Powering Through: Building Climate Resilience into Canada's Energy Future

Zurich Resilience Solutions & Zurich Canada in collaboration with Sussex Strategy Group

ZURICH
Resilience Solutions

Executive summary

Safeguarding Canada's energy future: Protecting electricity infrastructure against increasing climate risk.

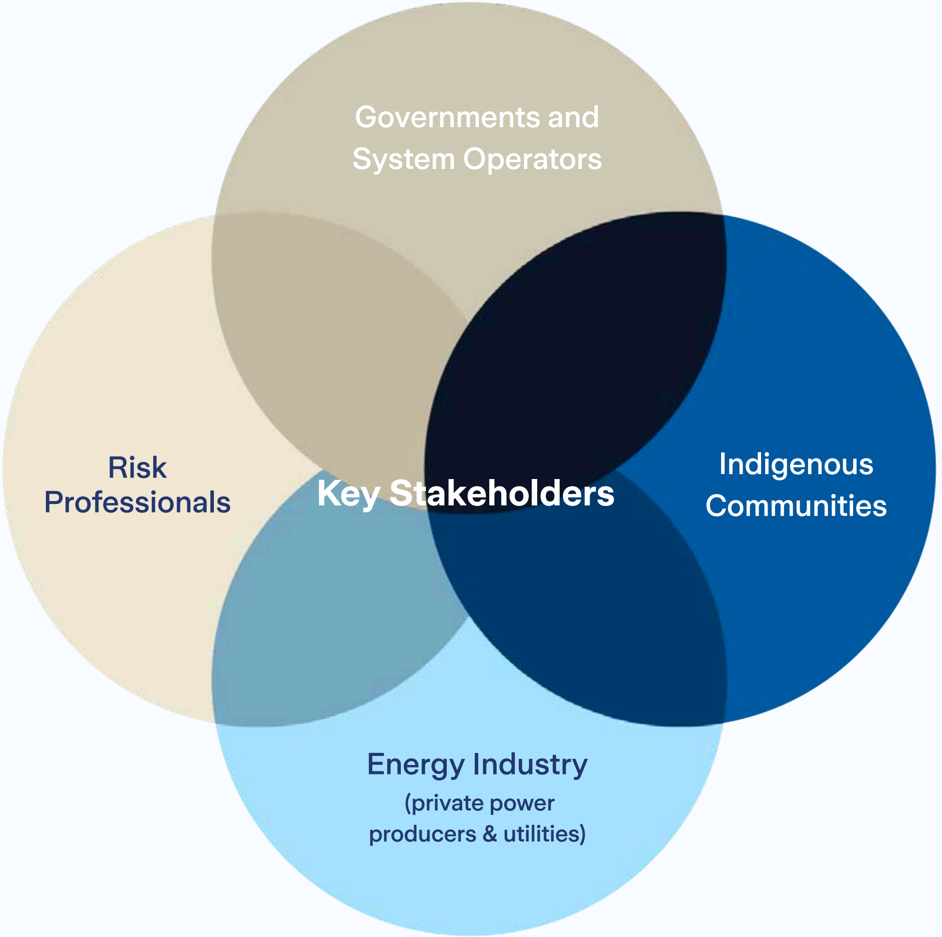
Electricity lies at the heart of modern Canadian society. It lights our homes, energizes our industries, and supports the activities necessary to secure Canada's future prosperity. From the icy coastlines of Newfoundland and Labrador to the temperate forests of British Columbia, electricity is the invisible current that connects daily life across Canada's vast and diverse landscape.

Investments in clean energy infrastructure go beyond addressing a climate imperative, they are a strategic necessity for economic prosperity, national security, and community resilience. Clean electricity already underpins Canadians' quality of life - from heating homes in the coldest winters to powering hospitals, schools, transportation and industry - and its importance is only increasing.

Against this backdrop, physical climate risks are intensifying. Wildfires, ice storms, floods, heatwaves, and droughts are occurring with greater frequency and severity.

These hazards present material risks to all forms of electricity generation, transmission, distribution and storage. For example, hydroelectric facilities face flooding and drought stress, while long-distance transmission lines are vulnerable to wildfires, heatwaves and extreme cold. Renewable generation and storage assets, which are growing within Canada's future energy mix, are particularly exposed to climate risks.

Clean, reliable, safe and affordable electricity is essential to maintaining Canadians' standard of living and enabling long-term economic growth. Yet without enhanced resilience, the manifestation of climate risks will progressively cause supply disruptions, raise costs, and present challenges to the investment needed to sustain a clean energy future. Significant climate events impacting the reliability of electricity grids across Canada are unfortunately becoming, at minimum, an annual occurrence.



Interconnected stakeholders working together to shape Canada's energy future.

Successful delivery of resilient energy infrastructure in Canada will require close collaboration between governments, industry, Indigenous communities, and risk professionals. The decisions taken today will determine whether Canada's electricity system is prepared for a more volatile climate.

While provinces set jurisdictional energy policy, the federal government is playing an increasingly active and crucial role, particularly through funding, legislation, and national climate commitments. As Canada facilitates its transition to net-zero, the resilience of our electricity system is no longer a regional concern - it is a national imperative.

Over the past decade, Canada has made significant progress in building renewable energy infrastructure. Renewable power generation increased by more than 20,000 megawatts (MW), or 23.1%, between 2014 and 2024, and now represents more than 65% of all electricity generated nationwide.

Additionally, according to Natural Resources Canada, 140-190 gigawatts (GW) more clean electricity generating capacity will be required by 2050 to meet the country's net-zero electricity amibition. This growth will be driven by expansions in wind, solar, nuclear and hydroelectric capacity. With the gradually declining cost of integrating new renewables to complement legacy sources of generation, their role in Canada's energy mix has been expanding.

However, this growth must be matched by efforts to safeguard energy systems from rising climate risks. Severe weather events are becoming more frequent and intense, threatening all aspects of electricity infrastructure. CatIQ, Canada's insured loss and exposure indices provider, noted that Canada faced an unprecedented $8.5 billion in insured losses in 2024, marking the costliest year for severe weather in the country's history.

For policymakers, this means embedding resilience into energy planning, regulation, and funding frameworks. For energy companies, it means investing in climate risk assessments, adaptation strategies, and technologies that enhance system flexibility and reliability. Clean energy must be protected as it grows in importance, because resilient infrastructure is essential to maintaining insurability, attracting investment, and delivering on Canada's energy and economic goals.

By working together across jurisdictions and sectors, Canada can build an energy system that is not only clean and affordable but also resilient, secure, and future-ready. This report sets out to show the value of closing that assessment gap and securing a resilient energy transition.

Source: Canadian Renewable Energy Association; Natural Resources Canada; CatIQ

Understanding risk is the first step to delivering resilience and resilience in turn will be essential for insurability.

Using proprietary modeling and risk engineering insights, Zurich Resilience Solutions, a division of Zurich Canadian Holdings Limited (“ZRS”) and Zurich Insurance Company Ltd (Canadian Branch) (“Zurich Canada”), with advisory support from Sussex Strategy Group Inc. (“Sussex Strategy”), have used publicly available asset data to map and proprietary ZRS climate data to assess the climate risk exposure of energy generation and storage assets across Canada to 2030 and 2050 under a 2°C warming scenario.

Given the criticality of renewables to the future energy mix across the country, our analysis has focussed on solar, onshore wind and hydroelectric assets, as well as a consideration for battery and pumped hydro storage. Our report provides insights as to how physical climate risks will impact Canada’s energy system in both the short (to 2030) and longer term (2050).

Our analysis highlights that across Canada, physical climate risks are already posing a threat across all energy assets. However, it is clear from our analysis that renewable generation and storage assets face unique exposure to these risks.

A note on transmission: A report detailing the climate risks to electricity generation assets in Canada would be incomplete without a mention of Canada’s complex and vast transmission network. While our research focused on renewable generation and storage, we would recommend resilience gaps addressed for the country’s transmission network as well.

The clean energy transition is important as we look to mitigate increasing climate risks and energy insecurity globally. This is the outcome which underpins most countries' transition plans and assumes a successful transition to clean energy by 2050. Absent that transition, the change in physical climate risk would be much more significant across the considered time horizon, with consequences for all types of energy infrastructure and significant economic downsides.

An overview of our findings

By 2030, 40 percent of the total renewable generation capacity in Canada will fall into our Critical-Risk Category (which is defined later in this report as 'assets face ~25% chance of experiencing a major, relevant climate event by 2030 and typically have 3 to 4 key climate hazards'). Without future-proofing resilience measures, energy generation and storage infrastructure across this country will face physical and financial risks.

This report highlights the critical need for adaptive strategies across regions and sectors to ensure our generation infrastructure remains robust, secure, and capable of withstanding climate pressures now and into the future.

Highlights

Baseload hydroelectric is not immune to climate risks: Canada's reliable, baseload hydro power is exposed to shifting water flows and more volatile seasonality highlighting the need for supply diversity and enhanced planning considerations.

Wind and solar investments are diversifying Canada's clean energy supply, but exposure exists across renewable generation and storage: Wind, solar, and battery storage are all vulnerable to increasing environmental risk, with solar and wind exposed to hail, wildfire, and ice.

Regional and seasonal variation in risk: Canada's geography presents unique climate risks across the country. Western Canada faces wildfire and drought; Central Canada is vulnerable to ice storms and flooding; Atlantic provinces face coastal storm surges. Northern and Indigenous communities, many reliant on isolated grids, face distinct climate-related challenges.

Opportunity in new build-out and storage: With clean electricity capacity set to expand, there is an unprecedented opportunity to embed resilience by design into new infrastructure and system planning.

Failing to deliver on resilience would undermine Canada's ability to achieve both its economic and environmental targets and would leave communities, industries, and taxpayers exposed to escalating physical and financial risks.

There is cause for optimism, because proven resilience solutions exist. Insurers can model climate exposure and identify where interventions, such as asset hardening, site selection, and emergency planning, will be most effective. By embedding resilience into planning, design, and investment decisions, Canada can protect its clean energy future and avoid billions in potential damages and disruptions.

Tried and tested resilience solutions to reduce risks and avoid damage are available. By working with system operators, utilities, power generators and government to deploy these insights more consistently, there is an opportunity to better quantify the value of investment in resilience, secure the promise of clean energy and storage capabilities (affordability, security and efficiency), avoid significant costs and help with insurability.

Successful delivery of enhanced energy infrastructure resilience will require a combination of national and provincial planning and coordination, with localized assessments and tailored solutions. Close collaboration between public and private sector will be essential to deliver supportive policies and aligned incentives.

A balanced renewable portfolio of hydroelectric and non-hydroelectric resources can address the inherent weather and seasonality risks associated with each technology. Furthermore, there are risk mitigation solutions available for some of the key risks (notably during planning, design and construction), such as wildfire risk reduction with enhanced vegetation management; hail risk reduction; and tornado risk reduction for wind with resilient blade designs.

Energy storage solutions can support system balancing and meeting peak demand while offering the potential for broadening the pool of important ancillary services, providing facilities all electricity grids rely on. This likewise complements the characteristics of additional pumped hydro storage capacity and can displace fossil fuels when non-emitting generators are unavailable.

To advance resilience in the energy sector, action is recommended in the following five areas:

1. Address resilience gaps for existing energy assets
2. Stress test new generation assets against dynamic climate scenarios
3. Embed resilience in planning and design
4. Improve availability of resilience relevant data
5. Unlock investment in resilience measures

Overarching insights from Zurich Resilience Solutions' analysis are captured in this report.

The evolving Canadian energy sector

Our asset data confirms the marked differences in current and future installed capacity across provinces.

Canada's electricity generation landscape is diverse, shaped by regional resources, market structures, and climate conditions. This country relies heavily on hydroelectric power, particularly in provinces like **Quebec, British Columbia, and Manitoba,** where hydro accounts for the vast majority of electricity generation. Quebec alone produces about one-third of Canada's electricity, primarily from hydro, and plays a major role in exporting power to other provinces and the U.S.

Ontario operates a mixed system with approximately 91% of its electricity coming from zero-carbon sources, including nuclear (55%), hydro (24%), wind (8%), and solar (4%). It uses natural gas for peak demand and is governed by a competitive market overseen by the Independent Electricity System Operator (IESO).

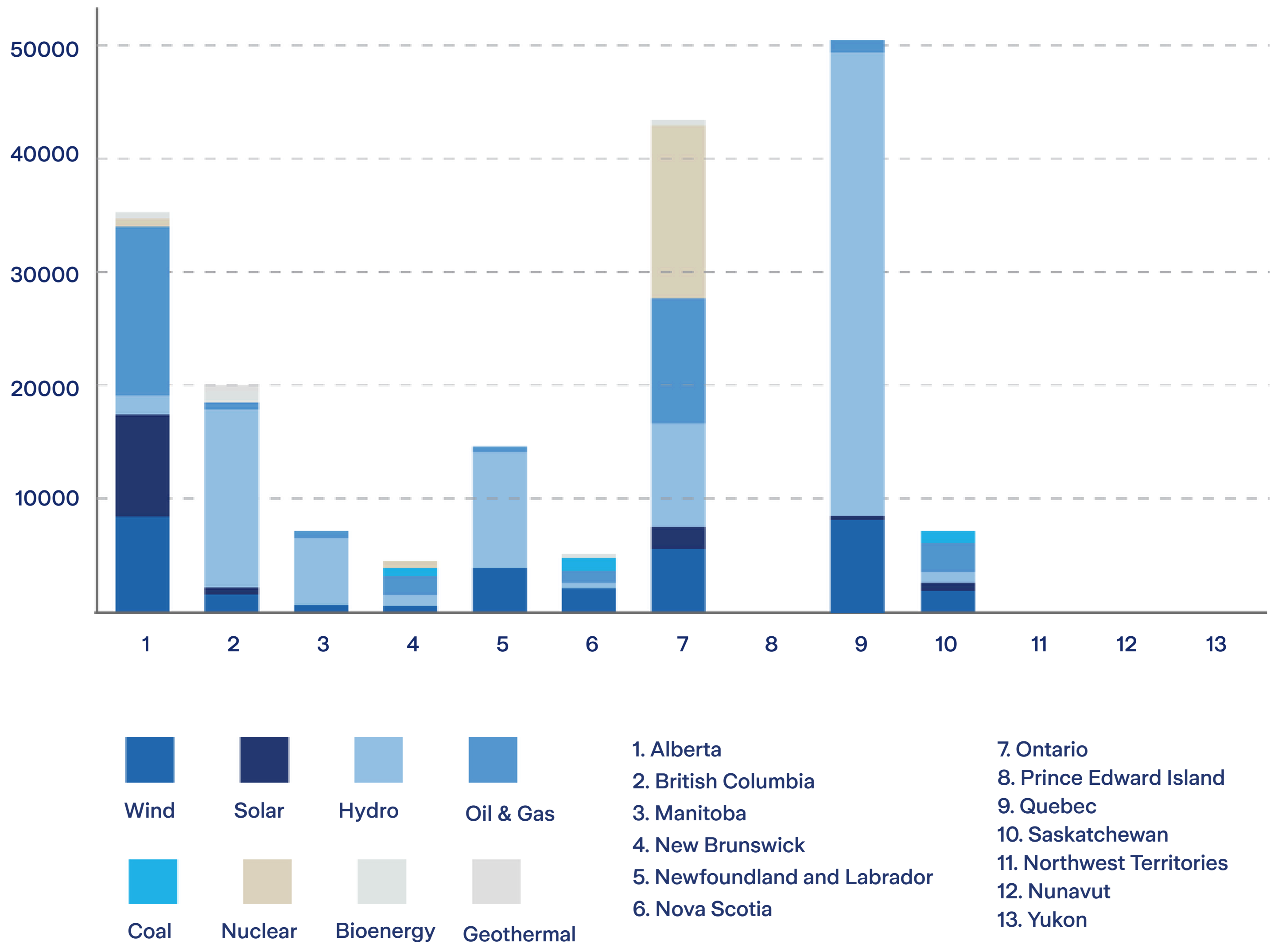
British Columbia also has a hydro-dominant system, with around 89% of its electricity coming from hydro. **Alberta, on the other hand, has transitioned away from coal (fully phased out in June 2024) and now relies on natural gas and rapidly growing wind and solar capacity.** It is the only fully deregulated electricity market in Canada.

Saskatchewan maintains a portfolio of gas, coal, and hydro, with plans to retire coal and expand wind and solar through its utility, SaskPower. Manitoba continues to be heavily reliant on hydro (over 85%) and maintains strong export ties to the U.S. Midwest.

In Atlantic Canada, provinces are also shifting away from coal. Nova Scotia is aiming for 80% renewables by 2030, supported by imports via the Maritime Link from Labrador. **New Brunswick** has a mixed energy profile, including nuclear, hydro, and fossil fuels, and is exploring coal conversion options. **Prince Edward Island** is wind-centric and relies on imports to balance its grid. **Newfoundland & Labrador** is hydro-dominant, with Churchill Falls and Muskrat Falls as key assets managed by the Crown utility, NL Hydro.

The territories show a different picture. Yukon generates over 70% of its electricity from hydro, while the **Northwest Territories** and **Nunavut** depend more on diesel and natural gas, though renewable energy is gradually expanding in remote communities.

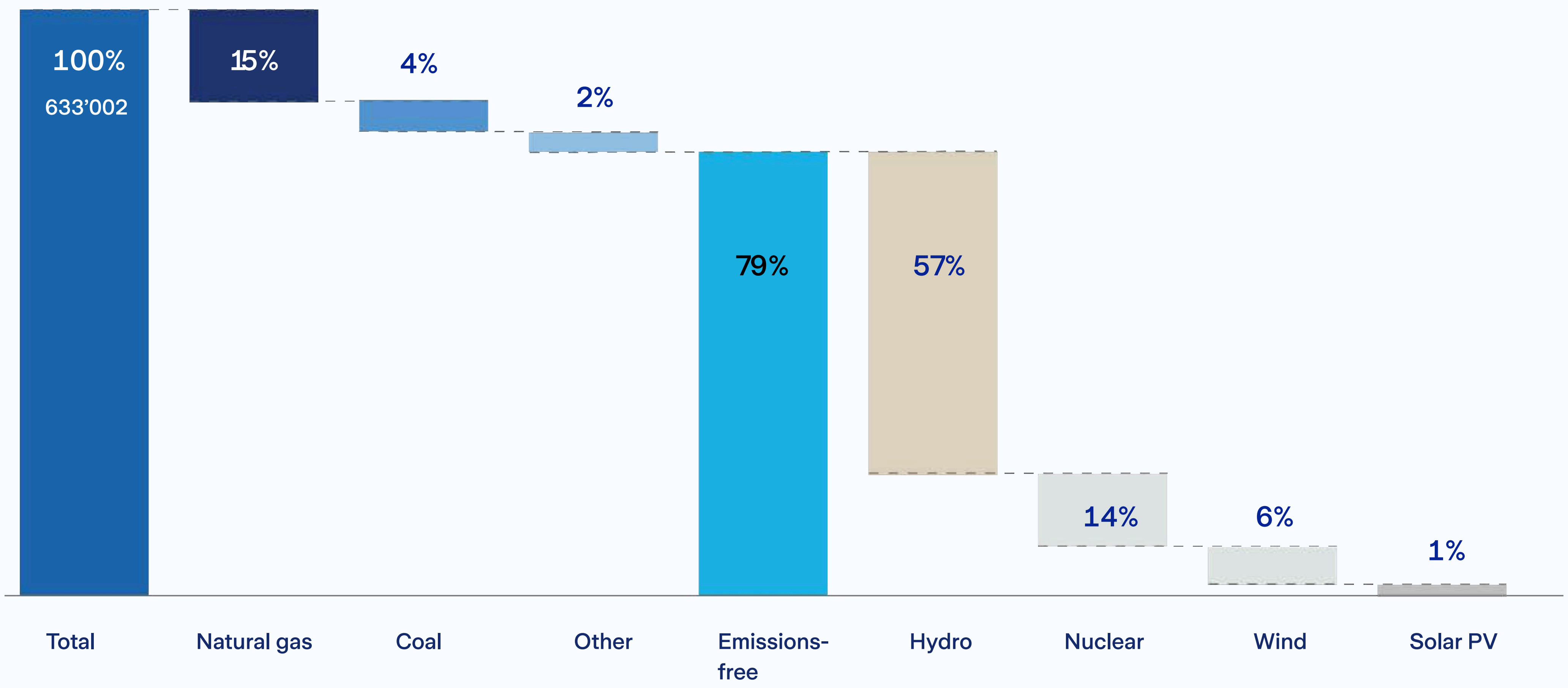
Generation Capacity by Province and Energy Type (MW)



Source: Canada Energy Regulator; Hydro-Quebec; Independent Electricity System Operator (IESO); Alberta Electric System Operator (AESO); Government of Alberta; SaskPower; Government of Canada; Nova Scotia Government; Natural Resources Canada; Yukon Government; NW Territories Power Corporation

~80% of Canada's electricity is already generated via emissions-free sources

Electricity generation by type in GWh (2023)



Overall, Canada's electricity generation is largely (79%) emissions-free - 57% Hydro, 14% nuclear and 7% wind and solar.

Regional differences in energy sources and climate vulnerabilities underscore the need for tailored resilience strategies across provinces.

Source: International Energy Agency (IEA)

The future of Canada's electricity supply mix (2025–2030)

Canada's electricity generation landscape is undergoing a transformation, driven by national net-zero commitments, climate resilience objectives, and the growing demand for clean, secure energy. This shift is further accelerated by the widespread adoption of energy-intensive digital infrastructure, industrial electrification and low carbon transportation - all of which are expected to substantially increase electricity demand across residential, commercial, and industrial sectors.

Projected Growth and Shifting Composition

Total electricity generation in Canada is projected to grow from approximately **600 terawatt-hours (TWh) in 2025 to 700 TWh by 2030**, marking a nearly **17% increase** over five years. This growth reflects both rising demand and the country's strategic push toward decarbonization.

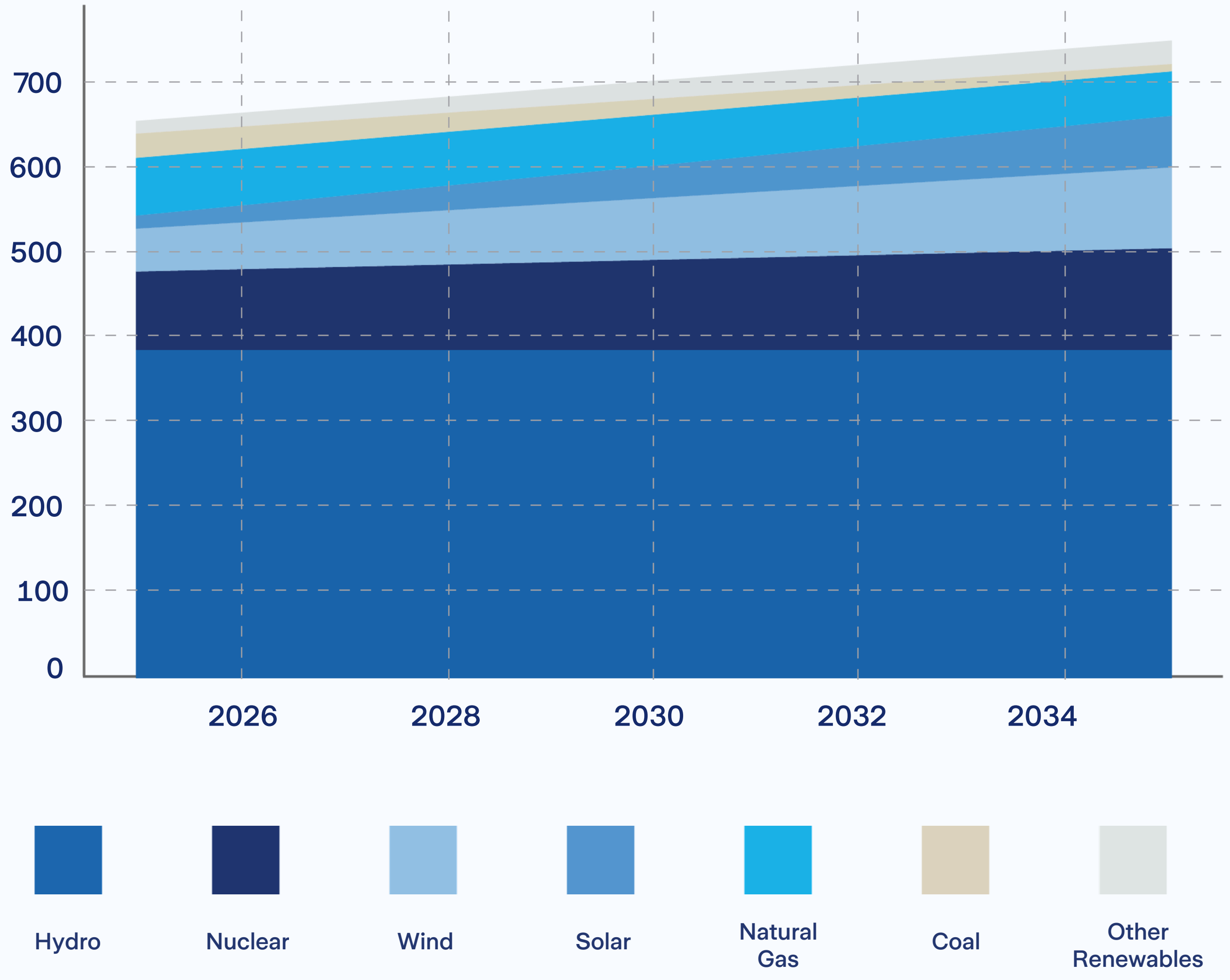
Renewable energy sources will continue to dominate Canada's supply mix. Their combined output is expected to increase from **~380 TWh in 2025** to ~**520 TWh by 2030,** raising their share of total generation from **63% to nearly 74%.**

Hydropower will remain the backbone of Canada's clean energy system, with generation rising steadily from **300 TWh to 350 TWh.** This includes investment in hydro infrastructure refurbishment. Meanwhile, wind and solar are set to expand rapidly, with **solar nearly tripling** and **wind doubling** in output over the same period.

Nuclear energy will maintain a stable contribution of approximately **85-90 TWh.**

Fossil fuel-based generation, which includes coal, natural gas, and oil, is projected to decline from **130 TWh in 2025** to **95 TWh in 2030**, reducing its share of the supply mix from **22% to under 14%.**

Projected Electricity Generation in Canada by Source (2025-2035)



Source: Government of Canada; Natural Resources Canada

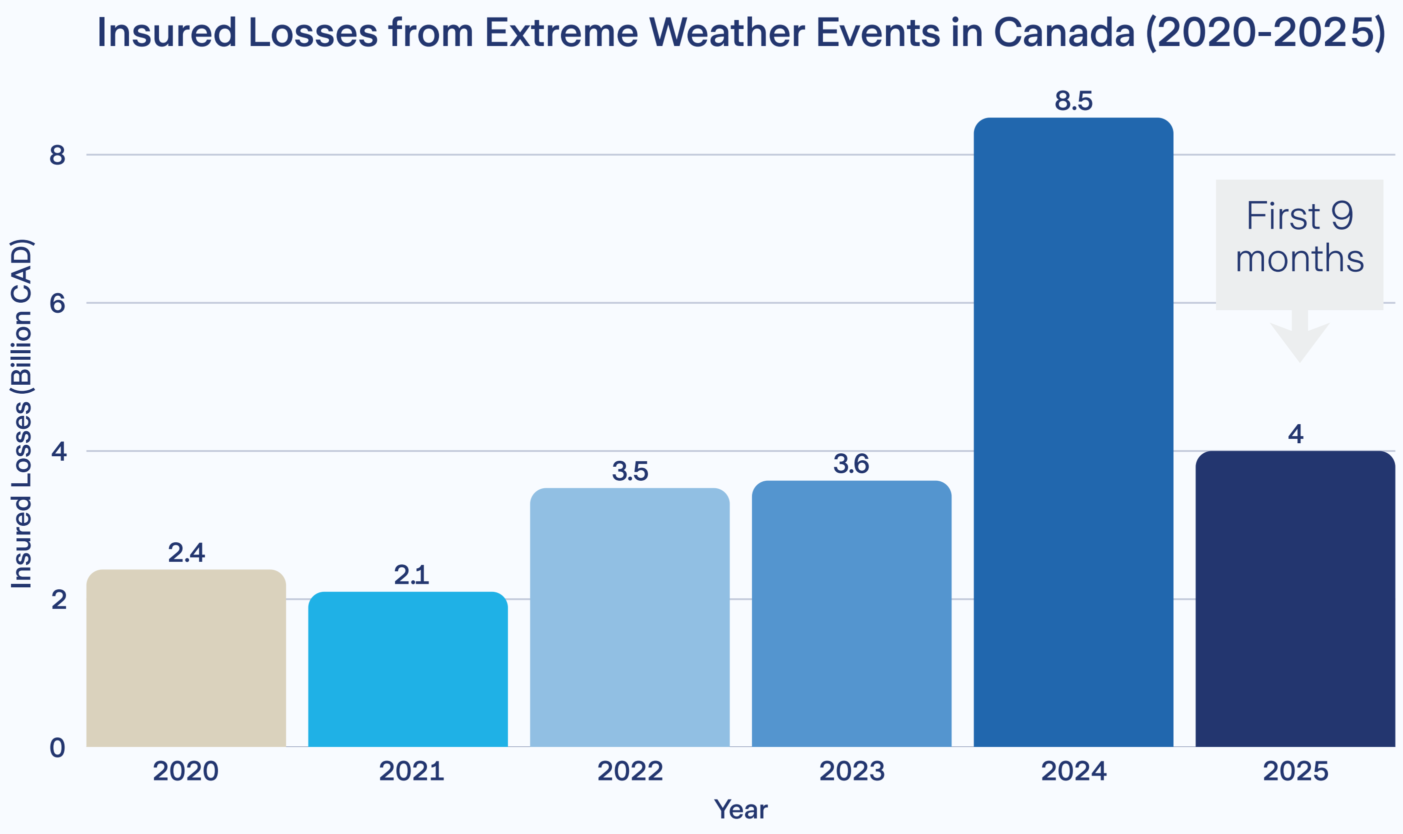
Climate risks and the Canadian energy sector

Extreme weather risks and energy generation in Canada

Climate-driven extreme weather events are fundamentally reshaping Canada's risk landscape, with natural catastrophes no longer rare occurrences but increasingly frequent and severe. According to CatIQ, in 2024 alone, insured losses from catastrophic weather events reached a record-breaking **$8.5 billion,** surpassing the previous high of $6.2 billion set in 2016 during the Fort McMurray wildfire. This figure is **12 times higher** than the annual average of **$701 million** recorded in the early 2000s. These losses stem from a series of devastating events, including the Calgary hailstorm ($3 billion), remnants of Hurricane Debby in Quebec ($2.7 billion), the Jasper wildfire ($1.1 billion), and widespread flooding in the Greater Toronto Area. Over 273,000 insurance claims were filed in 2024, a 50% increase over the typical annual volume.

Climate models and insurance data suggest this trend will continue, with rising frequency and intensity of hazards such as wildfires, drought, floods, hailstorms, and deep freezes. These events are placing increasing pressure on Canada's infrastructure, insurance systems, and energy generation and distribution assets.

For further context, according to Environment Canada, Canada's annual average temperature has increased by 2.4°C from 1948 to 2024, roughly twice the global average rate, with 2024 tying 2010 as the warmest year on record at 3.1°C above the 1961–1990 reference value.



Source: CatIQ; Insurance Bureau of Canada (IBC); Insurance Institute of Canada

Climate risks facing power generation assets

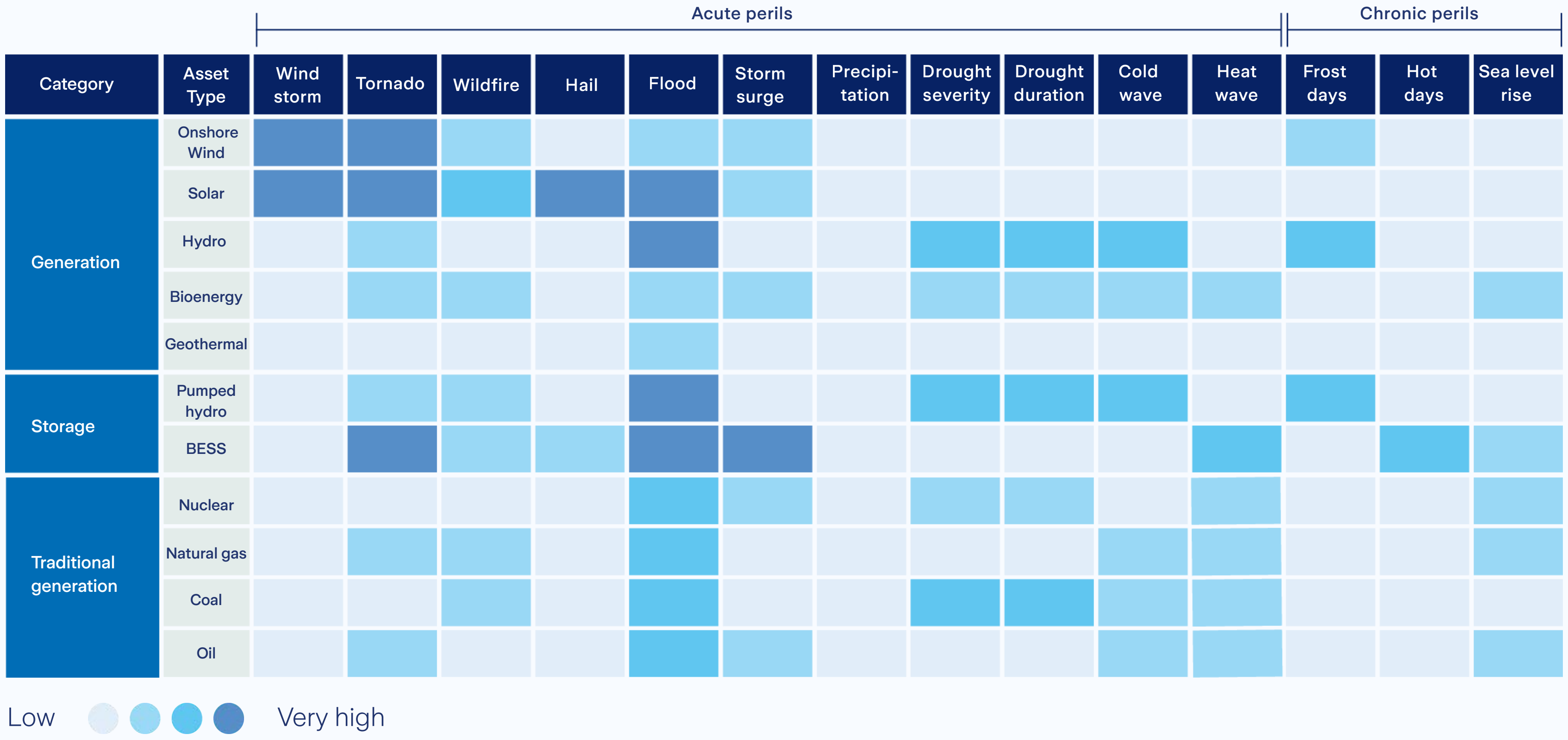
Electricity generation assets are increasingly vulnerable to climate-related challenges – and when you look at the hazard impact assessment for energy assets, sustainable energy assets are at elevated risk.

Extreme weather events can cause significant volatility in production output. This unpredictability affects both revenue streams and the reliability of energy supply. Additionally, physical infrastructure is also under greater stress, with climate-induced damage leading to higher repair costs, increased downtime, shorter lifespan and growing reliance on original equipment manufacturers (OEMs) for support.

Managing physical climate risks in Canada's energy transition

Effectively managing physical climate risks is a critical part of ensuring a successful energy transition in Canada. The encouraging news is that there are tools and expertise to meet this challenge. For example, advanced modeling capabilities to assess evolving risks over time. Understanding risk is the foundation of resilience and insurability. These insights are already being applied in collaboration with asset owners across Canada, but more urgent action is needed. Without it, we risk facing avoidable financial losses, compromised energy security, and diminished public confidence in the shift to clean energy.

Hazard impact assessment for energy assets



Strategic integration of climate risk

Embedding climate risk into core business strategies enables organizations to transform challenges into opportunities. This proactive approach helps protect assets, goods, and operations while ensuring business continuity and operational resilience. It also enhances control over critical processes such as generation availability, equipment efficiency, and supply chain logistics.

Moreover, integrating climate considerations builds stakeholder trust and positions the organization ahead of evolving regulatory requirements, reinforcing long-term competitiveness and sustainability.

Assessing the risks

To better understand the potential exposure to physical climate risks of Canada's current and future energy system, ZRS and Zurich Canada worked with strategic consulting firm Sussex Strategy Group, who specialize in Canada's energy sector, to gather data on generation assets. We then used ZRS' geospatial climate modeling data and methodology to assess physical climate risks over time and to classify generation and storage assets by risk level.

We used publicly available information to develop a dataset of over 1,000 existing and planned energy generation and storage assets. This captured details on location, status, capacity and technology. This dataset was then processed using ZRS' proprietary risk assessment tool, which allowed the mapping of individual assets to ZRS data. This data models the evolution of 15 different climate hazards over short- and medium-term horizons (2030 and 2050) using IPCC aligned scenarios and drawing on unique insight into historic loss and damage. For the purposes of this analysis, the IPCC scenario used was SSP2-4.5, which assumes a warming level of 2°C by 2041–2060 and aligns with the net-zero transition plans of most countries, as the outcome that a transition to clean energy in Canada is designed to achieve. Physical climate risk refers to the risk of physical damage or service disruption to a generation or storage facility from a climate peril (e.g., flood, drought), determined by the severity of the peril and the materiality (impact) on the technology.

Having mapped assets to ZRS modeling of future hazard evolution, risk engineering experts from ZRS' sustainable energy and climate teams assessed the potential severity of the risk posed by each climate hazard to different types of generation and storage assets. This expert assessment was combined with modeling outputs to create a hazard impact score, using a synthetic index showing the frequency and the severity of climate hazards and allowing classification of assets into five risk categories.

The impact of risk in categories 3 and above are significant and for the purposes of this analysis we have therefore defined those assets above category 3 as high risk and those falling into categories 4 and 5 as critical risk.

Category 1	Assets face ~5% chance of experiencing a major, relevant climate event by 2030 and typically have maximum 1 key climate hazard (such as hail).
Category 2	Assets face ~15% chance of experiencing a major, relevant climate event by 2030 and typically have 2 key climate hazards.
Category 3	Assets face ~20% chance of experiencing a major, relevant climate event by 2030 and typically have 3 key climate hazards.
Category 4	Assets face ~25% chance of experiencing a major, relevant climate event by 2030 and typically have 3 to 4 key climate hazards.
Category 5	Assets face ~25% chance of experiencing a major, relevant climate event by 2030 and typically have 4 or more key climate hazards.

Category	Asset Type	Total capacity (MW)	Total critical-risk[1] capacity (MW)	Proportion of capacity in critical-risk category (MW)	Acute perils: Wind storm	Tornado	Wildfire	Hail	Flood	Storm surge	Precipi-tation	Drought severity	Drought duration	Cold wave	Heat wave	Chronic perils: Frost days	Hot days	Sea level rise
Generation	Onshore Wind	33'255	748	2%														
	Solar	11'897	3'140	26%														
	Hydro	83'278	48'913	59%														
	Bioenergy	1'545	153	10%														
	Geothermal	345	-	0%														
Storage	Pumped hydro	2'143	2'143	100%														
	BESS[2]	3'703	996	27%														

Low Very high

Renewable assets face greater risk from wind, drought, and hail, which can disrupt generation and result in significant physical damage

Heatmap breakdown of renewable assets' exposure to climate perils in Canada under SSP2-4.5 (2°C warming scenario)

Colour intensity represents the hazard-impact severity

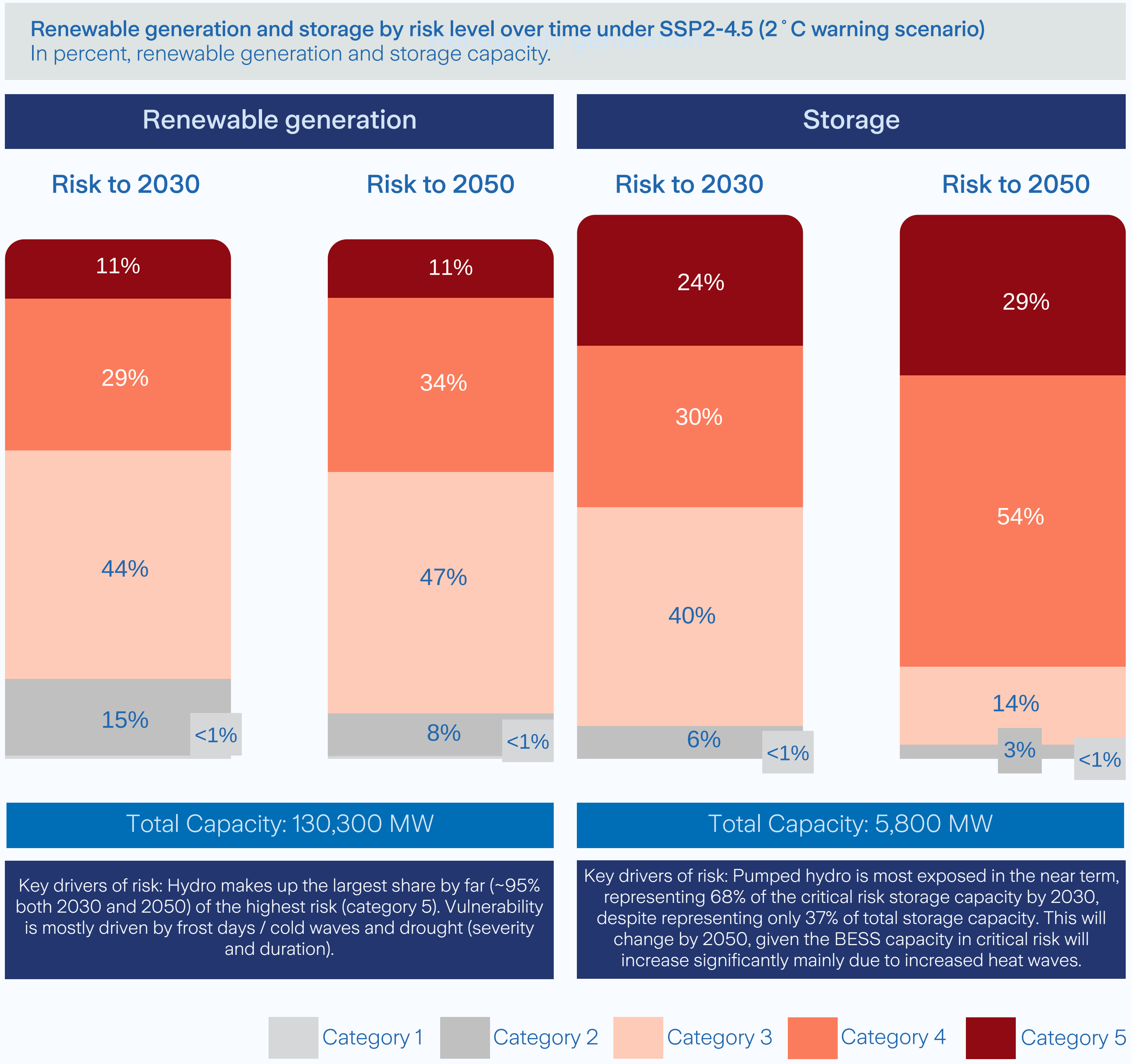
Footnote:
1. Capacity in critical risk (risk categories 4 and 5) in the near term (by 2030)
2. Battery Energy Storage System.
Source: Global Energy Monitor data; Zurich Resilience Solutions (Climate Spotlight)

By 2030, without adopting future-proofing resilience measure, 40% percent of the total renewable generation capacity in Canada will fall into our Critical-Risk Category.

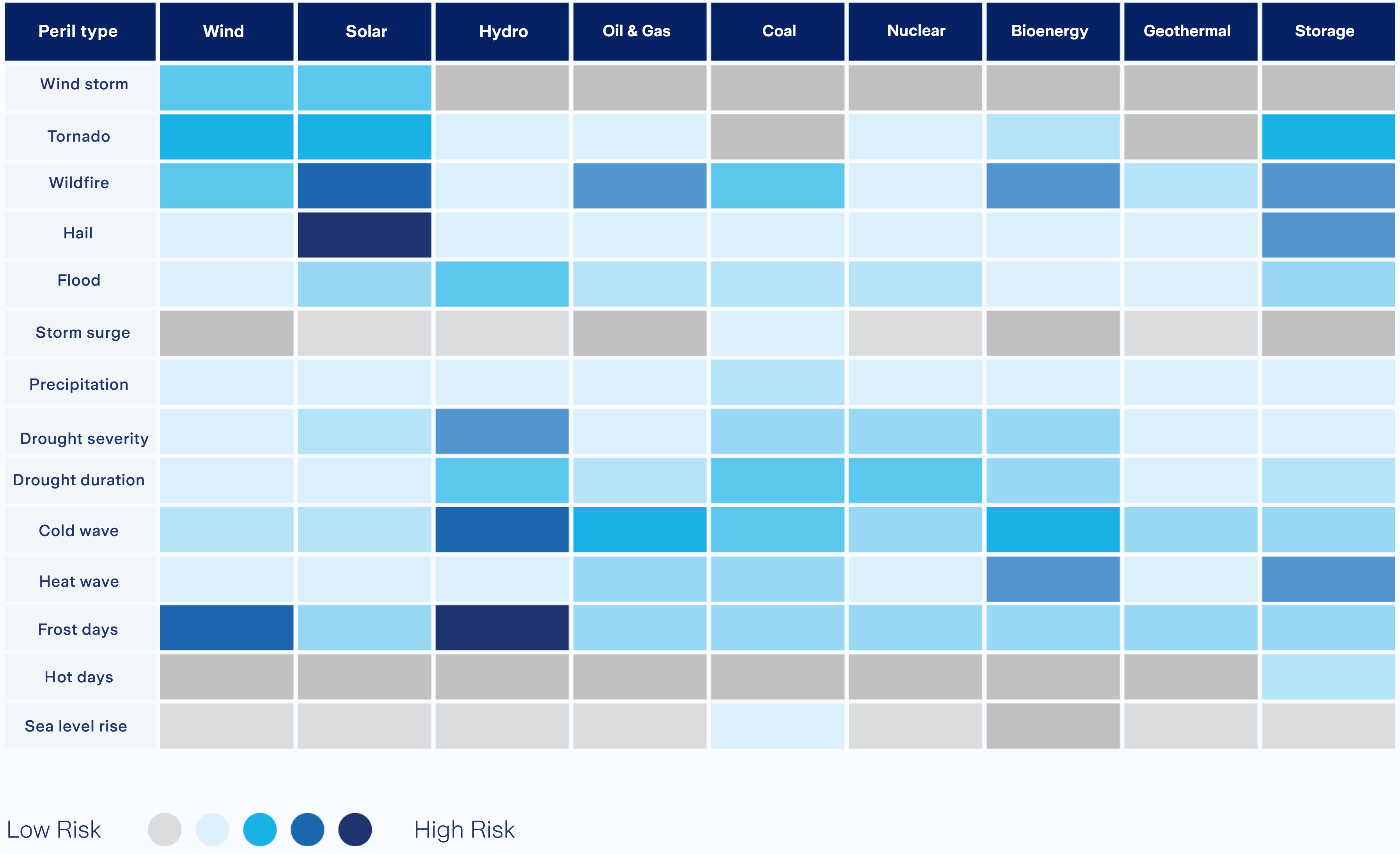
Our analysis shows that while a proportion of all energy generation assets are vulnerable to climate risks, hydro is at critical risk, and the majority of wind and solar generation assets are vulnerable to physical climate perils as well.

In the next five years, the share of all energy generation facing heightened climate risks will increase. Across Canada, hydro has the most material vulnerability with 59% of the capacity falling into the high-risk category (risk categories 4 and 5) in the near term (to 2030), comprising 127 assets. Hydro is most at risk of perils impacting output - flood, drought and cold wave.

Solar & wind are less exposed with 9 percent of wind and solar capacity falling into the high-risk category in the near term, comprising 103 assets. Wind and solar are most at risk of impact to physical infrastructure - windstorm, tornado, wildfire and hail.



Hydro is the most exposed asset class in Canada with risk mostly driven by frost/cold waves, drought and flood



Source: Zurich Resilience Solutions; Sussex Strategy Group

Examples of physical climate risks and their impacts on renewable infrastructure across Canada

Hydropower – Drought

Location: Beauharnois Generating Station, Quebec

Event description
2023–2024 drought across Quebec

Damage
Low reservoir levels reduced hydroelectric output, forcing Hydro-Québec to cut electricity exports.

Key Learning
- Hydropower is highly sensitive to prolonged dry conditions and declining water availability.
- Future planning must include drought-resilient water management and infrastructure upgrades to maintain hydropower reliability.

Wind – Heavy winds

Location: Prince Edward Island

Event Description
December 2023 – severe windstorm

Damage
The Hermanville Wind Farm in Prince Edward Island suffered significant structural damage to its turbines due to a windstorm. The damage led to a drastic reduction in the farm's energy production.

Key Learning
- Planning for future climate risks must include engineering design standards and operational protocols that account for increasingly intense wind events.
- Infrastructure resilience should prioritize turbine design, anchoring systems, and emergency response capabilities to protect generating assets in high-wind zones.

Solar – Wildfire

Location: Alberta

Event description
May–June 2023 wildfires near Grande Prairie, Edson, and Valleyview

Damage
Dense wildfire smoke reduced solar irradiance by 30–70%, lowering solar panel output and causing surface contamination.

Key Learning
- Wildfire smoke can significantly reduce solar efficiency and increase maintenance needs.
- Solar infrastructure must be designed to withstand smoke-related efficiency losses and incorporate adaptive maintenance strategies.

Source: CBC News; Empower Energy; Hydro-Quebec

Hydropower: A dominant but vulnerable backbone

Canada’s baseload hydro supply
Reliable hydro today. Diverse, sustainable energy tomorrow.

Hydroelectricity in Canada: Overview and seasonal dynamics
According to the Government of Canada, hydroelectricity accounts for approximately 62% of the country’s electricity generation, making Canada the third-largest producer of hydroelectric power globally.

Natural Resources Canada further reports that in 2021, Canada operated 595 hydroelectric stations with a combined installed capacity of 82,232 megawatts. In 2022, these stations generated 393,789 gigawatt-hours of electricity, representing 61.7% of the nation’s total electricity production.

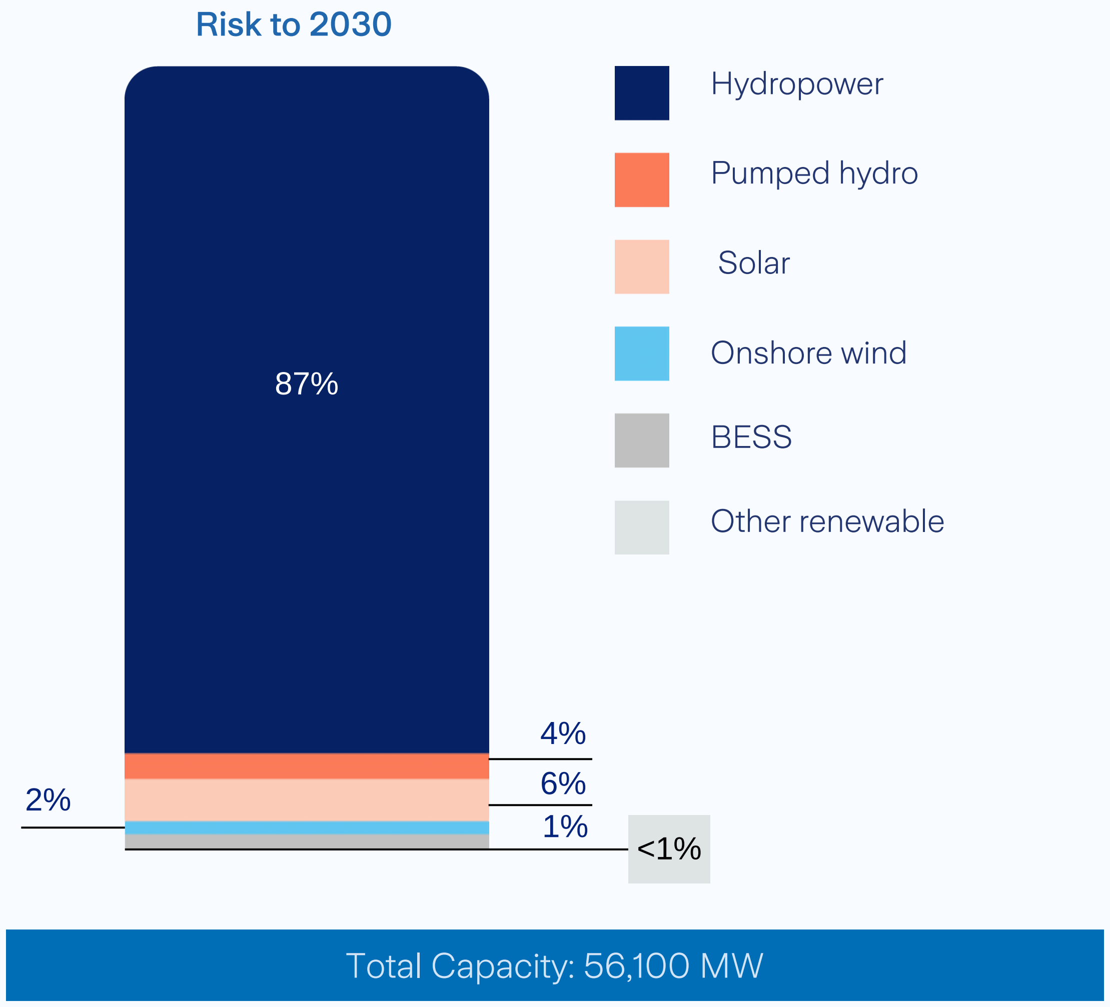
Seasonal variations in hydroelectric demand and output
Electricity consumption in Canada, particularly in Quebec, experiences significant seasonal fluctuations. During winter months, demand nearly doubles compared to summer, largely due to increased heating needs. On February 3, 2023, Hydro-Québec recorded a historic peak demand of 43,124 megawatts.

Conversely, summer conditions - especially hot and dry weather - can lead to reduced water levels in reservoirs. This limits hydroelectric output and forces provinces such as British Columbia and Quebec to reduce electricity exports and, in some cases, import power to meet domestic needs.

The role and risks of hydroelectric infrastructure
Hydroelectric power remains a cornerstone of Canada’s energy system, providing reliable, affordable and clean electricity. It supports essential services such as heating homes, powering hospitals, and driving industrial activity.

However, current trends suggest that this critical infrastructure may be increasingly at risk, underscoring the need for continued investment and strategic planning.

Critical- risk renewable generation and storage capacity in 2030 under SSP2-4.6 (2˚C warming scenario)



Note: Other renewable generation includes bioenergy and geothermal
Source: Natural Resources Canada

Climate hazards and risk exposure in Canada's hydropower sector: Manitoba, British Columbia and Quebec are most exposed

In the near-term (2030) 59% of Canada's hydropower capacity falls in the Critical-Risk category - this stays relatively consistent as we move into 2050.

Among the most exposed provinces are Manitoba, where 74% of total generation capacity falls into the Critical-Risk category; British Columbia, at 69%; and Quebec, at 44%. These three provinces collectively represent approximately 40% of Canada's population, underscoring the widespread implications of this vulnerability.

When we look closely at the risks faced by hydropower, this type of generation is increasingly vulnerable to diverse climate hazards: flood, cold waves and drought.

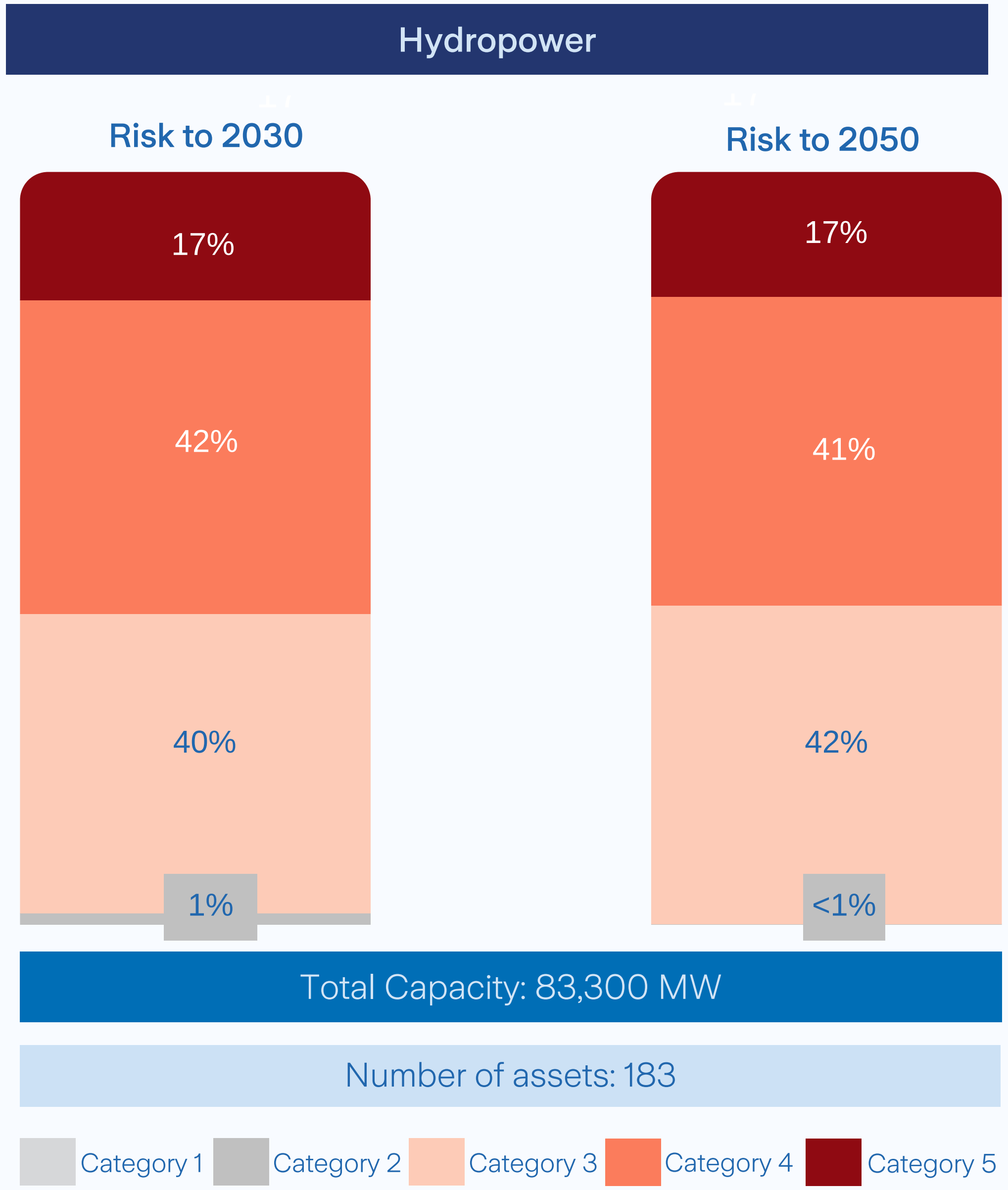
Flooding can overwhelm reservoirs and damage critical infrastructure, while severe droughts can drastically reduce water availability, significantly reducing hydroelectric generation entirely.

Seasonal implications of perils on hydropower

The risk of these perils highlights that seasonal climate hazards pose significant challenges to hydroelectric generation, particularly during periods of peak electricity demand. For example, in Ontario, summer droughts can severely constrain supply just as demand surges due to air conditioning and cooling needs. Similarly, in Quebec, winter cold waves can threaten supply at a time when heating demand reaches its highest levels.

The year 2023 illustrated the severity of these risks. A combination of drought and record-breaking summer heat led to an 8.4% decline in national hydroelectric output. The impact was particularly pronounced in key provinces: **British Columbia: -21.5% Manitoba: -12.1% Quebec: -9.3%**

These figures underscore the urgent need to address climate resilience in Canada's hydroelectric infrastructure to ensure continued reliability and sustainability.



Source: Zurich Resilience Solutions; Sussex Strategy Group; Statistics Canada; Hydro-Quebec; Government of Canada; IEA

Canada's hydro story
Reliable hydro today. Diverse, sustainable energy tomorrow.

Future-proofing Canada's baseload power generation

To ensure the long-term reliability of Canada's baseload power generation, it is essential to invest in resilience measures for both existing and future hydroelectric infrastructure.

Building seasonal resilience into hydro infrastructure requires a comprehensive understanding of regional climate risks, operational vulnerabilities, and demand patterns. We should consider the following seasonal resilience measures when building new hydro projects and future-proofing current assets.

Summer resilience recommendations

1. **Optimize water use and conservation**
   Hot, dry summers and droughts reduce river flows. Adjusting reservoir operations and supporting upstream conservation helps sustain water levels for power generation and ecosystems.

2. **Monitor water and safeguard infrastructure**
   High temperatures impact water quality and equipment. Sensors and heat-resistant upgrades protect operations from heat and wildfire risks.

3. **Enhance emergency preparedness and access**
   Storms, wildfires, and heatwaves threaten generation and site access. Regularly updated emergency plans and coordination with local authorities ensure rapid response and reliable hydropower.

Winter resilience recommendations

1. **Reinforce and winterize infrastructure**
   Snow, ice, and extreme cold can damage dams and disrupt operations. Strengthening structures and using cold-resistant materials keeps facilities running smoothly.

2. **Monitor ice and weather proactively**
   Ice jams and severe weather threaten water flow and safety. Real-time monitoring and early intervention tools help prevent major disruptions.

3. **Ensure access and emergency readiness**
   Blocked roads and winter storms delay response efforts. Snow removal, winter-ready vehicles, and updated emergency plans ensure quick action and reliable service.

Canada's hydro story
Reliable hydro today. Diverse, sustainable energy tomorrow.

Canada should and will remain a global leader in hydroelectric generation.

There is significant upside to refurbishing Canada's hydroelectric infrastructure. By replacing turbine-alternator groups, refurbishing water intakes, and upgrading control systems, we can achieve up to 15% higher efficiency and greater reliability in hydropower generation. Additionally, spillway modifications and modernized equipment help our plants adapt to changing weather conditions, ensuring consistent energy supply even during challenging winter months.

When we asses the climate risk to our current, refurbished and future hydro capacity, the calls to action are clear:

1. **Investment in resilience measures for future, refurbished and current hydroelectric assets.**
2. **Investment in resilient infrastructure built to support generation assets and the entire electricity system.**
3. **Consider risk resilience when managing construction & supply chain risks.**

As Canada looks to invest in diversified renewable generation, it is imperative that risk resilience be embedded into the planning and construction of all energy projects. This includes proactive management of construction and supply chain risks, which are increasingly relevant in today's volatile global environment.

Renewables and storage: Growing but exposed

Wind and solar: Growing but exposed

Given the planned increase in investment in wind, solar, and storage capacity over the next 5–10 years—and the critical role these technologies play in achieving net-zero emissions—there is both a pressing need and a clear opportunity to ensure renewable energy infrastructure is resilient to climate-related hazards.

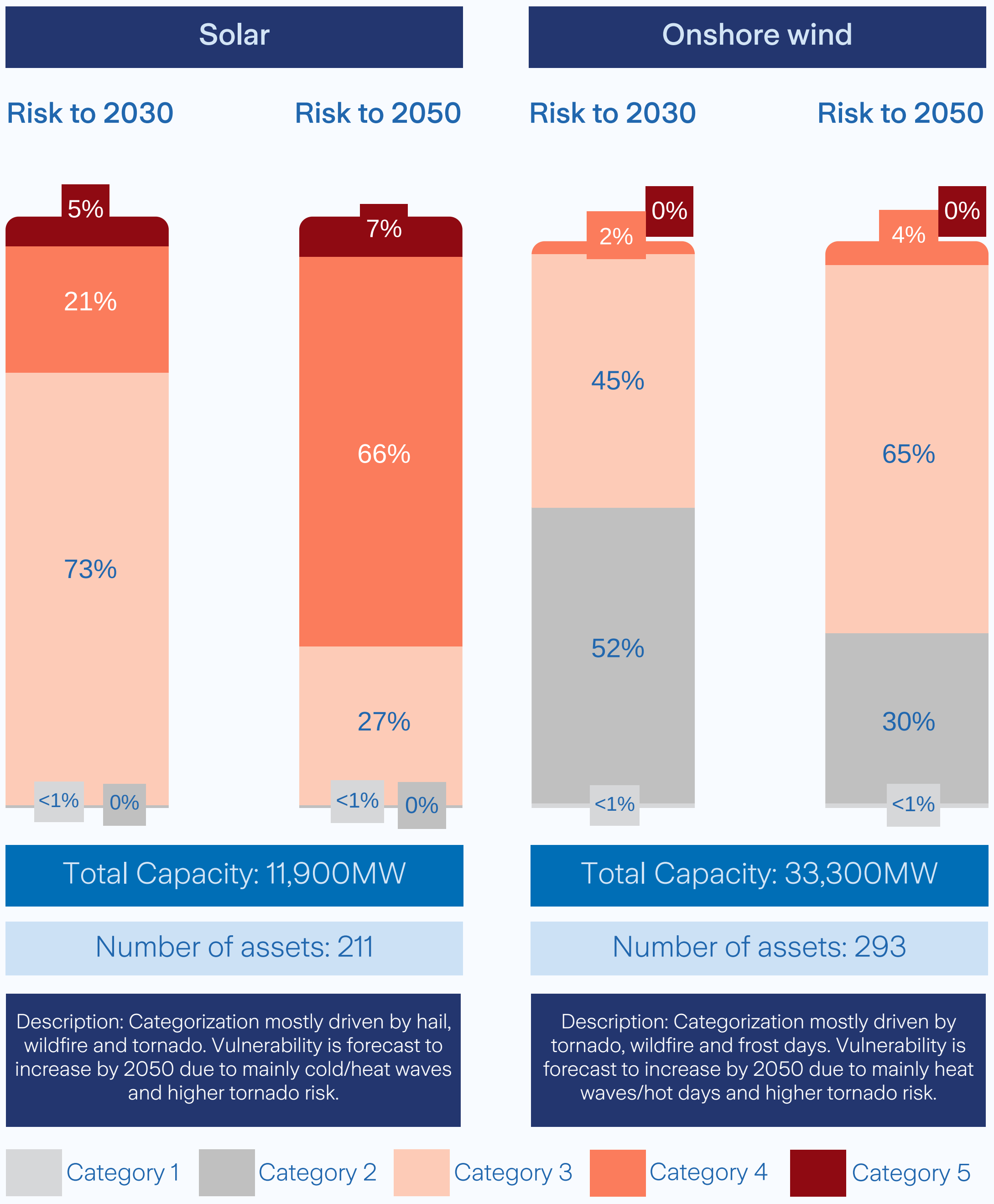
In the near-term, 26% of **solar generation** will fall into the Critical-Risk category. When we look to the long-term that number increases to 73%. This increase is due mainly to cold/heat waves and higher tornado risk.

When examining the distribution of physical climate risks across solar generation they stand out as vulnerable to tornado, wildfire and hail. Solar farms are often located in regions with high solar irradiance, which also tend to be prone to extreme weather events. Hailstorms pose a significant threat to photovoltaic panels, potentially causing widespread damage in a single event. Wildfires, increasingly frequent and intense in Canada due to rising temperatures and prolonged droughts, can destroy infrastructure outright or degrade air quality, reducing solar efficiency. Wind events, including tornadoes and severe storms, can also damage panel arrays and mounting systems, leading to costly repairs and downtime.

In the near-term, 45% of **onshore wind generation** fall into the high-risk category. When we look to the long-term that number increases to 65% with 4% in the Critical-Risk category. The vulnerability is forecast to increase by 2050 due to mainly heat waves/hot days and higher tornado risk.

Onshore wind generation faces a similar risk profile to solar. Frost and ice accumulation on turbine blades can impair performance and increase mechanical stress, while wildfires threaten both the turbines and the transmission infrastructure that supports them. High wind events – ironically – can exceed design tolerances, leading to blade damage or structural failure, especially in older or poorly maintained assets. These risks are compounded in regions where climate volatility is increasing, requiring more robust design standards and adaptive maintenance strategies.

Provinces with rapid plans to expand deployment of wind and solar infrastructure, Alberta, Ontario, the Maritimes and Quebec, should pay close attention to future-proofing this generation. As climate hazards intensify, integrating resilience into the planning, design, and operation of renewable energy assets will be essential, not only to protect investments, but to ensure continuity of supply in a decarbonized grid.



BESS in Canada is set to grow massively in the coming years

Battery Energy Storage Systems (BESS) are poised for significant growth in Canada, playing a pivotal role in achieving the country's net-zero emissions targets.

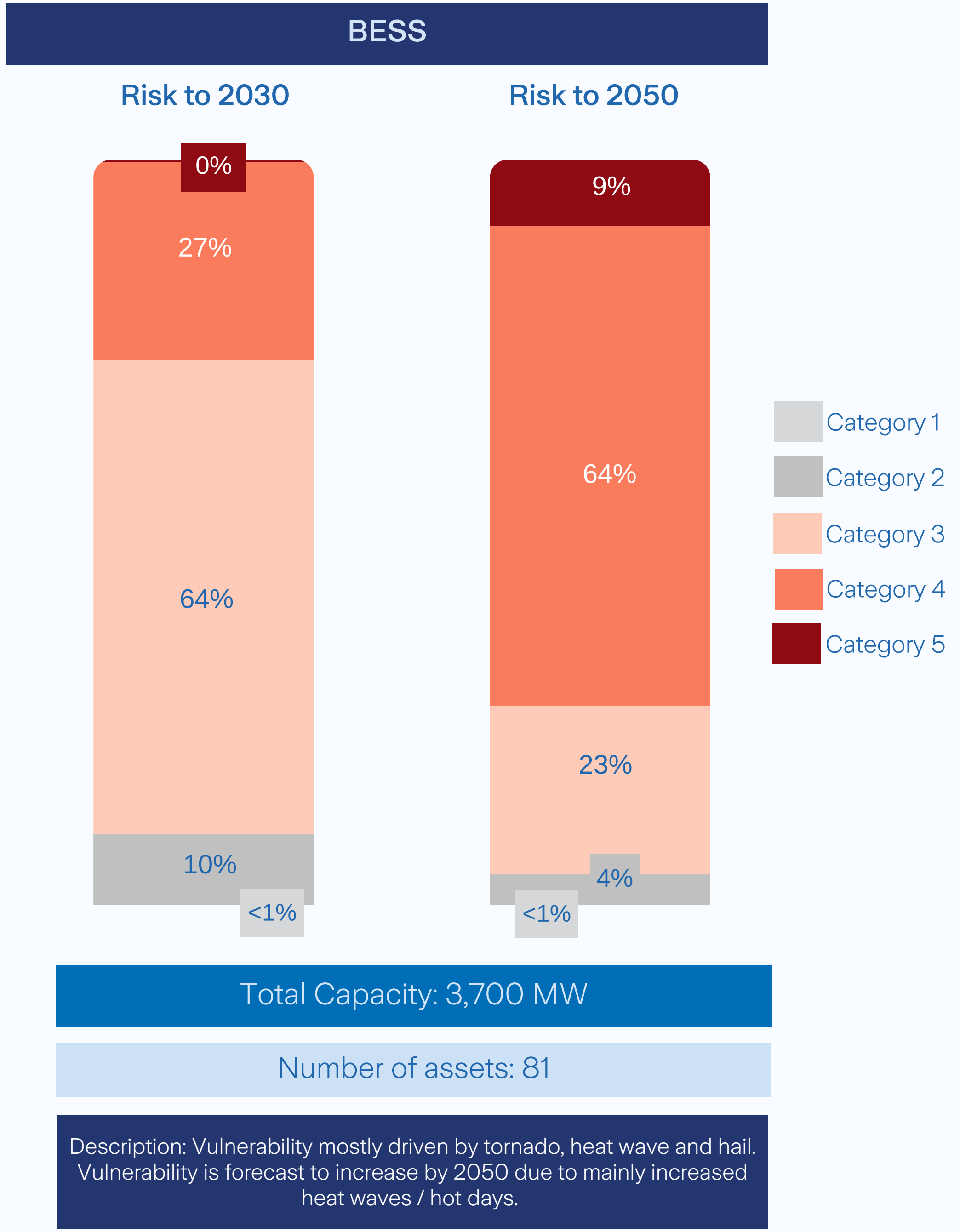
Strategically, BESS enables greater integration of renewable energy, enhances grid stability during demand fluctuations, and reduces reliance on emitting generation—aligning with Canada's climate goals.

As of now, Canada has approximately 400 MW of installed large-scale grid-connected BESS, with an additional 500 MW under construction. If all announced projects proceed, total capacity will reach 3,700 MW by 2030.

Alberta, Ontario, and Quebec are the primary regions for deployment, reflecting their respective energy profiles. The Canadian Climate Institute projects that national energy storage capacity could exceed 4 GW by 2028 already, while Energy Storage Canada estimates a need for 8–12 GW by 2035.

In the near-term, 27% of BESS infrastructure falls into the Critical-Risk category. When we look to the long-term that number increases to 73%. The vulnerability is forecast to increase by 2050 due to mainly increased heat waves/hot days.

When examining the distribution of physical climate risks across solar generation stand out as vulnerable to tornado, heat wave and hail. BESS infrastructure is especially vulnerable to extreme temperatures —particularly for lithium-ion technologies—underscoring the importance of resilience planning in future deployments.



Source: The Canadian Climate Institute

Protecting our wind, solar and storage infrastructure today and our investments in tomorrow

As Canada accelerates its transition to a net-zero electricity system, it is critical to ensure that wind, solar and storage infrastructure is designed and operated with climate resilience in mind. The following strategies are examples of best practices for protecting these technologies from the most at-risk climate perils:

1. **Wildfire Risk Mitigation**
    - Implementing vegetation management around wind, solar, and BESS sites helps reduce ignition potential.
    - Advanced fire detection systems, including heat and smoke sensors, paired with automated suppression technologies, are increasingly standard in BESS installations.
    - Site selection and design should prioritize fire-resistant materials and avoid high-risk wildfire zones.
2. **Hail Protection for Solar Infrastructure**
    - Solar panels constructed with tempered glass and reinforced frames offer greater resistance to hail damage.
    - Tracker systems can be programmed to move panels into protective stow positions during hailstorms, minimizing exposure.
3. **Cold Climate Adaptation**
    - Wind turbines and solar panels deployed in Canada are increasingly equipped with cold-rated components and anti-icing technologies.
    - Seasonal maintenance protocols, including thermal imaging and pre-winter inspections, help ensure operational reliability during extreme cold events.
4. **Wind Resilience Measures**
    - Wind turbines are being designed with aerodynamic blades capable of withstanding high wind speeds and gusts.
    - Solar panels and BESS enclosures use reinforced mounting systems to prevent damage or displacement during storms.
5. **Climate-Resilient BESS Design**
    - BESS facilities incorporate advanced thermal management systems to maintain performance during heatwaves and cold snaps.
    - Real-time monitoring and predictive analytics enable operators to respond proactively to weather threats.
    - Compliance with evolving fire safety and electrical standards ensures long-term resilience and safety.

These measures are essential to safeguarding Canada's growing portfolio of renewable energy assets and ensuring their reliability in the face of increasingly volatile climate conditions.

What's at stake: Further actions to mitigate risks

Recommendations

In response to our findings, we have developed five strategic recommendations for stakeholders involved in renewable electricity generation. These recommendations are designed to enhance resilience, mitigate risk, and ensure continuity of supply.

While the solutions exist, their consistent and efficient deployment will require cross-sector collaboration. Public and private stakeholders must work together to raise awareness, align incentives, and unlock the investment needed to build a more resilient energy future for Canada.

1. **Improve climate resilience of existing assets**
   Risk preparedness is the first line of defense, and lowering exposure and vulnerabilities to evolving physical climate risks will help companies that own energy generation assets avoid losses and improve insurability. There is a role for policymakers to look at opportunities to incentivize investment in resilience measures.

2. **Adopt climate stress testing for new generation and storage assets**
   Understanding future risks and modeling the development of climate hazards should be a key part of any design decisions for new energy infrastructure. Companies across the whole value chain should adopt a resilience by design approach, while governments should shape a policy environment that encourages scaling of engineering innovations that enhance resilience.

3. **Embed resilience in planning and design processes**
   A clear, stable and predictable policy environment which embeds resilience as a key principle in the roll out of new energy infrastructure will support investment and encourage innovation.

4. **Improve data access and quality**
   Better access to public data will help refine risk modeling and enhance the development of open-source datasets on climate hazards. Public authorities must improve the availability and usability of resilience relevant data (e.g. location of planned assets; zoning decisions; climate peril exposures). There are countries in Europe that do this already and best practice should be shared.

5. **Unlock investment in resilience measures**
   A greater focus on resilience should secure insurability and support investment. However, in order to ensure the future security of energy systems in the face of increasing physical climate risks, policymakers should look at ways of leveraging blended finance mechanisms to crowd in investment and collaborate with industry and investors to ensure a pipeline of investible resilience assets.

Targeted adaptation measures can significantly improve the reliability of the transitioning energy system

Overview of key adaptation methods by type of clean energy asset type

Asset Type	Key Perils	Example of physical impact	Selection of key climate resilience adaptation measures
Solar	• Wind gusts • Hail • Wildfires	 Solar panels battered by hail.	• Install **hail- and heat-resistant modules** with durable frames, anti-soiling coatings, and cooling-ready inverter enclosures. • Design for cold and snow with **steep tilt angles, anti-icing systems, and snow removal plans** for priority installations.
Wind	• Wind gusts • Wildfires • Tornadoes	 Wind turbine destroyed by a tornado.	• Select the right **wind turbine variant** that can withstand higher winds with storm-stow blade positioning and use deeper foundations. • Use **robust foundations and spacing** to stabilise towers in extreme wind zones and reduce turbine-to-turbine turbulence in high-wind events.
Hydropower	• Floods • Cold waves • Droughts	 Floods burst a hydropower dam.	• **Expand spillway capacity and reinforce dam structures** to handle extreme floods, including fuse plugs and early warning-driven reservoir management. • Integrate **early warning systems and regular dam inspections** to proactively manage extreme inflow or upstream landslide/glacial flood risks.
Battery energy storage systems (BESS)	• Heatwaves • Tornadoes • Floods	 A battery facility is damaged by heatwave.	• Ensure **climate-controlled enclosures** with HVAC systems, insulation, and backup power for cooling during heatwaves. • Create wildfire-safe perimeters using **fire-resistant materials, automatic suppression systems, and pre-emptive shutdown protocols.**

Methodology

Methodology

Zurich Resilience Solutions' geospatial climate risk modeling was used to assess physical climate risks to generation and storage assets

Definition

Physical climate risk refers to the risk of physical damage or service disruption to a generation or storage facility from a climate peril (e.g., flood, drought), determined by the severity of the peril and the materiality (impact) on the technology. **This analysis includes only land-based assets, excluding offshore wind.**

Method

1 Asset data collection

- Sussex Strategy Group and Zurich Canada developed a dataset of energy generation and storage assets through desktop research including sources such as the provincial electricity system operators.
- This dataset consisted of the location of each asset, its operational status (e.g., announced, in construction, operating), capacity and the generation/storage technology (e.g., solar, nuclear, battery, flywheel).
- The analysis in this report is based on energy asset data available as of May 2025.

2 Mapping data to Zurich climate modeling

- ZRS's proprietary climate data was used to determine the climate risk faced by each asset, based on IPCC definitions of climate scenarios, scaled to the asset- level under a range of time horizons.
- ZRS' Climate Spotlight digital platform was used to analyze and visualize the combination of climate and asset datasets. The hazard ratings were expressed qualitatively from low to very high, for 15 hazards.
- The most likely climate scenario of SSP2-4.5 (2°C warming by 2050) with near-and-medium-time horizons was selected as it aligns with current emission trends and typical renewable asset lifespans.

3 Impact assessment

- In coordination with ZRS energy and climate specialists, an impact assessment was developed that determined the materiality of each climate hazard on technology types
- The potential impact of each hazard type was assigned a value of 'low' to 'very high', reflecting the impact a particular climate peril would have on an asset. This was to ensure that assessment of climate risk would reflect the probable likely impact on an asset.

4 Total hazard-impact score

- A total score was then developed for each asset site in the database. This calculation converted the ratings of hazard and impact, which were categorised as low to very high, to a 1 to 4 scale.
- The value of the hazard and impact for each asset was then multiplied.
- For example, if a solar farm has a 'very high' hazard level for hail (a value of 4) and a hail impact score of very high (a value of 4), the total hazard-impact score for that solar farm would be 16.

5 Risk Categorisation

- Assets are grouped into five categories (1 to 5) using z-scores, where 1 represents less risky assets and 5 represents highly risky assets. Z-scores measure how far each asset's hazard-impact value deviates from the mean.
- The impact of risk in categories 3 and above are significant and, for the purpose of this analysis, we have therefore defined those assets above category 3 as high risk and those falling into categories 4 and 5 as critical risk.
- The probability of experiencing a climate event is calculated using the return period for each asset and then averaged across all assets within each category.

Note: Shared Socioeconomic Pathways (SSPs) are climate change scenarios of projected socioeconomic global changes by the UN Intergovernmental Panel on Climate Change Source Source Zurich Resilience Solutions: ZRS; Sussex Strategy Group

Probability of climate peril occurrence at an asset location

First statistical step: Converting return periods to probability

Extract return period for each climate hazard from ZRS' data

→

Use the probability mass function for Poisson's distribution to calculate the probability of the peril not **taking place** in the next five years

Example: If the return period of occurrence for a wind gust peril is 100 years (μ = 0.01), then the probability of no occurrences in five years is:

$$P(r;t) = \frac{(\mu t)^r}{r!} e^{-\mu t} \longrightarrow P(r=0;t=5) = \frac{(5/100)^0}{0!} e^{-5/100} \approx 95.12\%$$

Intermediate step: Finding the cumulative probability of a climate event NOT taking place at an asset location in the next five years

When both the hazard level from ZRS' database and the risk impact score from the impact matrix exceed threshold 'L', the 5-year non-occurrence probability becomes one of the factors multiplied together in the cumulative probability calculation.
Note: This multiplication approach assumes all climate perils are statistically independent events, providing a simplified but practical basis to determine probability of climate events taking place

Probability any climate peril DOES NOT take place at that asset location in the next 5 years **=** Probability that **climate peril A** does not take place in the next 5 years **×** Probability that **climate peril B** does not take place in the next 5 years **×** Probability that **climate peril C** does not take place in the next 5 years **×** Probability that **climate peril...** does not take place in the next 5 years

Final probability: Finding the probability that a climate event DOES take place at an asset location in the next five years

Probability a climate peril DOES take place at that asset location in the next 5 years **= 1 -** Probability that climate peril A does not take place in the next 5 years

Key:

Intermediate output

Calculated output

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