Summit on the Future of Energy Security

Background paper

International Energy Agency

INTERNATIONAL ENERGY AGENCY

The IEA examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 32 Member countries, 13 Association countries and beyond.

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International Energy Agency
Website: www.iea.org

Foreword

The world is in a new era of energy security. As old certainties fall away and new realities emerge, the UK and IEA have brought the world together at this Summit to discuss how countries can work together in this new era.

The International Energy Agency (IEA) was founded in the wake of the 1973 oil crisis, which sparked major changes in the global energy system. Now we face a whole new range of risks and opportunities, including those caused by Russia's invasion of Ukraine, developments in digitalisation, and the huge potential offered by renewables and other clean energy technologies. In recent years, energy security has risen up the global agenda as countries have acted to respond to today’s challenges and protect themselves from future energy shocks.

The Summit comes at a moment when we have seen dramatic shifts in the pattern of energy deployment over the last decade. The rapid fall in the cost of renewables is driving strong growth of clean energy around the world, with over 80% of the increase in global electricity generation provided by renewables and nuclear and around $2 trillion invested in clean energy globally last year. Meanwhile, the world is entering a new age of electricity, with electricity use growing twice as fast as overall energy demand over the last decade and set to expand even faster in the coming years.

As the world changes, so do both traditional and emerging challenges around energy security. This Summit is an opportunity for us to come together and discuss the shifting energy security landscape – from traditional risks like those related to oil and gas supplies to emerging issues around electricity security, clean energy supply chains and critical minerals.

Recent years are a reminder that there is no national security without energy security. Energy security is the foundation of economic security, given the importance of a secure and affordable energy supply to living standards, job creation and economic growth. And it is fundamentally linked to climate security and the impacts of extreme weather events.

For the UK and many other countries, it is clear that the clean energy transition is not just a climate imperative but an urgent national security imperative.

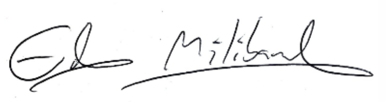
Families and businesses have been hard hit by the UK’s exposure to volatile international fossil fuel markets. That is why one of Prime Minister Keir Starmer’s five national missions is to make Britain a clean energy superpower, rapidly expanding clean energy as the route to energy security, lower bills, good jobs, growth, and tackling the climate crisis.

Thanks to the certainty and ambition offered through the UK's mission, investment in clean energy is booming – with over £43 billion of new investment announced in clean energy industries since July 2024.

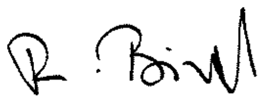
Each country faces its own energy security challenges and constraints. The Summit will reflect that in our discussions, recognising that every country will follow its own national interest in securing its energy supplies, taking into account its specific circumstances.

But we also face shared challenges, which is why we need to work together and learn from each other. In a changing world, countries have an opportunity to make their energy systems more secure, affordable and sustainable for the benefit of their citizens.

We look forward to co-chairing this landmark Summit and hope it marks the start of renewed co-operation on these issues over the months and years ahead.



Rt Hon. Ed Miliband M.P.
Secretary of State for Energy Security and Net Zero
United Kingdom



Dr. Fatih Birol
Executive Director
International Energy Agency

Introduction

For 50 years, the International Energy Agency (IEA) has been central to global energy security efforts, helping to anticipate, avoid, mitigate, and manage energy disruptions. While initially focused on oil security – coordinating five collective emergency stock releases throughout its history, including two in 2022 – the IEA has progressively expanded its scope to include natural gas, electricity, critical minerals, and energy technology supply chains.

Today energy systems are undergoing rapid transformations due to shifting demand patterns, increasing electrification, technological breakthroughs and evolving investment trends. Simultaneously, the global context has become more complex with recent disruptions including the Covid-19 pandemic, regional conflicts, physical and cyber-attacks on infrastructure, extreme weather events, and intensified geopolitical tensions. As our energy systems become more interconnected and interdependent, there is an urgent need to reassess energy security within a fragmented geopolitical landscape where traditional security challenges, emerging risks, and climate concerns increasingly intersect.

In this context, energy security considerations will increasingly need to be based on a whole-of-systems approach that maps interconnections across all fuels, technologies, and their interactions. It will also be necessary to position energy security within the broader contexts of economic, national, climate, and digital security. And increasing attention will need to be given to understanding diverse stakeholder perspectives, from governments and industry to civil society and different regions.

The Summit on the Future of Energy Security aims to advance the public and policy debate around energy security by:

- Identifying major current risks to energy security and exploring effective actions to address them;
- Anticipating emerging threats and vulnerabilities to enhance preparedness and resilience;
- Examining diverse stakeholder perspectives and regional contexts to develop a more holistic understanding;
- Expanding the scope and principles of energy security to align with evolving risks and opportunities; and
- Establishing common principles (such as resilience, flexibility, diversification, and co-operation) to guide future policy decisions.

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Session 1.
Mapping the Energy Security Landscape

Defining a Holistic Approach

Objectives of the Session

- Share diverse perspectives on the meaning of energy security, looking ahead into the long term, and shape a holistic definition of energy security
- Position energy security within broader security contexts and clarify its relationships with other forms of security
- Discuss common energy security principles to guide action (efficiency, resilience, flexibility, diversity, affordability, international co-operation, etc.)
- Emphasise the importance of mobilising cost-effective investment to support these goals

The opening plenary session will set the foundation for the Summit by examining energy security through a comprehensive lens that acknowledges its multidimensional nature and evolving challenges. Through two complementary panel discussions, we will explore how traditional approaches need to adapt while establishing the conceptual framework for the six specialized sessions that follow.

Introduction:
A Holistic Vision of Energy Security for a Changing World

Recent years have witnessed unprecedented energy disruptions – from pandemics and conflicts to cyber-attacks and extreme weather events alongside persistent issues of access, affordability, and reliability. As the global energy landscape evolves rapidly, a **more holistic vision** requires:

- Adopting a whole-of-systems approach mapping interconnections across all fuels, technologies, and infrastructure
- Positioning energy security within broader security contexts – economic, national, climate, and digital

Exploring Diverse Perspectives of Energy Security

While energy insecurity fundamentally arises when availability, affordability, or reliability is threatened, its meaning varies considerably based on stakeholder position and regional context.

- Governments prioritize uninterrupted supply, resilience, affordability, sustainability and national sovereignty
- Industry focuses on market stability, demand predictability, resource access, and investment frameworks
- Civil society emphasizes access, affordability, and environmental sustainability
- Importing and exporting countries have distinct priorities regarding supply/demand security

The increasing electrification of energy systems brings new emphasis on system flexibility, grid resilience, and secure supply chains for clean energy technologies and critical minerals.

Positioning Energy Security with Other Forms of Security

Energy security is deeply interconnected with multiple security domains that form a complex web of dependencies.

- Economic security: Energy price volatility affects inflation and investment
- National security: Energy dependence can create geopolitical vulnerabilities
- Digital security: Growing cyber-threats to increasingly digitalized systems
- Climate security: Extreme weather threatens infrastructure while transitions create new challenges

Guiding Principles for Energy Security Actions

To navigate this evolving landscape, we need guiding principles that can inform coherent policy while accommodating regional differences. The IEA's draft framework on the future of energy security provides a model that countries can draw upon to guide actions to safeguard energy security, including:

- Holistic approach: Considering all fuels, sectors, and technologies across the energy system
- Diversification: Reducing reliance on single sources, routes, and infrastructure
- Resilience and flexibility: Ensuring systems can withstand disruptions and adapt
- Affordability and access: Supporting economic activity and social welfare for all
- Sustainability and efficiency: Minimizing environmental impacts and energy demand
- International co-operation: Coordinating policies across borders

Panel 1. A whole-of-system approach – Addressing the energy trilemma

This panel will address the fundamental challenge of balancing energy security, climate sustainability and affordability in an increasingly complex global landscape. Discussions will highlight how leaders navigate competing priorities while building resilient systems through diversification, efficiency, strategic reserves, and strengthened critical infrastructure.

Themes

- Mapping system interactions and interdependencies between energy security, climate goals and geopolitics
- Balancing short-term needs with long-term sustainability objectives
- Regional variations based on resource endowment and development status
- Diversification strategies for energy resources and supply chains
- Energy efficiency as the ‘first fuel’ of security

Panel 2. Integrating Energy Security within a Broader Security Framework

This panel will focus on frameworks for assessing and managing both emerging risks and opportunities. As traditional threats evolve and new challenges emerge, our evaluation methods must similarly advance to develop forward-looking strategies that enhance resilience while enabling innovation.

Themes

- Economic risks: access, affordability, supply chains, market concentration, and price volatility
- Social dimensions: equity, access, and just transition considerations
- Technological opportunities: digitalisation, storage innovations, and grid modernisation
- Systemic risks: climate impacts, cyber-threats, and infrastructure interdependencies

Breakout 1a: Aligning Energy and Economic Security for All

From Access and Affordability to Competitiveness and Prosperity

Objectives of Breakout Session

- Identify emerging and long-term risks posed by a lack of secure access to affordable and modern energy, in particular to electricity and clean cooking, and to energy affordability for households
- Clarify and reaffirm the critical role of policy makers in improving rates of access to secure and affordable energy while achieving the intended socio-economic development and growth outcomes
- Evaluate the measures available to ensure affordable energy supplies and consider ways they can be targeted to vulnerable segments of the population
- Foster collaboration to scale up international financial support for energy access, finding new ways to integrate public and private sources of finance

Introduction: Universal access and affordable energy form the economic foundation of energy security

A lack of access to energy is the most fundamental form of energy insecurity and directly contributes to low levels of socio-economic development in regions with an access gap. According to the IEA's latest data, there are nearly 750 million people in the world living without electricity access, while more than 2 billion people continued to rely on harmful and polluting cooking fuels such as charcoal, wood, agricultural waste and animal dung – the use of which is a leading cause of poor air quality and premature death in many of the poorest regions of the world. The majority of these deficits are found within sub-Saharan Africa and disproportionately affects women and girls.

The IEA has been tracking energy access trends for decades. Rates of progress vary significantly across regions and have slowed or even moved backwards in recent years. While access rates have steadily improved in Asia and Latin America, population growth has continued to outpace progress in sub-Saharan Africa, where 80% of those who are without electricity access live and where four in five people do not have clean cooking access. The world remains off track to achieve universal access to both electricity and clean cooking by 2030, objectives set out in Sustainable Development Goal 7.

Unaffordable energy is also synonymous with energy insecurity. If households have access to energy but cannot afford to use it, they face difficult choices between heating and cooling their homes or purchasing other essential goods and services such as food or healthcare, putting at risk wider socio-economic development goals. This is particularly an issue for low-income households. In advanced economies, the 10% lowest-income households spend, on average, nearly a quarter of their disposal income on energy. If transitions are not designed with a view to ensuring people receive the benefits they can provide, they may be perceived as unfair and leave more people on the margins of energy systems.

Certain energy security measures – such as strategic reserves, spare capacity and diversity of supply – require investments which may lead to higher energy costs for consumers. Conversely, artificially low consumer prices can distort market signals, discourage measures to improve efficiency, and saddle energy companies or governments with economic liabilities. This in turn can lead to under-investment in resilient infrastructure or leave countries or consumers more exposed to price spikes and supply disruptions. Energy efficiency ultimately enhances affordability but requires upfront investment which may not be affordable for all.

Mapping risks:
The major economic barriers to universal access and affordability require targeted solutions

Sustainable progress on energy access faces significant financing challenges that threaten to leave millions behind. The path to universal access remains highly dependent on stable financial flows, including public funding and concessional finance, which can be jeopardized by high sovereign debt levels, economic uncertainty and competing budget priorities. Beyond initial infrastructure development, the quality and reliability of energy services present ongoing challenges. The benefits of continuous energy access can be undermined by grid reliability issues, supply bottlenecks and inadequate maintenance of systems like biogas units, solar arrays, mini grids alongside wider decentralised energy systems and improved cookstoves. These technical challenges are further compounded during economic downturns or fuel price spikes, which can push populations back into energy poverty even where physical infrastructure exists.

Energy affordability presents complex policy trade-offs that affect both immediate well-being and long-term transition goals. Many governments lack sufficient fiscal capacity to shield vulnerable populations from commodity price volatility, potentially leading to sharp increases in the share of household income spent on energy services during market disruptions. Current approaches to energy affordability often rely on fossil fuel subsidies – totalling approximately USD 500 billion worldwide in 2023 – which not only distort incentives for efficiency and resilience but also disproportionately benefit higher-income households. As energy systems transition, new affordability challenges emerge, particularly concerning the upfront costs of clean energy technologies, which may remain out of reach for many households despite their long-term economic benefits. This creates a significant risk that consumers with limited financial resources will become trapped in increasingly expensive fossil fuel systems. As these networks are gradually phased down, consumers are left shouldering a disproportionate share of operating costs while remaining exposed to volatile fuel prices.

Actions and tools: Strategic investment and policies can bridge the energy access gap while supporting security

- Increase direct engagement with countries on the issue of energy access, including through direct implementation support, capacity building, enhanced tracking and data collection, and increasing work with energy counterparts through various intergovernmental bodies and multilateral fora.
- Enhance tracking of energy access investments and financing transparency to help financiers better assess terms for future investments, including through the IEA's Cost of Capital Observatory and tracking the USD 2.2 billion worth of public and private sector commitments made at the IEA's Summit on Clean Cooking in Africa. Countries could also consider disclosure requirements for their development finance institutions that anonymises and makes public details on energy-related development finance.
- Adjust tariffs and duties on the import of key equipment and fuels that help extend electricity and clean cooking access, with appropriate terms that support local enterprise development and do not contribute to deteriorating fiscal dynamics for the state or energy companies.
- Take a 'multi-fuel and technology' approach to advance access. In clean cooking this includes LPG, electricity and modern bioenergy solutions. For electricity access, this includes levelling the playing field for distributed energy technologies such as mini-grids and solar home systems, which may not be eligible for the same support grid companies receive.

- Implement measures that facilitate private sector participation in the energy access space and consider aligning development assistance and finance options with these objectives. This could include enabling private sector purchases of carbon credits, which play a significant role in scaling up clean cooking technologies, and providing efficient industrial and agricultural equipment. Efforts should consider how to make these efforts sustainable, in particular by developing local supply chains, skilled workers and institutional capacity.
- Consider energy efficiency first. For example, well designed and implemented minimum performance standards can greatly reduce the running costs of all energy-using equipment, without necessarily adding to its upfront purchase cost. The IEA publishes policy toolkits that set out options for governments to strengthen their energy efficiency policies in all sectors. These are updated annually in discussion with ministers at the IEA's Annual Global Conference on Energy Efficiency, the 10th edition of which will take place in 2025.
- Help consumers make upfront investment decisions that ensure lower-cost energy in the long run. There are many possible tools, as set out in the IEA report, *Strategies for Fair and Affordable Clean Energy Transitions*, such as leasing, pay-as-you-go schemes, efficiency performance standards, and the use of climate funds or other public funding.

Guiding questions for Breakout 1a

- What policies have proven successful for improving energy affordability and access?
- What are the key actions to ensure that access to electricity and clean cooking is delivered in a reliable and sustainable way, particularly for the most vulnerable?
- What tools are available for governments to help protect consumers from supply shocks in the short run, and to reduce their energy bills in the long run?

Breakout 1b:
Oil and Gas Security

Ensuring Security and Affordability for Today and Tomorrow

Objectives of Breakout Session 1b.

- Identify current and emerging risks for secure and affordable oil and gas supply as part of a people-centred transition to low-emissions energy systems
- Consider how current buffers against supply risks could evolve and be future-proofed
- Discuss policies and actions by both governments and industry that could enhance the security and affordability of oil and gas supply in the long term

Introduction:
Oil and gas security remains part of the global agenda

Throughout clean energy transitions, the security of oil and gas supply will remain vital for governments across the globe. Global oil and natural gas markets are becoming increasingly complex and interconnected, geopolitical risk is high, weather patterns are becoming more extreme, and cyber-threats are growing. Meanwhile, reliance on oil and gas remains high, even as demand declines in some parts of the world. All of these factors mean the risks of oil and gas supply disruptions remain significant and will need careful management.

The market turmoil that resulted from a recalibration of trade flows following Russia's full-scale invasion of Ukraine in 2022 prompted IEA Member countries to implement the two largest collective responses in the Agency's history, with just over 180 million barrels of emergency oil stocks released in total, demonstrating the enduring importance of oil security and emergency preparedness.

The 2022-23 supply shock transformed natural gas markets in an even more profound manner. And while the immediate effects of the gas crisis have eased, the structural changes that occurred in 2022 will persist for years – and should be carefully assessed both by policy makers and market players.

The global gas balance remains fragile, with low storage levels in Europe and the halt of Russian piped gas transit via Ukraine tightening the outlook for 2025. This is set to change over the second half of the decade. Global LNG liquefaction capacity is set to increase by around 250 bcm/year by 2030 – an amount equal to almost half of current global LNG trade.

Both oil and natural gas are facing an uncertain long-term demand outlook as clean energy transitions unfold at varying paces in different regions. The petrochemicals sector is set to continue growing, but oil demand from the transport sector is more uncertain, with declines likely in advanced economies while diesel and gasoline demand in emerging and developing economies is set to continue to rise. The future role of natural gas depends on a range of key variables such as prices, policies, investment, the pace of renewables growth, declines in coal, rates of end-use electrification, the industry's record on methane abatement, and growth in low-emissions gases. There is no single global story about the future natural gas, as countries and regions respond to market and policy pressures in different ways, based on their national circumstances and stages of development.

Mapping risks: Oil and natural gas supply security risks are set to evolve over time

Risks to oil and gas supply security remains significant and are set to evolve over time. Geopolitical shifts, the growing concentration of oil and LNG flows through a limited number of chokepoints, along with more extreme weather patterns and other new threats, will keep oil and gas supply security at the forefront of energy policymaking for decades to come. In addition, there is need for a careful assessment of investment requirements to ensure oil and gas supply security, flexibility and affordability. In addition, new risks are emerging, including more sophisticated cyber-attacks which are difficult to predict and can have significant impact on oil and natural gas deliverability.

The volume of oil and LNG trade flows through a limited number of chokepoints, such as the Strait of Hormuz, is expected to increase over the medium term, posing additional risks to oil and natural gas supply security. Climate change and prolonged drought periods can limit the transit across certain trade channels, including the Panama Canal, while the sensitivity of natural gas demand to changes in weather patterns, including cold snaps and heatwaves, is expected to increase over the medium term.

Ensuring adequate investments will be increasingly important for emerging and developing economies. This includes investment along the entire value chain, including the spectrum of midstream flexibility assets, such as pipelines, underground storage facilities and LNG import/export capacity.

Developments along the oil value chain will also result in increased exposure to oil market risk for many countries. For instance, refineries in advanced economies are likely to struggle to remain competitive in the face of increased competition and an uncertain demand outlook. This is set to leave many countries increasingly reliant on imports of oil products, such as diesel and jet fuel, even as demand declines. As a result of increased import dependence, these countries will become more vulnerable to disruptions in oil product markets and may need to invest more in storage.

The existing gas system will play a key role in enabling the integration of low-emissions gases, including biomethane, hydrogen and e-methane in the longer term. An orderly transition from the current gas system to a model integrating multiple gases will require prudent market design taking into consideration the network integration challenges and changing supply flexibility of low-emissions gases.

An increased uptake of liquid biofuels and the electrification of transport will help to reduce reliance on oil, but these developments will also result in new energy security challenges. Biofuels, for example, account for 4% of liquid fuel use today and play a significant role in some countries to reduce oil import dependence. In the future, the oil supply chain allows for the integration and in some cases the production of low-emissions fuels such as biofuels and hydrogen-based fuels that can help diversify fuel production and supply routes. However, expanding low-emissions fuels also bring cost, feedstock and weather-related risks.

Based on today's policy settings, oil and gas are set to remain an important part of the global energy mix for years to come, and supply disruptions will have the potential to cause significant economic harm and negatively impact people's lives. Maintaining a resolute focus on oil and gas security and emergency preparedness will therefore be critical to ensure a secure and affordable energy supply. The IEA's emergency response capabilities will remain vital, most notably for oil. In order to maintain the effectiveness of this system, increased involvement of the countries driving consumption growth will be required.

Actions and tools: Supply security requires close international co-operation

- Continued focus on oil and gas market monitoring through the IEA.
- Improved data sharing to increase visibility on flows, stocks and refinery operations, particularly in non-IEA member countries.
- Sharing of best practices on oil and gas emergency policies between IEA Members and non-members.
- Strengthening of IEA oil stockholding system through expansion of IEA membership and participation of emerging and developing economies.
- Consider a potential voluntary gas stockholding system.
- A mechanism for dialogue between countries with different interests and positions in oil and gas supply chains.

The current oil and gas market context and evolving uncertainties highlights the need for responsible producers and consumers to work together to reinforce the architecture for secure global oil and gas supplies. To support this, the IEA established in late 2024 a permanent Working Party on Natural Gas and Sustainable Gases Security (GWP), building on the Agency's longstanding gas security activities, including the work of the Task Force on Gas and Clean Fuels Market Monitoring and Supply Security. The IEA will also continue to promote oil security and emergency preparedness through the Standing Group on Emergency Questions (SEQ).

Guiding questions for Breakout 1b

- What are the main current and emerging risks to ensuring more secure, affordable, and more sustainable oil and gas supply?
- How can measures against oil and gas supply risks be developed and future-proofed?
- What policies and actions can governments and industry implement that could enhance the security, affordability and decarbonisation of oil and gas supply in the long term?

Breakout 1c. Strengthening Energy Resilience

Managing risks from natural hazards, extreme weather and climate change

Objectives of Breakout Session 1c

- Outline risks of natural hazards for energy security and how climate change contributes to evolving risks
- Discuss how natural hazards are contributing to higher costs for the energy system
- Identify key actions to enhance energy sector resilience to natural hazards

Introduction: Natural hazards pose a significant risk to energy security

Natural hazards pose a perennial risk to energy security and include both geophysical hazards such as earthquakes and tsunamis, as well as extreme weather events such as heatwaves, droughts, flooding and storms. Each year, natural hazards damage energy facilities, cause power outages and disrupt oil and gas production. Over the past year alone, disasters have contributed to significant energy supply disruptions including flooding in Spain, heatwaves in India and wildfires in California and Korea. These events carried with them substantial costs to the energy sector and broader society – including repairs, lost economic activity due to outages, forgone revenues due to proactive shutoffs, and increased liabilities held by and insurance premiums paid by the energy sector.

Making future energy infrastructure more resilient to natural hazards is critical, as extreme weather events are likely to be exacerbated by climate change. Designing and building new energy infrastructure in a more resilient way can require additional upfront investments, however this is typically less expensive than retrofitting existing assets. Without robust natural hazard impact data, co-ordinated planning and regulatory oversight, responses to these risks will not be able to deliver the required operational improvements.

Mapping risks – to the whole energy system

While every part of the energy system is exposed to natural hazard risks, each type of energy asset faces different exposure risk and has different vulnerabilities. The table below provides a high-level assessment of different pieces of energy infrastructure and their relative exposure and vulnerability to a specific natural hazard. Beyond vulnerability, other factors are important to assess the full energy security risks posed by natural hazards, such as frequency or likelihood of natural hazards, the speed by which assets can be brough back online or replaced, and the impacts of such disruptions on overall energy security (i.e. their role in overall energy supply and the system's ability to absorb or weather disruptions).

Assessment of risk exposure and vulnerability of different energy infrastructure by hazard type

		Heatwave	Drought	Flood	High Wind Events	Wildfires	Earthquake
Power Plants	Coal	Moderate	Significant	High	Moderate	Low	Significant
	Gas	Moderate	Moderate	Significant	Low	Significant	Moderate
	Oil	Moderate	Moderate	Significant	Low	Significant	Moderate
	Nuclear	Significant	Significant	Significant	Low	Significant	Extreme
	Hydro	Moderate	High	Extreme	Low	Low	Extreme
	Solar	Moderate	Low	Significant	Moderate	High	Moderate
	Wind	Low	Low	High	High	Low	Moderate
Extraction	Coal	Low	Significant	High	Moderate	High	Significant
	Oil & Gas	Low	Moderate	Significant	Significant	Significant	Significant
	Nickel	Low	Moderate	High	Moderate	Significant	Significant
	Cobalt	Low	Significant	High	Moderate	Significant	Significant
	Lithium	Low	High	High	Moderate	Significant	Significant
	Copper	Low	Significant	High	Moderate	Significant	High
Other	Grid	Significant	Low	Significant	High	High	Significant
	Pipelines	Moderate	Moderate	Significant	Low	Significant	High
	Refineries	Moderate	Significant	High	Low	Moderate	Significant

Scale	Low	Moderate	Significant	High	Extreme

Note: Low risk indicates hazard poses few lasting impacts; moderate risk indicates hazard poses potential efficiency losses, low capacity factors or increased wear; significant risk indicates hazard poses potential curtailment or acute operational disruption; high risk indicates hazard poses potential forced outages, shut-ins or long term loss of capacity; extreme risk indicates hazard poses potential for total loss, with potential risk for further losses beyond the energy sector.

Measures that can improve resilience against natural hazards include hardening of existing infrastructure; building redundancy; incorporating flexible or adaptive grid systems; developing modular, distributed grids; diversifying energy supply; and locating new energy infrastructure in lower-risk areas. Developing robust early warning systems and response protocols can also play a key role in mitigating risks and the impact of hazards. These measures can also contribute to broader objectives, such as resilience against malicious attacks, and reduce pressures from secondary effects, such as migration patterns as populations move from areas that have become less habitable.

Efforts to improve energy sector resilience must also consider how energy systems and risks are set to evolve in the future. For instance, a rising share of electricity in energy consumption means greater focus will need to be paid to power sector resilience, especially as economies become increasingly dependent on digital services for day-to-day operations and rising surface temperatures due to climate change are increasing the use of air conditioning for cooling.

Natural hazards are contributing to rising energy costs for consumers today, with costs set to rise faster in the future without greater action. Heatwaves and changing precipitation patterns alone are already costing energy systems globally an additional USD 30 billion each year to cover for forgone hydropower and increased peak demand from cooling. Insurance premiums for consumers, utilities and other firms are rising in areas with higher climate-driven disaster risk. Energy providers face the need to cover greater liabilities, and new projects in exposed regions face difficulties getting approved. Policy makers must weigh the higher upfront costs of more resilient infrastructure against the benefits of reduced disruptions to energy supply. These assessments should be grounded in robust data and analytical tools, which are limited in many parts of the world today.

Actions and tools: Make energy system resilience a policy priority

- Establish energy system resilience to natural hazards as a key focus within the broader framework of energy security, acknowledging natural hazards are an ever-present risk to energy infrastructure, likely to be exacerbated by climate change in the future.
- Undertake a natural hazard resilience assessment for the global energy system, including an assessment of exposure risk, an estimate of costs incurred, and a list of key measures to help improve energy system resilience.
- Commit to take steps toward implementing disaster risk reduction measures, which could include:
  - A national assessment of natural hazard risks to energy infrastructure
  - Enhancing early warning and infrastructure monitoring systems to inform emergency response measures
  - Requiring data reporting on energy sector disruptions, causes, and costs
  - Identifying design standards for new energy assets and modifications to existing energy assets
  - Updating building and construction standards
  - Diversifying energy supplies and supply chains

- Call for increased coordination within and between governments to enhance efforts to reduce natural hazard risks to the energy sector, including efforts to:
  - Establish disaster risk reduction roadmaps across relevant government bodies, including early warning systems, emergency protocols and coordinated action, and integrated long-term planning
  - Engage with the insurance industry to enhance broader understanding of risks to the energy sector and those posed by the energy sector
  - Facilitate data and best practice sharing within and between countries.

Guiding questions for Breakout 1c

- Which natural hazards pose the greatest risks to the secure operation of your country's energy systems? How could climate change affect these risks?
- What are the most significant impacts and costs incurred by disruptions caused by natural hazards?
- What investments can improve energy system security to mitigate disruptions from natural hazards, extreme weather and climate change?
- How can energy affordability and security be achieved together?
- What near-term actions can be taken to improve understanding of natural hazard risks to energy security? What are key challenges to implementation?

Breakout 2a:
Electricity Security

Ensuring Security in the Age of Electricity

Objectives of Breakout Session 2a

- Identify emerging and long-term risks to electricity security in a context of strong demand growth and as electricity's role expands across sectors and economies
- Clarify and reaffirm the critical role of policy makers in shaping the electricity security landscape and ensuring a resilient and affordable power system
- Foster collaboration between policy makers and industry by sharing good practices and innovative approaches to mitigating risks, and initiate a collaborative way forward to address pending issues

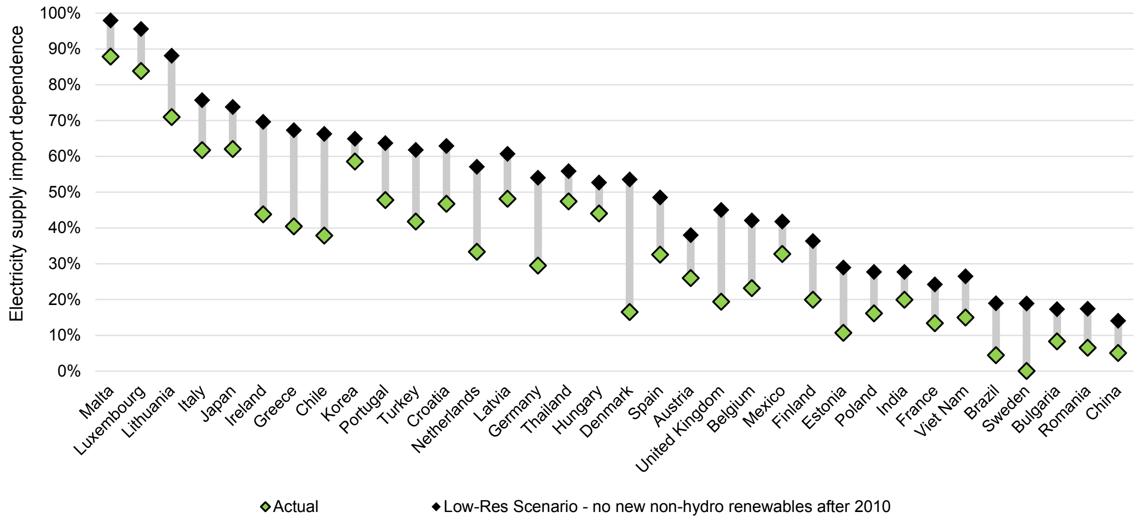
Introduction:
Electricity security is more important than ever

Modern societies are highly dependent on energy services from electricity, which already plays a critical role today, despite representing only one-fifth of total final energy consumption. Since 2010, global electricity demand has grown almost twice as fast as total energy demand. This acceleration is expected to continue, with the growth in global electricity demand forecast to be the equivalent of adding an amount greater than Japan's annual electricity consumption each year to 2027.

Recent electricity crises, such as the winter freeze in Texas (2021) and the price spikes in the European Union (2022), demonstrated that vulnerabilities may originate from policy and market structure decisions rather than technical failures. Electricity security encompasses not just the availability of supply but also its affordability, requiring a comprehensive framework that integrates technical expertise with market design, regulatory policies and geopolitical considerations.

The transformation of the power system enhances security and brings fresh challenges. Diversification of energy resources, driven by renewables, has substantially reduced dependency on imported fuels. At the same time, flexibility needs are growing across all timeframes to ensure secure and cost-effective integration of variable renewables. Addressing these needs will require dispatchable capacities, more grids and storage and demand side flexibility. The role of thermal power plants is evolving from baseload to providers of system services, requiring proper investment mechanisms. Grid scarcity is already a significant bottleneck, with at least 1 650 GW of renewable capacity waiting for grid connection globally in 2024. Connection queues affect various grid users, including 540 GW of standalone battery storage projects worldwide. Meanwhile, a more interconnected, digitalised system increases vulnerability to cyber-intrusions, with electricity-related significant cybersecurity incidents rising from 6 between 2006-2010 to 27 between 2021-2023.

Import dependence of electricity supply in selected countries, actual and in a scenario assuming no new non-hydro renewables after 2010, 2022



Mapping risks: The evolving landscape of electricity security challenges

The electricity security landscape today faces a complex array of interconnected challenges beyond traditional fuel security concerns. Current vulnerabilities stem from premature retirement of dispatchable generation without adequate replacements, severe grid infrastructure constraints hampering integration of new resources, and increased price volatility affecting vulnerable consumers disproportionately. These technical and market challenges are compounded by escalating cyber and physical threats – including more frequent climate-related disruptions – while market power concentration during supply scarcity creates affordability concerns. Looking further ahead, the risk landscape will evolve, assuming energy transitions accelerate. Systemic challenges will emerge from balancing more frequent mismatches between supply availability and demand during extended periods in increasingly renewable-dominated power systems, managing complex interdependencies as sector coupling increases, and navigating uncertainties over future demand from growth areas such as artificial intelligence, data centres, cooling and electrification. The most significant long-term risk, however, may be the missed opportunity to embed security and resilience considerations into today's system design decisions that will shape electricity infrastructure for decades to come.

Actions and tools: Elevating electricity security to a strategic policy priority

- Enhance system-wide electricity supply diversification and resilience by expanding renewables and (where appropriate) nuclear, improving energy efficiency and decreasing reliance on fuel imports, while preserving the benefits of regional integration
- Improve market design and regulatory frameworks to deliver a diverse portfolio of resources and flexibility as a security imperative during energy transitions
- Strengthen international co-operation and co-ordination
- Adopt best practices more widely, such as integrated and co-ordinated planning, and extending planning horizons to cover the lifetime of assets
- Improve assessment of electricity security by better incorporating uncertainties (climate, contribution of variable renewable energy and demand-side response) and conducting stress tests

Guiding questions for Breakout 2a

- What are the most pressing electricity security risks that require policy action today – and how can policy makers work with industry to proactively address emerging threats over the coming decades?
- Recognising the critical role of grids to electricity security, what policies and regulatory frameworks are needed to unlock long-term investment in strategic infrastructure – and how can AI support more secure and reliable grid operations?
- As power systems transform, what reforms are needed to ensure investment in a diverse set of dispatchable resources – including storage and demand-side flexibility – to ensure flexibility across all time frames?
- (Subsidiary question on power markets) How can countries ensure electricity supply is better insulated against volatile global fossil fuel markets?

Breakout 2b: Technology and Innovation including role of AI

Including role of AI – Assessing its Role as Friend or Foe for the Future of Energy Security

Objectives of Breakout Session 2b.

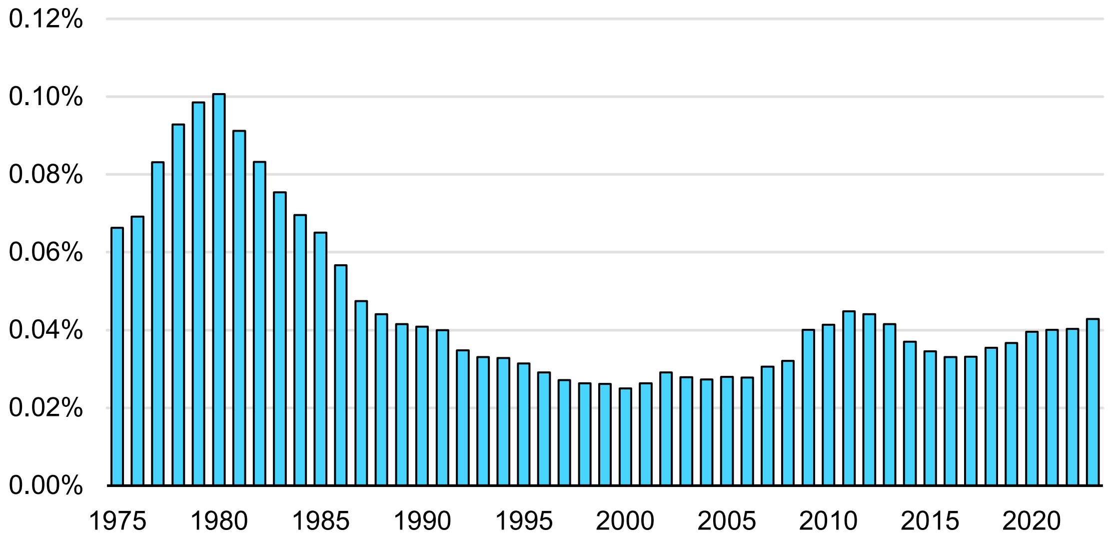
- Identify key risks to energy security that might be mitigated by enhanced efforts and greater co-operation on targeted energy technology innovation priorities
- Draw out the ways in which energy technology innovation policy should be integrated into broader definitions of energy security policy
- Share good practices for managing energy security risks that could impact the roll out of artificial intelligence (AI) and data centres, and broader risks that could potentially be compounded by AI, while harnessing AI as a powerful tool that could also enhance energy security

Introduction: Innovation is a core component of long-term energy security planning

Programmes for exchanging information about R&D progress have been a part of the IEA framework since the 1970s, including in areas such as energy efficiency, nuclear energy, hydrogen as an energy carrier and renewables. In response to the energy security crises of the 1970s, IEA Member governments raised energy R&D spending to 0.1% of GDP. Much of this was directed to nuclear power research, and in the following two decades, growth in nuclear electricity generation significantly moderated oil and gas demand in that sector. Today, as countries face energy security challenges on several fronts simultaneously, spending on energy R&D as a share of GDP stands at half this level.

In the past four decades, energy technology innovation has been a major contributor to higher levels of energy security. The improvement and commercialisation of new technologies has increased the diversity of energy sources and options. However, it also takes time and patience: the processes of invention and scaling up, even for an incremental new design, can take a decade or more before the benefits of deployment are seen in the market. At any given time, there are always technologies with high potential that are nearing competitiveness and others that still need to be nurtured and evaluated.

IEA Member country public spending on energy R&D as a share of GDP, 1975-2023



Notes: To avoid discontinuities, US stimulus funding in 2009 has been partly reallocated over a five-year period.
Source: IEA The State of Energy Innovation

Technology innovation is an engine of economic growth. Most innovative companies stay close to where they were established and keep a share of their R&D and manufacturing there. Countries at the forefront of technology innovation are more likely to have a higher share of domestic products in their energy supply chains. This can increase resilience to potential equipment supply disruptions and safeguard the expertise and data needed to respond to security risks. There is an opportunity for innovation to help reduce supply chain concentration for several major energy technologies. Today, just one country, China, holds around 85-98% of battery manufacturing capacity, 80-95% of that for solar PV, 50-65% for wind, just under 60% for electrolysers and close to 40% for heat pumps.

Strategic partnerships between countries are effective for strengthening technology leadership. They can also safeguard supply chains and ensure knowledge exchange between like-minded partners. This can be especially effective in fast-moving areas such as AI, including for understanding how it can support greater energy security.

Mapping risks: Technology helps address security challenges but also brings new ones

In the near and medium term, adopting improved technologies is a key strategy for addressing energy security risks. In the power sector, technologies for smarter and more resilient grids – including fault detection, predictive maintenance and advanced grid management systems – can reduce network congestion, optimising supply and demand in real time, and enable efficient integration of variable renewables. The cutting-edge technologies available in these areas today, many of which are already bolstering grids around the world, are the result of research efforts over the past decade or more. Identifying and prioritising emerging risks and challenges as early as possible allows research funding and finance for technology scale-up to be targeted. To lay the groundwork for the next generation of critical equipment and software, there is considerable scope for reviewing public energy technology innovation programmes through a medium-term lens of energy security risks.

One area of potential risk is the rapid integration of new technologies into the energy system, which can bring new challenges. The energy sector has always had to ensure it is resilient to new technological risks. The internet, for example, has enabled networks to be more connected and flexible, but also connected them to an ever-growing range of smart third-party devices that pose security or malfunction risks. In this regard, AI represents a new wave of technology innovation whose implications must be understood and managed. For example, rapidly rising energy demand for AI data centres may present challenges to the reliability of some grids. To mitigate the impact of growing AI energy demand, whole system planning, as well as innovation in software and hardware, including advanced cooling technologies, will be critical for managing energy demand of AI. Innovation in infrastructure – such as low-emissions backup power sources and thermal energy storage – could help data centres operate more flexibly and lessen their impact on electricity systems.

However, AI also brings substantial opportunities. Real-world demonstrations and studies, including the IEA's upcoming Special Report on Energy and AI, show how AI can be used to optimise energy supply and demand, including by helping networks to respond in real time. Higher electricity demand from data centres presents an opportunity to scale up renewable energy, modernise infrastructure and explore a greater role for nuclear power. It can also support energy security in ways unrelated to power grids from optimising fuel logistics to improve the safety of power plants. For example, in nuclear power, AI could help raise utilisation rates and efficiencies by aiding design, construction and safety.

In the longer term, there is a risk that energy systems continue to be vulnerable to disruptions because the full potential of energy efficiency and diversification are not realised. Advancing the competitiveness of various renewable energy sources and nuclear can deliver a more resilient energy system. Improving the energy efficiency of industrial processes, vehicles and buildings is also a core component of raising energy security. However, several key energy technologies that bring energy security dividends are yet to be demonstrated adequately at commercial scale. These include hydrogen-based sustainable aviation fuels, cellulosic biofuels, advanced nuclear technologies including small and advanced modular reactors, and CO_2 capture in sectors that are heavily reliant on fuel combustion. Another set of large-scale demonstration projects – in heavy industry, aviation and shipping – are struggling to reach final investment decisions yet are crucial for enabling greenhouse gas emissions reductions. Bringing these critical demonstration projects to fruition globally is a part of the energy innovation challenge that is deserving of international co-operation.

Actions and tools: Prioritising innovation support and co-operation over the long term

- Explore a possible commitment to raising public energy R&D and innovation support in all its forms, with 0.1% of GDP as a guiding benchmark, prioritising technologies for secure, affordable and sustainable energy systems.
- Support and provide input to the IEA's Observatory on Energy and Artificial Intelligence and other means of updating assessments of energy security implications of the AI and energy nexus, building on the recent IEA special report.
- Undertake a mapping of energy technology innovation priorities for addressing security challenges in the medium term, by working with the IEA – and in collaboration with Mission Innovation – to enhance data and analysis, including within the framework provided by the IEA Energy Innovation Forum events.
- Commit to supporting a global portfolio of key large-scale demonstration projects for pre-commercial technologies.

Guiding questions for Breakout 2b

- What are the priority areas of energy R&D and innovation to ensure that the world has the technology tools to tackle emerging energy security concerns?
- What examples of effective regulatory and commercial practices demonstrate how new technologies can reduce outages, avoid supply disruptions and diversify energy markets?

- How can the safe, secure and energy efficient use of AI-related technologies in energy systems be ensured, and what further work is needed to understand and manage the security implications of the AI and energy nexus?

Breakout 2c: Securing Energy Technology Supply Chains

From Critical Minerals to Manufacturing

Objectives of Breakout Session 2c

- Outline energy security risks posed to energy technology supply chains, from critical mineral extraction and refining to technology manufacturing
- Identify actions to avoid, mitigate and manage these risks, including measures that can be implemented in the short term
- Define solutions to strengthen the security of energy technology supply chains in the medium and long term, and how countries can begin to lay the groundwork for them now

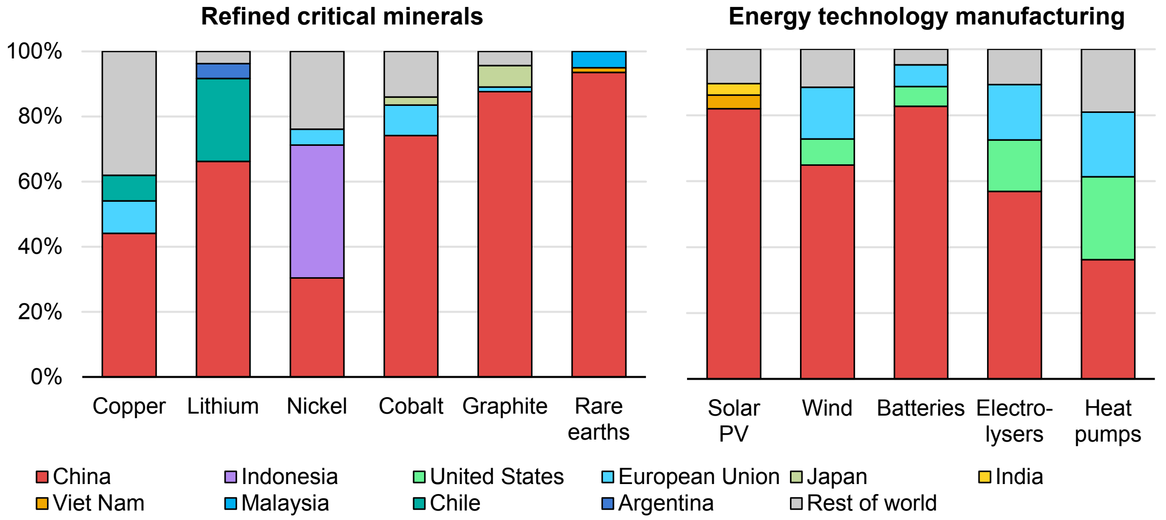
Introduction: An evolving energy security paradigm

An evolving global energy system demands an evolving approach to energy security – one that considers the risks posed to energy technology supply chains, from critical minerals extraction and refining to energy technology manufacturing. The increasing adoption of energy technologies – such as solar PV, wind, batteries, EVs, nuclear and electricity grids – implies a future global energy system that is more capital- and material-intensive, and less reliant on fuels. While this transition offers some inherent benefits for energy security, threats resulting from disrupted production or trade in critical minerals and energy technologies can still have far-reaching economic implications.

Mapping risks: Supply chain concentration is a major concern

Geographic concentration of energy technology supply chains increases the risks of supply disruptions. Manufacturing capacity of energy technologies, and mining and processing of materials and minerals required for their production are highly concentrated in a few countries. For example, China accounts for more than half of global output for most of the key energy minerals. In most cases, IEA analysis of announced projects shows limited progress in diversifying supply sources, as some 75% of planned projects for refined mineral production are being developed in today's leading jurisdictions.

Geographical concentration of refined critical minerals and technology manufacturing capacity, 2023



Notes: Only showing the value of the top three producing countries/regions. The graphite figures are for battery-grade graphite. The figures for rare earths are for magnet rare earths only. Shares for critical minerals are based on production volumes. Shares for manufacturing are based on installed capacity. Source: IEA (2024), Global Critical Minerals Outlook 2024, Advancing Clean Technology Manufacturing and Energy Technology Perspectives 2024.

Insufficient investment in energy technology supply chains – including mining, refining and manufacturing capacity – could also result in an imbalance between demand and supply. Demand for technologies like solar PV and batteries is rising faster than for many traditional fuels and technologies, which could catch markets off guard. When looking solely at today's demand, production and capacity, many energy technology supply chain steps appear well supplied. However, other steps in energy technology supply chains see significant shortfalls when it comes to meeting future demand. The supply of critical minerals could also be subject to supply-demand imbalances, particularly in relation to the lengthy lag between exploration-to-first operation of new mines and processing facilities. To meet future needs, it is essential to increase the speed of supply and volume, as well as ensure greater geographical diversification.

There is a paucity of publicly available data that shed light on the functioning of markets that exist across energy technology supply chains, including production, capacity, trade, investment and price data. The lack of information transparency makes it challenging for industries to identify potential risk areas and for policy makers to direct support where it is most needed.

Resource rich countries, particularly in Emerging Markets and Developing Economies, may not fully benefit from their natural resources. Limited access to energy and under-developed infrastructure could also limit the development of new projects in some countries. It is crucial to ensure economic benefits for local communities through job creation, skills training and infrastructure investment. Mining and processing projects can have negative environmental impacts and affect local ecosystems, which makes the adoption of sustainable and responsible practices crucial. Such practices will help protect people and communities while bolstering security of supply by reducing supply disruption risks.

Actions and tools: Ensure secure and resilient energy technology supply chains

- Build robust security mechanisms to be prepared against supply crises. The IEA Voluntary Critical Minerals Security Programme aims to support governments in strengthening critical mineral security, providing a platform for countries to coordinate actions in response to risks and emergencies. Beyond government action, it would be useful to create a platform for industry to collaborate around long terms offtake agreements.
- Strengthen the fundamental resilience of supply chains by increasing investment in diversified supply sources through well-designed policy mechanisms and promoting recycling.
- Harness technological innovation to develop technologies that use less materials or increase production efficiencies; leverage the IEA Technology Collaboration Programme on critical minerals to advance research across IEA Member countries.
- Support the IEA's ongoing efforts to enhance systematic market monitoring and outlooks, and improve data transparency by identifying and addressing gaps in supply chain data (e.g., trade, production, capacity).
- Commit to supporting further IEA analysis on opportunities for emerging economies to play a greater role in energy technology supply chains, identifying key barriers and strategies to overcome them while also leveraging opportunities for job creation.

Guiding questions for Breakout 2c

- Which actions is your country/organisation ready to implement now to swiftly strengthen supply chains?
- What examples of effective global actions should be initiated/reinforced for increasing diversification and securing supply chains in the medium term?
- What data on supply chains are lacking and in need of harmonisation?

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