66 million (Byers, 2021). A similar study by North Carolina State University studied the impact of drought conditions in California between 2012 to 2016. The research found that the state's reliance on hydropower fell from 13% to 6% during this period, incurring costs of GBP 1.9 billion for the state's three main investor-owned hydropower firms—costs that were then passed on to consumers (Science Daily, 2020).

Similarly, drought conditions in Europe in 2022 had a significant impact on France's power generation sector, of which nuclear power makes up 63% and hydropower 11% (The Local France, 2023). The French utility firm, EDF, witnessed a 30% decrease in hydropower generation in the first half of 2022 compared to the same period in 2021. Along with outages at its nuclear power plants, this resulted in a loss of USD 1.4 billion for EDF (SP Global, 2022). In Kenya, meanwhile, a national disaster was declared in response to a major drought in 2017. The country's reserve energy margin, which it used to prevent blackouts and meet high energy demand, dropped to 4.4% (World Resources Institute, 2017). The previous year, a similarly severe drought in India caused the country's coal power sector to suffer profit losses of USD 350 million due to its dependency on water for cooling (World Resources Institute, 2017). Hydropower generation in the country dropped by 20% from the previous year (Power, 2016). The same story played out in Ghana after droughts in 2016 caused the country's largest energy supply, the Akosombo Dam, to operate at minimum capacity (World Resources Institute, 2017).

One of the repercussions of water stress is that countries reliant on hydropower may be forced to shift power production to other sources. Due to low levels of rain in China since mid-2022, for example, the country's hydro production has decreased by 82 billion kWh. As a result, it has had to increase power production from coal-fired power plants, which has jumped by 149 billion kWh. The provinces of Sichuan and Yunnan, which produce about half of China's hydroelectric power, have been particularly hard hit. Rainfall in the two provinces was 56% below the seasonal average in 2022. Drought conditions continued into the first half of 2023, during which time China registered its lowest level of hydro generation since 2015. As a result, coal became vital to meet electricity demand in the short term. Coal miners expanded production and coal-fired generators were encouraged to accumulate fuel by the government (Reuters, 2023). It should be said that China has also turned to wind and solar sources for additional power generation. Even so, the example demonstrates how the increasing occurrence and severity of droughts due to climate change may worsen reliance on fossil fuels, thus intensifying transition risks.

Case Study 5: Impact of severe droughts in Brazil

Hydroelectric power is Brazil's top electricity source, comprising 61% of its total electricity generated. Droughts in 2021 reduced water flows into the country's hydroelectric dams to a 91-year low (UNDRR, 2021). Particularly affected was South America's second largest river, the Paraná River, which flows southwest from its source in eastern Brazil to some of the country's most populous areas. Brazil has more than 50 large dams and reservoirs throughout the Paraná River Basin, making it critical for the country's energy security. As a result of the water shortages, Brazil's national electricity supply fell by 17% (ECPAmericas, 2021).

To cope with the decreasing energy supply, relative prices increased by an average of 6.78%. Brazil had to import electricity from its neighbours and generate more power at fossil fuel plants (which are more financially and environmentally costly) (Al Jazeera, 2021). Given the restricted energy supply, the Brazilian federal government sought to cut public service electricity use by 10 to 20%. Residential use of energy was also affected. Many medium-sized towns started rationing, for instance. In September 2021, the then Brazilian president, Jair Bolsonaro, requested Brazilians to stop using elevators if possible and to take cold showers in order to budget electricity. Residents in the São Paulo state only had access to tap water at home every other day (ECPA, 2021).

The drought also caused fluctuations in the nation's energy spot market, reflecting unusual precipitation patterns. The lack of rain throughout most of the year encouraged Brazil to increase its use of thermal power, which, at around USD 59/MWh, costs around double to produce than hydroelectricity (Argus, 2021a). The volatility posed significant difficulties for the market to accurately and consistently determine the price of different energy sources. This, in turn, deterred energy suppliers from offering long-term contracts. By June 2021, the drought conditions had driven prices up by 40% (Reuters, 2021b). For large industrial customers that desired to purchase energy from the power suppliers, this complicated the planning processes and posed further difficulties in raising capital (ECPA, 2021).

Figure 24: Drought along the Paraná River Basin (ECPA, 2021)

Case study 6: Water stress-related risk

Capital Power Climate Change Disclosure 2022

Canadian power producer

Key assumptions

- Water resources are increasingly affected by climate change (impacts vary by jurisdiction); water conservation and use are increasingly scrutinised and subject to more stringent regulation.
- Long-term changes in weather patterns will affect the design and operation of new and existing renewable assets.

Risks

- Short
  - Water use and conservation efforts are increasingly scrutinized, and requirements are strengthened to mitigate the chronic impacts of climate change on water resources.
- Mitigation
  - Capital Power has approved and is executing a Water Management Strategy that will mitigate risks associated with increasing scarcity of water resources.
  - Actions to be off-coal will reduce Capital Power's overall water consumption.
  - Capital Power monitors developments in policy and regulatory frameworks that address management of water resources.
  - Risks relating to the regulation and management of water are identified and mitigated in due diligence processes.

3. Wildfires

If the impacts of climate change worsen, the frequency and severity of wildfires are expected to rise, which is a significant concern for utility companies. Wildfires create several pain points for power-producing companies, such as power outages and infrastructure damage. These carry with them massive expenses. During wildfires, for example, burnt trees and debris can collapse onto power infrastructures such as transmission lines and substations. The consequent physical damage can be very costly and time-consuming to rectify. Over the past 50 years, for example, damages from wildfires have cost power companies in the United States an average of USD 1 billion per year (adjusting for inflation). Globally, the scenario is similar. Between 2017 and 2021, wildfires are estimated to have caused a total of USD 81.6 billion in damages, a nine-fold increase on the period 2012–2016 (National Oceanic and Atmospheric Association, 2023).

Power generation and utilities firms can sometimes be held accountable for causing wildfires when power lines come into contact with dry vegetation and cause it to ignite. Hawaiian Electric Industries is facing exactly this charge in the wake of the deadly Maui fires on Hawaii in 2023. Although the cause of the fire remains under investigation, local residents point the finger at the company's power lines. If proved correct, Hawaiian Electric Industries could be held liable for billions of dollars' worth of damage, resulting in its potential bankruptcy. Either way, many investors have already chosen to play safe; the firm's stock plummeted by 70% in the month immediately after the fire (Time Magazine, 2023). In California, meanwhile, 10% of wildfires from 2016 to 2020 were caused by electrical power (The Conversation, 2023). Since 2017, for example, equipment owned and managed by PG&E, the largest utility company in the United States, has been blamed for over 30 wildfires in California. Previously, the company had reached a settlement of more than USD 25.5 billion with wildfire victims (PBS, 2022). It subsequently filed for bankruptcy in 2019 (UtilityDive, 2020). As the frequency and severity of wildfires rise due to climate change, firms in the sector face a dilemma as to whether to shut off power on days with a high chance of a wildfire or to continue providing reliable electricity to households and risk wildfires (Wall Street Journal, 2023).

Figure 25: The 'Dixie Fire' spreading through Genesee, California, in 2021 ABCnews.com, n.d.

Wildfires can also decrease the efficiency of solar energy generation. Wildfires produce excess clouds and aerosols, which can decrease the amount of solar beam that reaches the earth's surface. This impacts the amount of energy that solar panels can capture from the sun, decreasing solar energy production. It is estimated that aerosols can reduce solar PV production by 30 to 50%. A study on solar power production in India revealed that aerosols and clouds caused an estimated 82% reduction in total solar energy production. The financial loss from one day of high levels of aerosols and clouds was estimated at USD 98,000 and USD 171,500, respectively, for Indian total solar plant's capacity potential of 40 GW (Dumka et al., 2022). The impact of wildfires on solar power was also witnessed during the 2019 Australian bushfires, which released almost one million tons of smoke into the stratosphere. The Australian Energy Market Operator (AEMO) and energy analytics company Amperon surveyed four solar farms. The study found a mean decrease of 4.1% in output per plant between December 2019 and January 2020 due to the bushfires (Amperon, 2020).

Furthermore, wildfire-induced runoffs can cause sediments from wildfires to end up in reservoirs used for hydroelectric power generation. For example, in 2018, the Thomas Fire in California increased the influx of fine sediment in nearby rivers by 200 times (Jumps et al., 2022). Currently, around 0.5 to 1% of the total volume of 6800 km^3 of water stored in reservoirs globally is lost annually due to sedimentation. Sedimentation can reduce the storage availability of a reservoir, negatively impacting the generation of hydroelectricity (Schellenberg et al., 2017).

4. Intensifying storms and floods

Floods cause significant damage to power infrastructure, including power grid assets. These damages are commonly associated with power outages (Karagiannis et al., 2017). In 2023, devastating flooding in the Emilia-Romagna region in Italy left around 50,000 people without electricity (NBC news, 2023a). The floods killed nine people and caused billions of dollars' worth of damage, with at least 10,000 people forced to leave their homes and more than 5,000 farms left underwater (NBC news, 2023b). As climate change causes an increase extreme storms and flooding events, firms in the sector are likely to face a growing risk of damage to infrastructure and unscheduled halts in operations. Firms in the sector are expected to face higher costs related to infrastructural damages and higher prices of raw materials due to extreme storms. For example, in 2017, a significant storm struck Ireland. The extensive damage that followed led the Electricity Supply Board to allocate approximately USD 16.7 million to restore power to residences and businesses throughout the nation (The Irish Times, 2018).

A study by Opperman *et al.* (2022) estimates that about 75% of existing hydropower dams and 83% of projected dams are located in areas of medium to very high risk of flooding. The proportion of existing hydropower dams exposed to very high or extreme risk of flooding is projected to increase five-fold under a 3.5°C warming scenario (Figure 26). For projected dams, the risk in some areas is expected to increase by up to 20 times by 2050 due to climate change. Myanmar, Cameroon, Laos, Thailand, Uganda, Bangladesh, Colombia, China, Ethiopia, India, Kenya, and Vietnam are just some of the countries with operational hydropower dams that are expected to become more vulnerable to flooding as global temperatures rise (Figure 27a). Countries with projected projects that will face rising flood risk under a 3.5°C warming scenario include Myanmar, Kenya, Uganda, Ecuador, and Cameroon (Figure 27b).

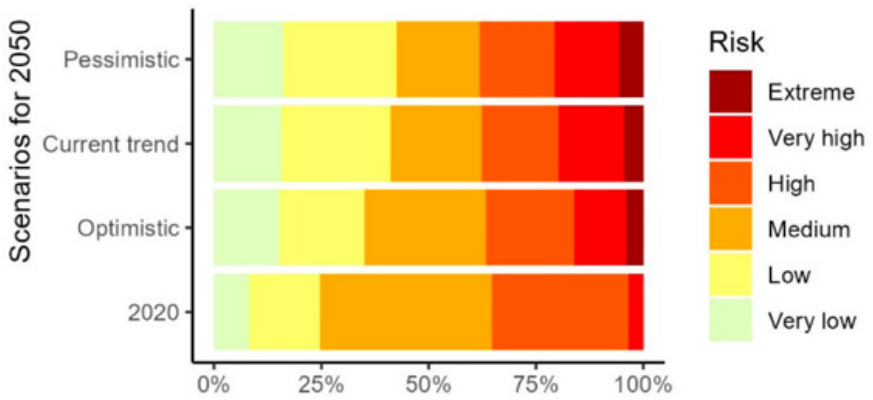


Figure 26: Proportion of existing hydropower dams at risk of flooding under three scenarios—optimistic (1.5°C warming), current trend (2°C warming), and pessimistic (3.5°C warming) (Opperman et al., 2022)

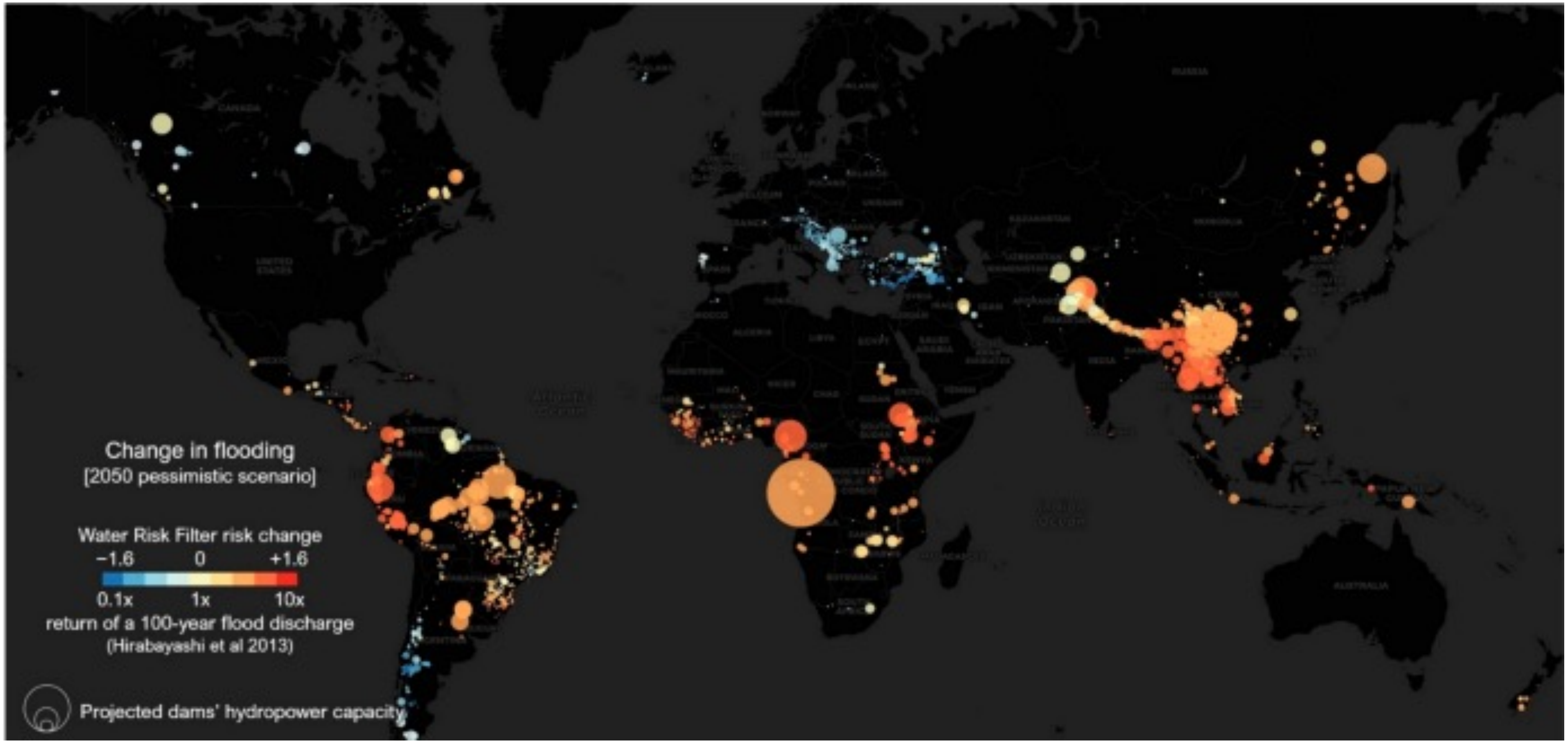


Figure 27a: Projected change in flooding across regions with existing dams in 2050 under a 3.5°C warming scenario ([Opperman et al., 2022](#))

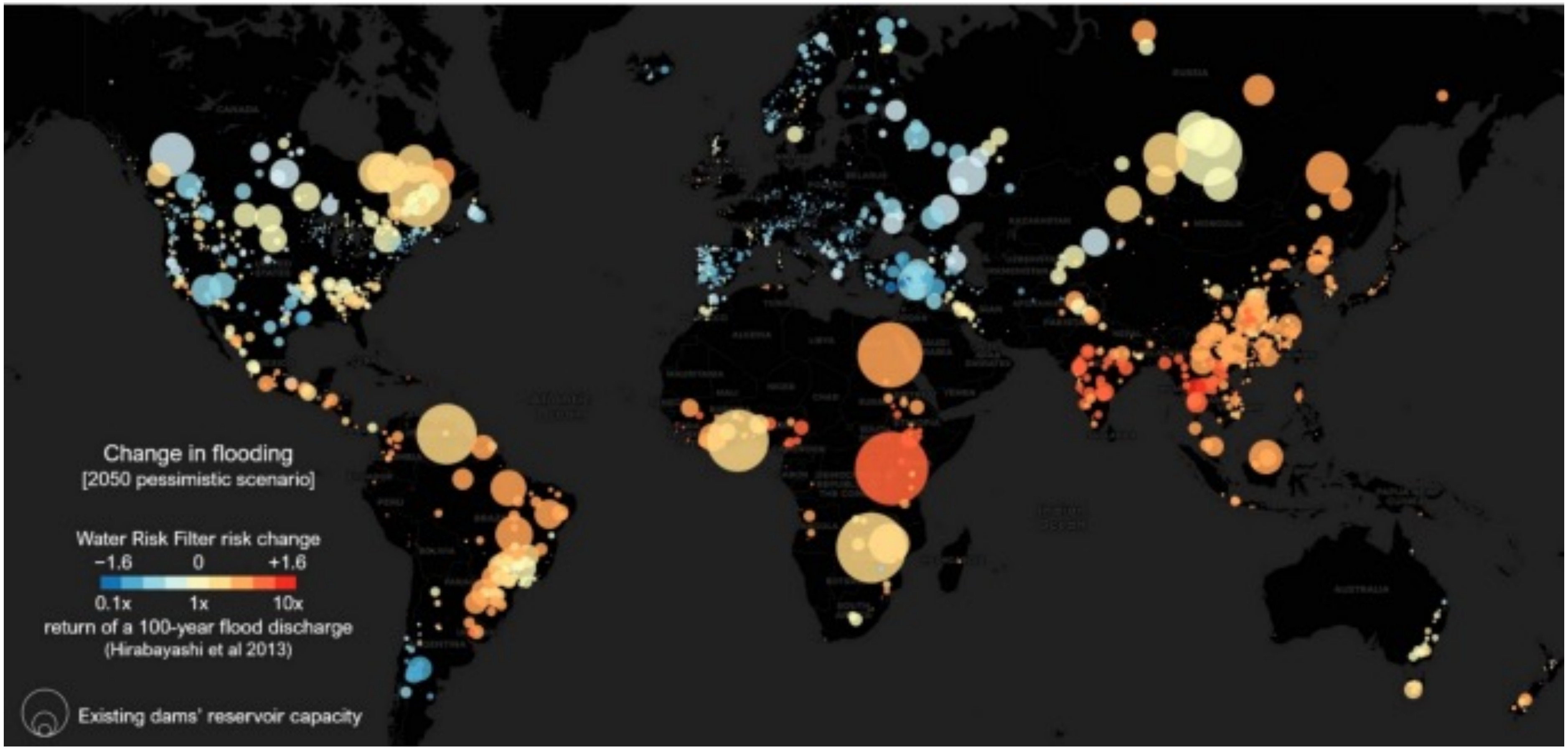


Figure 27b: Projected change in flooding across regions with projected hydropower dams in 2050 under a 3.5°C warming scenario (Opperman et al., 2022)

Other energy assets can also be exposed to the increased frequency and severity of floods. For example, in 2021, heavy rain and flooding in the state of Victoria in Australia forced the closure of the Yallourn power station. The power plant was the largest plant in the state and produced 25% of Victoria's power (9news, 2021). Nuclear power plants located in close proximity to water bodies are also vulnerable to flooding. In the summer of 2020, extreme floods in Bangladesh caused half of the country's districts to flood, impacting over 4.7 million people. Among the affected sites was the Pabna district, where two nuclear power reactors were under construction at the Rooppur Nuclear Power Plant site (Center for Climate and Security, 2020). Similarly, analysis by Moody's Investors Service has showed that 37 gigawatts of the United States' nuclear capacity is vulnerable to flooding, including nuclear plants located along the East and Gulf Coasts that are growing susceptible to hurricanes. Flooding in nuclear plants can cause damage to infrastructure, such as transmission lines, resulting in plants being unable to generate and deliver power (Scientific American, 2020).

In 2021, Germany faced the worst flooding it had seen in decades, resulting in many companies having to cut power supply. Particularly hard hit were the states of Rhineland-Palatinate and North Rhine-Westphalia. The floods cost 185 lives and caused damage valued at USD 32 billion (EUR 30 billion). RWE, one of Germany's major energy generators, reported that the floods endangered many of its power stations. Nearly all of the run-of-river power plants on the Mosel, Saar, and Ruhr rivers in the Eifel region were shut down during the event (Power, 2021). E.ON SE, a German utility giant, cut power to 165,000 people following heavy flooding that impacted the energy infrastructure of the country. The company also stated that fallen trees damaged power lines, triggering supply outages. RWE reduced its operations at a coal mine after it flooded, reducing supplies and causing it to function at a limited capacity. Due to the flooding, German power for same-day delivery doubled to USD 236/MWh (Bloomberg, 2021).

Figure 28: Flooding in Germany in 2021 (CNN, 2021)

The year 2021 also saw Hurricane Ida hit the United States, resulting in power outages for 1.2 million customers across eight states, including Louisiana, Alabama, New York and New Jersey (EIA, 2021c). The impacts mirror those of Hurricane Sandy in 2021, which left the majority of the lower Manhattan district of New York without power (Chondrogiannis et al., 2017). Transmission lines are especially susceptible to damage from strong winds and flood water pressure, with repair costs commonly passed down to customers. In the US state of Louisiana, for example, legislators voted to allow Entergy, an energy company, to pass on the repair costs from damage caused by five storms in 2020 and 2021 to its customers. It is expected to take 15 years for customers to pay the USD 3.2 billion repair bill (Louisiana Illuminator, 2022). Should climate change continue, customers will likely face higher energy bills due to the cost of repairing damage to energy infrastructure and assets caused by the growing severity of storms and flooding.

Extreme flooding and storms can also increase the costs of raw materials for power generation due to the constraints on supply that they create. Many of these costs are reflected in increased prices for customers. Thermal coal, which is a primary source to generate steam for the production of electricity, has seen its price significantly increase during extreme climate events (EIA, n.d.). For instance, floods caused by heavy rainfalls in parts of Indonesia's main Kalimantan coal-producing region in 2021 caused the price of thermal coal to reach USD 75.22 per ton, its highest level since 2008. Indonesia is the biggest thermal coal exporter in the world. As such, these disruptions to its coal logistics and supply constraints had knock-on effects for the global thermal coal market, with power plants running low on coal. Many international buyers had to find alternative sources of supply as a consequence. India looked to increase domestic coal availability, for instance, while China turned to other markets such as Bangladesh, Vietnam, Thailand, and the Philippines (Argus Media, 2021b). In the same year, flooding in Shanxi in China caused disruption to coal supply. The floods, which caused 100,000 people to be displaced, caused Chinese coal futures to increase by 11.6% and reach an all-time high (FT, 2021). Global energy prices also witnessed considerable volatility as leading countries sought power supplies at increasingly high costs. With most of China's domestic coal coming from the region, the flooding event combined with other local factors to cause power rationing for industry and residential users.

As the risk of intense storms and flooding increases, firms may have to take costly precautions against flood damage.

Case study 7: Intensifying flood risks

EVNGENCO3 Annual Report 2022

Vietnamese power generation company

Risks

Vietnam has witnessed extreme weather phenomena in recent years, such as rainfall and sea level rise. Therefore, input factors of EVNGENCO3's hydropower plants are also hit by flood season flow, erosion, reservoir sedimentation, etc. These abnormal changes have caused direct impacts on power production (energy safety), construction safety, flood, etc.

Risk management plans

- Build a plan on natural disaster prevention & control, search and rescue with a "4 on the spot" motto: command manpower-materials and logistics to improve capacity and specialised responsibilities.
- To timely provide information of production operations and reservoir regulation to communities downstream, the Corporation has established 24 flood warning stations downstream (Buon Tua Srah: 14 stations; Buon Kuop Reservoirs: 10 stations) and along the river downstream to get local people alerted. At the same time, the Corporation has installed Zalo groups at 3 reservoirs with local authorities to announce, exchange and provide information in a timely and quick manner to related parties to improve efficiency of flood & rain response.

5. Rising sea levels

If climate change worsens, rising sea levels threaten power plants located along coasts. Flooding caused by rising sea levels can damage power plant infrastructure, including electrical and cooling systems. Damage to nuclear power plants can even result in the release of radioactive materials (Vidal, 2018). Flooding caused by rising sea levels can also damage urban infrastructure that can, in turn, result in power outages. Equipment in substations used to distribute electricity can become disrupted, for instance. Powerlines can also become damaged or they can collapse and collide with other objects (Burillo, 2018).

By 2050, the heightened risk of flooding due to sea-level rise will affect 270 power plants, directly impacting 800 million people. Globally, an estimated 6,700 power plants are situated in the low-elevation coastal zone, resulting in rising exposure of firms in the sector to higher sea levels. Power producers operating in Asia, Europe, and the east coast of North America will be exposed to an above-average level of sea-level rise (c40 cities, 2018). A sea-level rise of one metre could double the number of vulnerable power plants in the US coastal states of Florida and Delaware (Power, 2018). A recent study assessed the proportion of power plants in the United States that could become exposed to a 100-year sea-level rise by 2100. It found that, without any adaptation actions, the exposed power capacities in relation to current average generation capacities for Delaware, New Jersey and Florida would be 80%, 63% and 43%, respectively (Bierkandt et al., 2015).

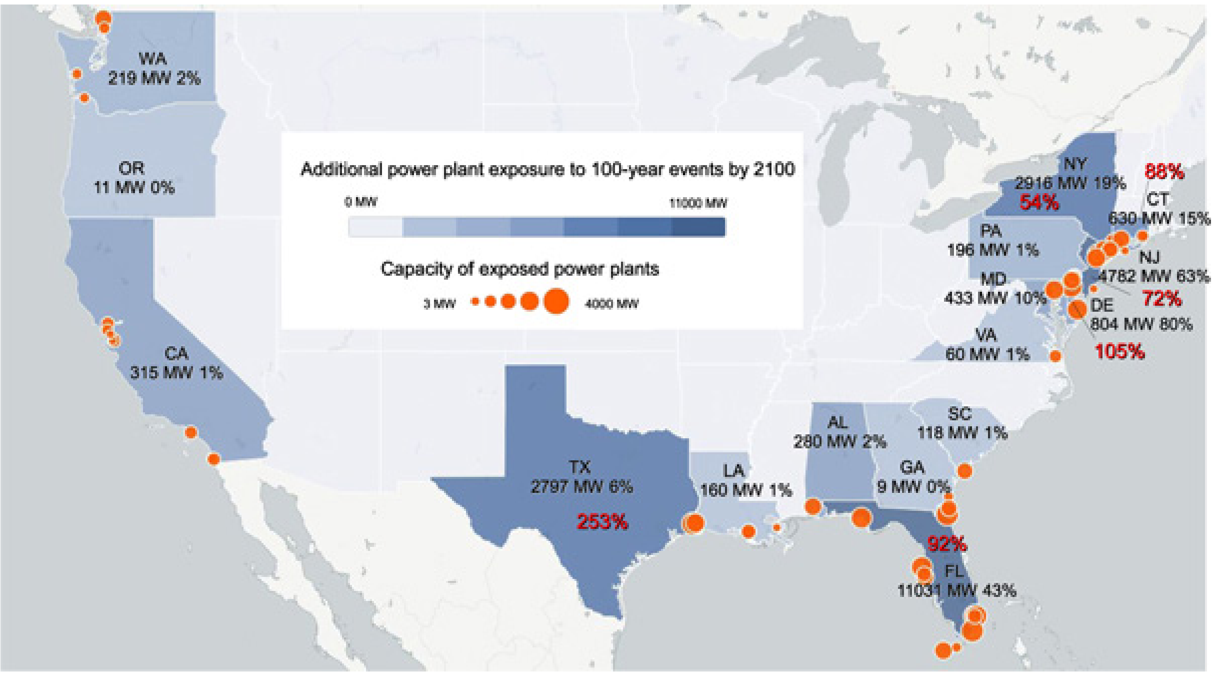


Figure 29: Additional exposure of US power plant sites to extreme sea-level rise without additional mitigation action (Bierkandt et al., 2015)

Due to higher costs and increasing obstacles to the construction of new nuclear power plants, companies are considering extending the lifespan of operational plants for decades longer than expected. However, exposure to rising sea levels could threaten such plans. For example, in 2019, officials in the United States approved a 20-year extension of Florida's nuclear plant, Turkey Point, pushing its lifespan forward into the 2050s. Three years later, however, the decision was reversed after a review of the plant's potential environmental risks, which includ flooding from a rise in sea level due to climate change. Climate models project that frequent flooding in the area of the plant would be highly likely by the 2040s (AP News, 2022; Miami Waterkeeper, 2023).

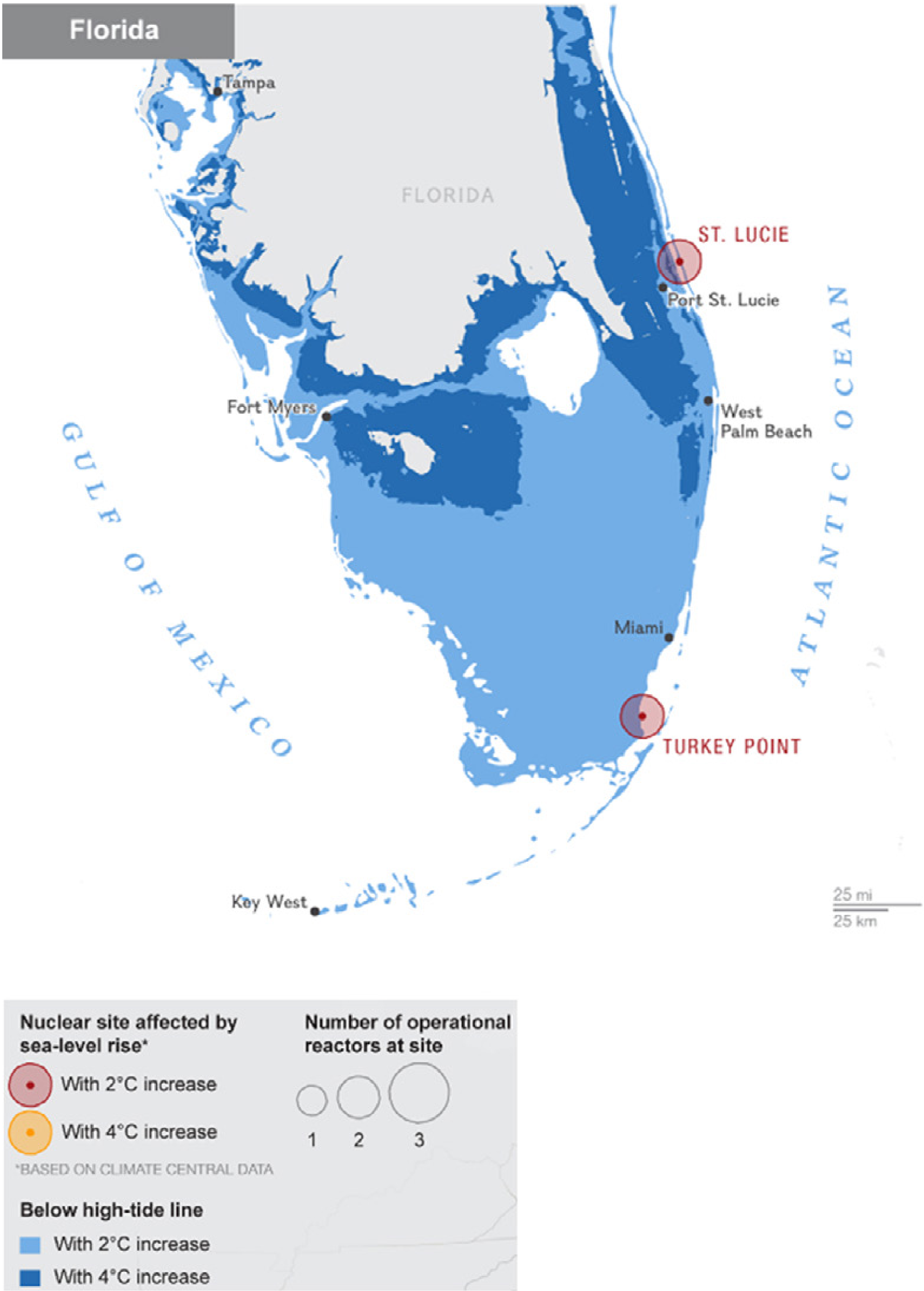


Figure 30: Exposure to sea-level rise of nuclear power plants in Florida (National Geographic, 2015)

The risk of land loss are disproportionately higher for the power generation sector of small island nations because of their vulnerability to sea-level rise. On the island of Hulhumalé in the Maldives, for example, 50,000 residents generate about 1.5 MW of power through solar panels for the local grid (World Bank, 2022). At the current rate of rising sea level, nearly 80% of the archipelago is projected to be uninhabitable by 2050. This places coastal power generation like that of Hulhumalé in jeopardy, as it does for the country's overall energy supply (ABC News, 2021).

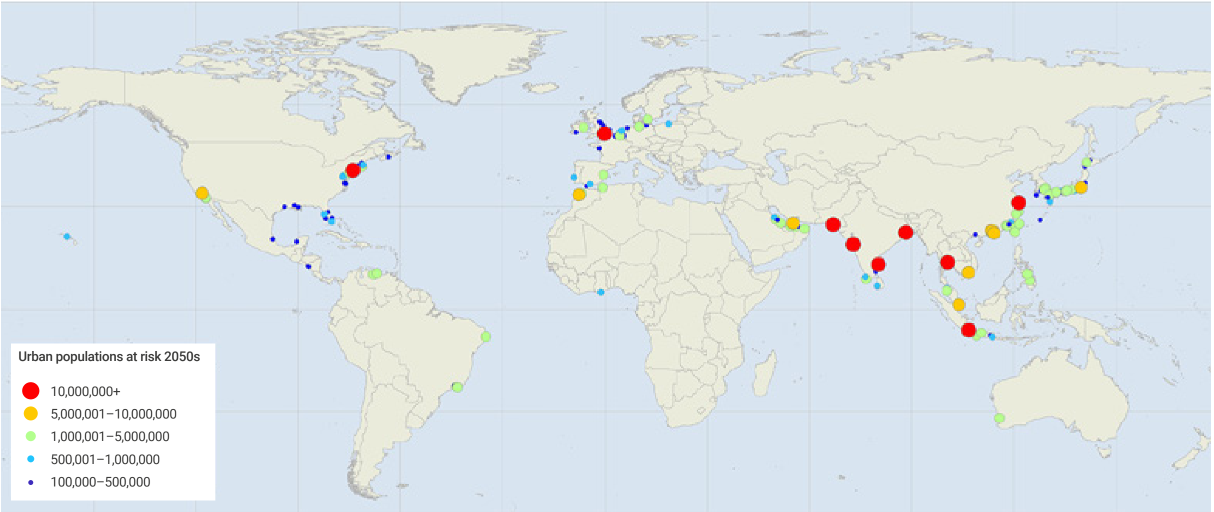


Figure 31: Cities with power plants vulnerable to coastal flooding due to a sea-level rise of 0.5 metres in the 2050s (c40 cities, 2018)

6. Physical risk guidance

This section offers guidance on how financial institutions can address physical risks within the sector and support their clients in the process.

Key physical risk questions for financial institutions to consider

1. Gathering information

- What are the most prevalent physical risks across our portfolio footprint?
- What have our clients disclosed in their financial, sustainability, and climate reports regarding their physical risks?
- How many of our clients have business resiliency plans or a climate change risk assessment in place?
- Do we have locational data on the major assets of our clients?

2. Assessing the risks

- How much of our portfolio operates in areas of high physical risk?
- What does our exposure to higher-risk clients look like? What are the terms of our financial relationship (e.g. debt/equity, tenor)?
- Have we looked at physical risk scenarios to see how these risks will evolve over time across the portfolio? Have we considered short-term, medium-term, and long-term risks?
- How would physical hazards disrupt our clients' production and distribution activities?
- How long might disruption last for the client? What might be the potential loss in revenue?
- What indirect damages[8] might result from physical hazards (e.g. business disruption, changes in value of assets) for individual clients?
- How might insurance markets (and insurability) change in the face of worsening physical risks?
- What proportion of our clients are covered? Which hazards are covered? Is uninsurability a risk in areas of more frequent physical hazards?
- Are water availability issues a concern for the client's operations? If they are, do the client's plans consider the water needs of the local populations?
- Have we explored if local adaptation measures are being taken individual clients and, if so, how they will increase the resilience of assets to climate change?

8 Indirect damages can result from tangible damages caused by a physical risk. An example of this is business disruption caused by the physical damage to a business's property or facilities.

- How much are clients investing in adaptation and resiliency measures?
- Have we considered the potential environmental and social risks that might emerge from changes in the value chain as a result of physical hazards?

3. Engaging with clients and updating strategy

- Do our senior leaders understand the physical risks of our clients?
- How are we helping our clients to transition to more resilient infrastructure, equipment, and other assets?
- How will the physical risks that we have identified and assessed influence our strategy in the power generation sector?
- What specific updates to risk management practices or business activities will be needed to appropriately consider these physical risks in our operations?

Recommendations for risk management

1. Conduct geolocated, asset-level analysis

Power plants are extremely vulnerable to physical hazards, such as flooding and water stress. Temporary disruptions in operations as a result of an extreme event can significantly increase the operating costs of power plants. These costs are commonly passed on to consumers, thereby increasing electricity prices. Financial institutions need to have an in-depth understanding of the major capital assets of their clients and the location of their assets. Financial institutions should assess the exposure of their assets to physical hazards based on the type of energy source (such as coal-fired, hydropower, or solar) and its location, as well as existing insurance coverage and any mitigating or exacerbating risk factors. Financial institutions or their clients should conduct periodic analysis of their assets to be aware of the magnitude of the risks that they face and how these change over time.

2. Review clients' resiliency plans

Many firms in the power generation sector have identified the negative financial impact posed by physical risks such as to heat stress and wildfires. These can be seen through the disclosure examples above. Some firms have started to develop and disclose business continuity plans and actions to improve resiliency against physical hazards. For financial institutions, information about the resiliency and adaptive capacity of their clients is important. As a first step, financial institutions should review their clients' annual reports and climate-related financial disclosures to gain information on resiliency. Clients should also be requested to provide further information on adaptation measures being undertaken for major assets. For assessing the credibility of these plans, they should be compared to national adaptation plans (NAPs) issued by governments as well as to other suggested resiliency measures (e.g., those within the IPCC AR 6 WG 2 report).

Adaptation and mitigation actions clients can take

1. Resiliency planning

If the impacts of climate change worsen, infrastructure of power stations face increasing risk of damage from physical hazards. Firms can develop resiliency and adaptation plans for these sites. To develop these plans, firms can conduct an assessment of their current climate risks and asset vulnerabilities. As part of the assessment, firms can explore different climate scenarios to understand how climate risks may evolve in the coming decades as the frequency and intensity of physical hazards increase. As part of their resiliency planning, clients should create procedures for different business units to respond to potential disruptions in the upstream supply of raw materials for power generation. Clients of the power generation sector should consider the development of green infrastructure and the strengthening of synergies for adaptation measures and other environmental issues, such as flooding, water availability, air quality, resource efficiency, and biodiversity conservation.

2. Climate-ready infrastructure

Given the capital-intensity of the power generation sector, firms in the sector should invest in climate-ready infrastructure to ensure that their power stations, grids, and equipment are resilient to worsening climate hazards. For new infrastructure, this will need to take place during the planning process by enacting standards that are appropriate for today's conditions and potential future tail-risk events. Furthermore, firms may need to consider relocation or building plants in newer locations, for example, considering cooler locations for power generation impacted by higher temperatures. Retrofits and climate defences can be considered for existing infrastructure, for example, efficient cooling, flood protection, implementing safety measures for fuel storage and improving drainage systems and structural levels. The most effective of these investments may be those that offer environmental and social co-benefits. Examples of projects that build resiliency and support nature include the restoration of mangrove forests and wetlands and that also consider affected communities.

Additional guidance

- The Equator Principle's guidance note on Climate Change Risk Assessment provides detailed information on physical risk assessment.
- The note by the Network for Greening the Financial System, titled 'Physical Climate Risk Assessment: Practical Lessons for the Development of Climate Scenarios with Extreme Weather Events from Emerging Markets and Developing Economies', offers a framework to complement existing climate risk assessment practices.
- The European Central Bank has published good practices for climate-related and environmental risk management for financial institutions
- UNEP FI and the Cambridge Institute for Sustainability Leadership's report on Leadership Strategies for Client Engagement: Advancing climate-related assessments includes guidance on advancing climate-related assessments for effective use in client engagement.

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