Energy security

Integrating Sustainability and Resilience

EnergiaTurva

Work Package 1

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Co-funded by the European Union
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Abstract

Energy security has expanded from being narrowly focused on fuel supply to a multidimensional concept shaped by decarbonization, digitalization, and geopolitical volatility. This report examines these shifts across global, EU, national, and regional levels, showing how climate change, renewable energy deployment, and technological change are redefining vulnerabilities and policy priorities. Globally, the conflict in Iran and the closure of the Strait of Hormuz have destabilized energy markets and accelerated a realignment of energy policy and security strategies, while digitalization, rising prosumer activity, and renewable expansion reshape energy sovereignty amid growing cybersecurity and critical-material risks. In the EU, the 2022 energy crisis following Russia's invasion of Ukraine exposed structural dependencies and hastened moves toward renewables, resilient infrastructure, and strategic autonomy. Nationally, Finland's transition highlights challenges such as intermittency, declining forest carbon sinks, and biomass use within the LULUCF framework. Across all levels, energy security is now inseparable from sustainability, resilience, diversification, and just-transition principles, requiring coordinated multilevel governance to manage emerging socio-technical risks and support long-term climate goals.

Keywords

Energy security, Geopolitical risks, Renewable energy transition, Multilevel governance

Contents

1. Introduction

Energy security, traditionally framed around supply stability, affordability, and geopolitical risks, is increasingly understood as *a dynamic and multidimensional concept* embedded within broader sustainability transitions. Ang et al. (2015) demonstrate the conceptual heterogeneity of energy security (identifying 83 definitions) and highlight a shift toward holistic interpretations that integrate environmental and socio-political dimensions. Fundamentally, national energy outcomes are created by the interaction between energy security (reliable, uninterrupted supply of energy), economic competitiveness (energy equity, affordability and access), and environmental sustainability (reduction of ecological impacts of energy production, e.g. greenhouse gas (GHG) emissions and air pollution) (Ang et al., 2015), as illustrated in Figure 1

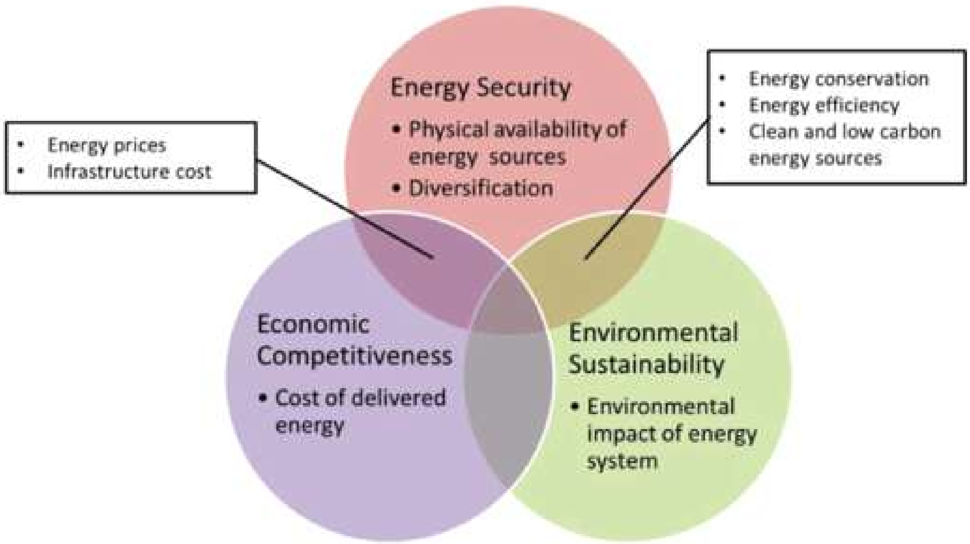

Figure 1. The energy trilemma (Ang et al. 2015)

Despite this conceptual broadening, sustainability transitions scholars have paid limited attention to security threats that may shape or constrain decarbonization pathways (Kivimaa & Sivonen, 2021). Transitions introduce new vulnerabilities, including *cybersecurity risks* (Turtola et al., 2025), *critical minerals required for low-carbon systems* (IEA-5. 2025);(Calderon et al., 2020), and *land-use conflicts* associated with renewable energy deployment (Koelman et al., 2025). These risks illustrate that transitions do not eliminate security concerns but rather transform them. The rapid expansion of intermittent renewable energy sources further challenges the stability and resilience of energy systems, requiring new forms of system integration, storage, and governance (Williges et al., 2022). Policymakers must therefore navigate complex trade-offs between technological feasibility, environmental goals, and system reliability, necessitating more sophisticated and coordinated policy mechanisms (Wilson, 2019).

Energy geopolitics are also undergoing profound transformation. Renewable energy systems (RES) have the potential to reduce traditional geopolitical tensions due to their distributed and replenishing nature. Yet, RES introduce new forms of strategic dependency, particularly in relation to critical materials and digital infrastructures, potentially heightening cybersecurity and supply-chain risks (Vakulchuk et al., 2020). The technological changes required for RES deployment reshape geopolitical relations and influence the internal security of energy systems, especially given the intermittency of solar and wind power (Kivimaa, 2024). While decentralization may reduce the scale of disruptions, it also requires new governance and institutional structures.

Against this backdrop, national and regional energy security emerges as a crucial domain. Energy transitions unfold unevenly across territories, shaped by local infrastructures, political cultures, and institutional capacities. This study contributes to theoretical debates on energy security and offers insights into how localized policy interventions can support both the stability and sustainability of energy systems during periods of profound structural change.

The report is organized as follows. First energy security is examined from a historical point of view. In the following sections energy security is examined at Global, European, national and regional level.

2. Energy Security from a Historical Perspective

Energy security has historically been tied to national security and defence, but today contemporary debates focus on the energy transition and the electrification of societies. Although energy security remains a central driver of energy policy, its meaning is contested among policymakers and scholars (Jewell & Brutschin, 2019). The concept is embedded in temporal and spatial contexts, and its use in public discourse reflects underlying power dynamics (Sivonen, 2025).

Traditionally, energy security was defined through the "four A's": Availability, Affordability, Accessibility, and Acceptability (Strojny et al., 2023; APERC, 2007; Sovacool, 2011).

- **Availability** concerns the physical supply of resources, increasingly shaped by global trade and renewable energy technologies.
- **Affordability** relates to infrastructure and energy costs, now influenced by short-/long-term price dynamics and renewable intermittency.
- **Accessibility** covers infrastructure, transport, and geopolitical factors, expanding to include protection against external threats.
- **Acceptability** addresses environmental impacts, public acceptance, and justice considerations.

Cherp and Jewell (2014) reframed energy security as a form of security more broadly, requiring clarity on "*security for whom*?", "*for which values?*", and "*from what threats?",* and defining it as the "*low vulnerability of vital energy systems".*

Recent scholars highlight that the four A's increasingly overlap. Technological change, climate policy, and geopolitical instability have broadened the concept to include resilience, diversification, sustainability, and alignment with the green transition (Schmitz et al., 2025).

- **Resilience** refers to the capacity to withstand and recover from extreme disruptions, characterised by redundancy, diversity, adaptability, and modularity (Jasiūnas et al., 2021).

- **Diversification** is the strategy of using a variety of energy sources to enhance energy security, reduce economic risk, and support sustainable development. Currently it involves expanding renewable electricity and heat supply to reduce dependence on limited suppliers and enhance supply security (Gitelman et al., 2023; Triguero-Ruiz et al., 2023; Malek et al., 2025).
- **Sustainability** emphasises energy sources that do not deplete or harm the environment. Lifecycle analysis is central to evaluating environmental and economic impacts (Randolf et al., 2018).
- **Green transition** links energy security to renewable deployment, carbon-neutrality goals, and economic competitiveness (IEA-3, 2021).

Energy security is now a standard component of both energy and security policy. With fast-moving socioeconomic and technological change, energy security has become a broader, multi-scale challenge spanning households, national systems, and global policy (Pasqualetti & Sovacool, 2012). Kivimaa & Sivonen (2021) highlights its intersections with national security, defence, and cybersecurity. Our study focuses specifically on local energy security and the role of regions in shaping it. In today's rapidly changing socio-economic and technological landscape, the understanding of energy security has expanded. The literature offers many competing definitions, reflecting ongoing debate. However, experts agree on the need to refine and update the concept. Strojny et al. (2023) show that energy security is shifting from a narrow focus on supply toward viewing energy as a driver of broader social and economic change, shaping consumption patterns, reducing demand, and promoting efficiency and environmental standards.

3. Energy security at Global level

Energy security is a multifaceted and evolving policy domain with implications at international, national, and regional scales (WEC, 2025; IEA-2, 2025). As a foundational element of economic development, societal stability, and geopolitical strategy, energy shapes global power relations and national resilience (Jiang & Liu, 2023).

The closure of the Strait of Hormuz on 2 March 2026, following US-Israel strikes on Iran, has triggered a global energy concern. Nearly one fifth of the world's oil and gas normally passes through this narrow corridor, and its shutdown has sent prices surging across major markets. Shipping insurers have raised premiums or halted coverage, and several energy companies have declared force majeure (Reuters, 2026). Import dependent economies, especially in Asia, have released strategic reserves and introduced fuel saving measures, though such steps offer only temporary relief. The disruption is also affecting industries reliant on Gulf hydrocarbons, including fertilizers, helium, and sulphur. While governments manage the immediate fallout, the crisis underscores the need for longer term strategies to strengthen global energy security.

Contemporary energy systems are increasingly globally interconnected yet locally differentiated (Man et al., 2024). The green transition is accelerating a structural shift from centralized generation toward distributed renewable energy production, offering significant benefits but also introducing new vulnerabilities related to system resilience, intermittency, and local disruptions (World Economic Forum, 2024).

To monitor and benchmark this transformation, the World Economic Forum developed the Energy Transition Index (ETI), which evaluates both (i) global energy system performance and (ii) countries' readiness for a secure, equitable, and sustainable energy future (World Economic Forum, 2024). The ETI comprises 46 indicators across two dimensions:

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- System performance (equity, security, sustainability)
- Transition readiness, including core enablers (regulation, political commitment, finance, innovation) and enabling factors (infrastructure, education, human capital)

As an analytical framework, the ETI assesses progress toward an energy system that ensures sustainability, universal access, and security, supported by institutional capacities that enable effective implementation and long-term transformation.

4. Energy Security at EU Level

The recent energy crisis, driven by geopolitical tensions, supply instability, and rising prices, has underscored the strategic importance of the EU energy sector and the urgency of accelerating green and sustainable pathways to reduce import dependence (Kivimaa & Sivonen, 2021).

Energy security is a central element of EU climate policy and underpins economic and social stability. At both EU and national levels, it must be evaluated through a holistic framework such as the energy trilemma, which balances security, affordability, and environmental sustainability (Ang et al., 2015). Maintaining affordable energy supports competitiveness, yet this often conflicts with environmental goals and the high capital costs of clean-energy transitions. Renewables can strengthen security by reducing import dependence, but issues such as intermittency, high costs, and risks to water and food security, particularly from biofuels, limit their effectiveness. These trade-offs highlight the need for sustainability as the overarching principle of energy policy. Short-term security measures may undermine long-term resilience, making it essential to consider the full trilemma rather than isolated objectives.

Correljé and Linde (2006) argue that shifting geopolitics and the rise of regional power blocs require the EU to rethink energy security. They call for integrating energy policy into EU trade, foreign, and security strategies, and for deeper engagement with producers in the Persian Gulf, Africa, and Russia. Growing geopolitical risks increase the EU's exposure to supply disruptions, and effective policy depends not only on markets and infrastructure but also on the wider geopolitical environment. Without consensus among member states, the EU risks fragmented national approaches, making a unified and flexible energy security strategy increasingly necessary.

The 2022 Russian invasion of Ukraine exposed Europe's vulnerability, as Russian gas previously supplied nearly 45% of EU consumption. This shock accelerated the EU's energy transition and forced a rapid reassessment of supply strategies. Amid an unprecedented energy crisis, Europe had to act quickly to secure its energy supply as rising energy prices fuelled inflation (Man et al., 2024). Europe now faces a pivotal moment in shaping its energy future (EU Energy Security, 2025; World Economic Forum, 2025). Achieving net-zero emissions requires rapid expansion of domestic renewables, yet the infrastructure enabling this transition remains exposed to growing risks. A stronger policy framework is needed to support resilient infrastructure, technological innovation, and greater energy independence (Singh et al., 2019), aligned with the broader "3Ds": decarbonization, digitization, and decentralization (Di Silvestre et al., 2018). Technological innovation usually includes increased digitalization. Europe is positioning itself as a leading proponent of a rights-focused, regulation-driven model of digital governance, aiming to balance digital rights with economic growth and promote this framework globally (De Lombaerde, 2024). The digitalization of energy systems is driven by advancements in data, analytics, and connectivity, introducing new security and privacy risks, disrupting markets, businesses, and employment (IEA-4, 2017). Energy sovereignty used to focus on securing physical resources and infrastructure, but it is now reshaped by deregulation, decarbonisation, decentralisation, and digitalisation. Data analytics has become central, reducing dependence on external energy sources, improving system visibility for grid operators and local energy managers through enhanced monitoring and data-driven decision-making, and enabling prosumers to actively support energy security. As distributed renewable policies expand, sovereignty shifts from governments and utilities toward decentralised networks, where advanced analytics help coordinate voluntary demand reductions during supply constraints.

Xiao (2025) identifies the main digitalisation challenges for a carbon-neutral energy sector using fuzzy Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS). The digitalisation challenges are (i) improving financial viability and investment, (ii) strengthening regulatory and policy support, and (iii) building public trust and engagement.

To accelerate the phase-out of fossil fuels, the EU and its member states have revised climate policies (EC-2, 2025; FI-1, 2024; FI-2, 2024). Updated National Energy and Climate Plans for 2021–2030 call for strengthened measures to reduce GHG emissions (EC-1, 2025; IEA-1, 2025) in line with the EU's targets of carbon neutrality by 2050 and a 55% emissions reduction by 2030 (EC-3, 2025).

On 3 December 2025, the European Commission advanced its economic security agenda, expanding the 2023 Economic Security Strategy and the 2024 European Economic Security Package to better manage risks related to trade, investment, technology, and critical infrastructure (EC-6, 2025). While the EU remains open to global markets, economic security considerations will increasingly shape regulatory expectations.

Given rising climate, cyber, and geopolitical risks, the EU is preparing a revised energy security framework for 2026 (EC-4, 2025) aimed at ensuring a secure, resilient, and sustainable energy system capable of meeting evolving challenges.

5. Energy Security at National Level

Studies on energy security predominantly focus on national-level dynamics (Azzuni & Breyer, 2020; Jääskeläinen et al., 2018; Liwång, 2023) or on regional cooperation through interconnected European energy systems (EC-4, 2025). Some analyses address clusters of countries with shared objectives, such as, Galinis et al. (2020) examined how carbon-price trajectories affect energy security in the Baltic region, while Turtola et al. (2025) explored cybersecurity challenges in the increasingly digitalised Nordic energy sector.

As energy security is central to EU climate policy, it is embedded in member-state obligations. All EU countries must prepare National Climate and Energy Plans (NCEP, 2025) and submit biennial progress reports, which have led to more ambitious emission-reduction targets. Several states have adopted even stricter national goals: Finland aims for carbon neutrality by 2035 (FI-1, 2025), while Sweden and Germany target net-zero emissions by 2045 (Sweden, 2025; Germany, 2025).

Koivunen & Syri modelled Finland's nuclear capacity and expanding wind and solar for 2024 and 2030. Despite major growth in renewables, scarcity events are expected to become more frequent and severe by 2030 due to Combined Heat and Power (CHP) plants retirements, the shift to electrified district heating, and rising demand. Without further measures, Finland will remain vulnerable to cold periods with high heating and electricity needs.

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Biomass, derived from energy crops, forestry residues, cereal straw, and wood waste, serves as a renewable alternative to fossil fuels in power generation and is increasingly used to meet the rapidly approaching 2030 emission-reduction targets. Forests, acting as major carbon sinks, absorb and store more carbon than they release, but disturbances such as deforestation, fires, droughts, and storms weaken this sink. Across the EU, the average forest carbon sink in 2020–2022 declined by about 27% compared with 2010–2014 (EU Science Hub, 2025). In Finland, bioenergy was initially viewed as a fossil-free solution, but concerns grew as increased wood use contributed to declining carbon sinks (Kivimaa, 2024). The LULUCF sector is therefore critical for achieving EU net-zero goals, with a binding removal target of 310 $MtCO_2e$ by 2030 (EEA, 2025). Current measures remain insufficient, and additional policies are required to strengthen Europe's carbon sink. In Finland, biomass use is integrated into the national carbon-neutrality strategy, but this reduces LULUCF sinks and complicates the 2035 net-zero target (Hyvönen et al., 2024). The loss of Russian timber imports after 2022 has further increased domestic harvesting (FI-3, 2025), driven by demand for wood fuels and forest-industry by-products.

In electricity systems, biomass can complement variable solar and wind generation during periods of supply shortage (Millinger et al., 2025b). Although versatile, biomass remains a renewable resource with limited availability (Millinger et al., 2025a). When renewable electricity or hydrogen is scarce, the strategic value of biomass in fuel production increases. Biomass accounts for nearly 60% of all renewable energy in the EU, with consumption particularly high in northern and central Europe where forestry dominates (Scarlat et al., 2019).

6. Energy Security at Regional Level

The EU Covenant of Mayors for Climate & Energy is Europe's largest coalition of local governments taking action on climate change. More than 10,500 local authorities have voluntarily committed to supporting the EU's energy and climate targets.

Regions and cities argue that achieving the EU's climate targets and a just energy transition requires empowering local and regional authorities with adequate resources, skills, and political support. The European Committee of the Regions (CoR) stresses the urgent need to expand clean-energy production in the EU, to boost competitiveness, ensure security of supply, decarbonise the energy sector, and address energy poverty (CoR, 2025). It proposes serving as a Fit for 55 Local Implementation Forum, offering technical support and financial matchmaking, and calls on the European Commission to publish an annual Fit for 55 Local Implementation Scoreboard.

Stec et al. (2025) examined how Poland's local government units (LGU) responded to the 2022–2023 energy crisis, which stemmed from geopolitical tensions and supply instability. A nationwide survey of 167 LGUs revealed that most focused on renewable energy investments and upgrading infrastructure. However, almost half LGUs lacked contingency plans for supply disruptions, highlighting gaps in crisis management. Similarly, Du et al. (2024) evaluated energy security in 30 Chinese provinces from 2000–2019, identifying regional disparities in energy independence. They found that robust domestic emergency plans are vital for mitigating economic disruptions from energy supply shocks linked to international conflicts or climate change. The study suggests China should advance energy sector reforms, expand renewable energy, and consider weather pattern impacts on future energy security. Climate threats and pollution complicate achieving energy independence, especially given varying resource capabilities and development across regions.

Local and regional authorities (LRAs) are recognised as central to implementing climate and energy policies, given their ability to identify context-specific challenges and solutions (BuildUP, 2026). Around 70% of energy and climate measures rely on LRAs, who are also positioned to address digitalisation needs and social inequalities (Altun & Schulz-Ruhtenberg, 2022).

MacKay et al. (2021) examined energy security in cold climates and argue that community-driven, small-scale renewable projects may provide greater social and economic benefits, especially in remote regions, than top-down initiatives. They recommend future research that includes participants from diverse socio-economic backgrounds, ages, and genders to better capture community perspectives and inform energy policies that reflect local priorities.

7. Conclusion

Energy security is increasingly shaped at the local and regional level, where the impacts of global shocks and national policies are ultimately felt. While geopolitical disruptions, such as the closure of the Strait of Hormuz, where nearly one fifth of the world's oil and gas normally passes, and EU-wide crises expose systemic vulnerabilities tied to renewables, critical materials, and cybersecurity. National experiences like Finland's highlight the practical tensions of balancing reliability, sustainability, and land-use constraints. Municipalities and regions are the actors responsible for implementing most practical solutions. As the report notes, around 70% of climate and energy measures rely on local and regional authorities, who identify context-specific challenges and solutions. Local energy security now depends on strengthening distributed renewable systems, improving municipal preparedness, and ensuring that digitalization enhances rather than undermines resilience. Yet many local governments still lack contingency plans, revealing a gap between national ambitions and local capacity. Ultimately, building a secure and sustainable energy future requires empowering local authorities, aligning multilevel governance, and investing in community-level resilience. Energy security may be global in cause, but it is local in practice.

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Co-funded by the European Union
HÄMEEN LIITTO Regional Council of Häme
HAMK Häme University of Applied Sciences

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