ENERGY INDEPENDENCE: AN ESSENTIAL PILLAR FOR CRITICAL INFRASTRUCTURE RESILIENCE

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Abstract: *In the contemporary geopolitical landscape, characterised by instabilities, climate change, and mounting cyber threats, the pursuit of energy independence has transcended the realm of mere political aspirations, becoming a matter of strategic imperative. Recent events in Spain and Portugal, where a substantial blackout impacted critical infrastructure and communications, underscore the vulnerabilities of centralized and interdependent energy networks. This incident has led to a resurgence of interest in the necessity for local, sustainable, and secure energy solutions, particularly in regard to critical infrastructure. Such infrastructure may include hospitals, data centres, communication networks, public transport, and defence systems. The solutions are varied, but must be chosen in relation to the available and potential resources and infrastructure, and especially the level of importance of the objectives to be protected.*

Keywords: *energy independence, critical infrastructures, resilience, energy reserves, VUCA.*

1. INTRODUCTION: EUROPE'S GEOPOLITICAL AND ENERGY CONTEXT

In the contemporary geopolitical landscape, characterized by increased volatility, strategic uncertainty and the constant emergence of new hybrid and cyber threats, along with the challenges exacerbated by climate change, the concept of **energy security** has advanced on the agenda of global strategic priorities. The pronounced dependence on external energy sources has been recognized as a major systemic vulnerability, with the potential to generate economic dysfunctions and compromise the functional integrity of national critical infrastructures [1].

The European Union, a leading player in the global security and economic architecture, has faced increasing pressure in recent years to strike an optimal balance between **energy needs** and **strategic autonomy**. Recent statistical data acutely underline this challenge: in 2022, the European Union's energy dependency ratio (Figure 1) reached a level of 62.5%, indicating a considerable vulnerability to international market fluctuations and geopolitical events with a major impact. Although there was a slight decrease to 58.3% in 2023 [2], this persistent dependence constitutes a substantial risk factor for the internal and external stability of the community bloc. The need to reduce exposure to external shocks has spurred a fundamental reassessment of energy strategies, reinforcing the concept of **energy independence** as a central pillar of state sovereignty and resilience.

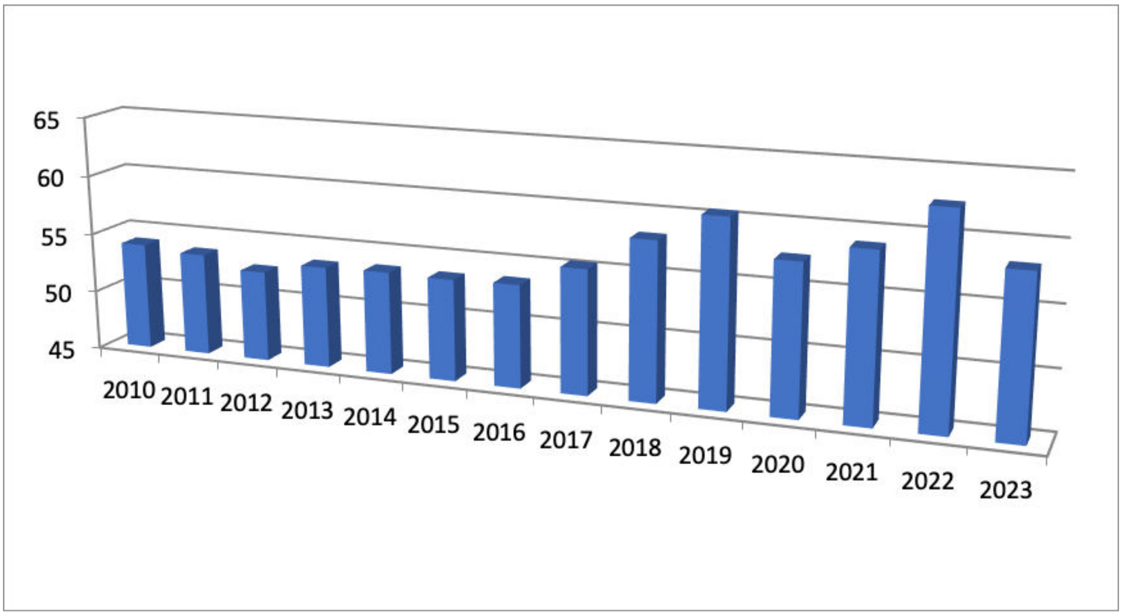

FIG.1 Evolution of the European Union's energy dependence (%)

At the same time as efforts to reduce dependence on imports, the European Union has taken a firm strategic direction towards **the energy transition**, aiming at a deep decarbonisation of its energy mix. The target of 42.5% of renewables in gross final energy consumption by 2030, up from 24.5% in 2023 [3], reflects a substantial ambition to combat climate change and build a sustainable energy system.

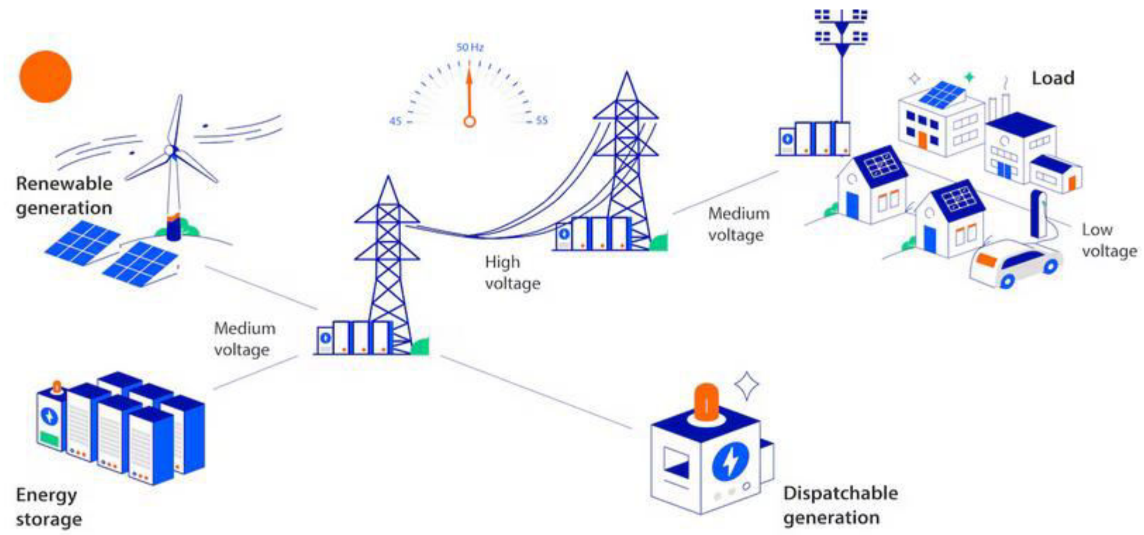

FIG.2 Components of the energy system *(Source: RaboResearch 2025)*

This structural transformation, while necessary for environmental protection and long-term sustainability, presents inherent challenges. The large-scale integration of renewable energy sources, characterized by **intermittency** and **variability** [4], requires prompt adaptation and significant modernization of existing energy infrastructure (Fig. 2), including the deployment of advanced storage and grid management solutions [5].

In this dynamic context, the concept of **resilience** acquires a particular importance. It is not enough just to ensure a continuous energy supply; It is necessary for energy systems to demonstrate the ability to absorb shocks, adapt to fluctuating operational conditions and quickly restore their functionality after major disturbances [6].

This requirement becomes even more stringent in the case **of critical infrastructure**, whose relevant components – including hospitals, communication networks, transport systems and, in particular, **defence and radar systems** – depend to a large extent on a reliable and uninterrupted power supply. Any malfunction in the energy supply of these infrastructures can lead to serious consequences, with widespread reverberations on national security, economic stability and societal well-being. This article aims to carry out an in-depth analysis of the intersection between energy independence and critical infrastructure resilience, with a particular focus on identifying vulnerabilities and proposing applicable solutions, integrating a relevant perspective for defence and radar systems.

2. CASE STUDY: POWER OUTAGES IN SPAIN AND PORTUGAL (APRIL 28, 2025)

Major incidents affecting energy infrastructure serve as alerts, highlighting the fragility of centralised and interdependent systems. One such event occurred on **April 28, 2025**, when a massive power outage simultaneously paralyzed Spain and Portugal, cutting off electricity supplies for millions of citizens [7], [8]. At 12:33 CET, the Spanish energy system experienced a steep loss of generation capacity. According to initial reports, around 15 GW were lost in Spain, equivalent to about 60% of national demand, in just a few seconds [9]. This rapid decrease in generation capacity illustrated the inherent vulnerability of modern grids to sudden disruptions.

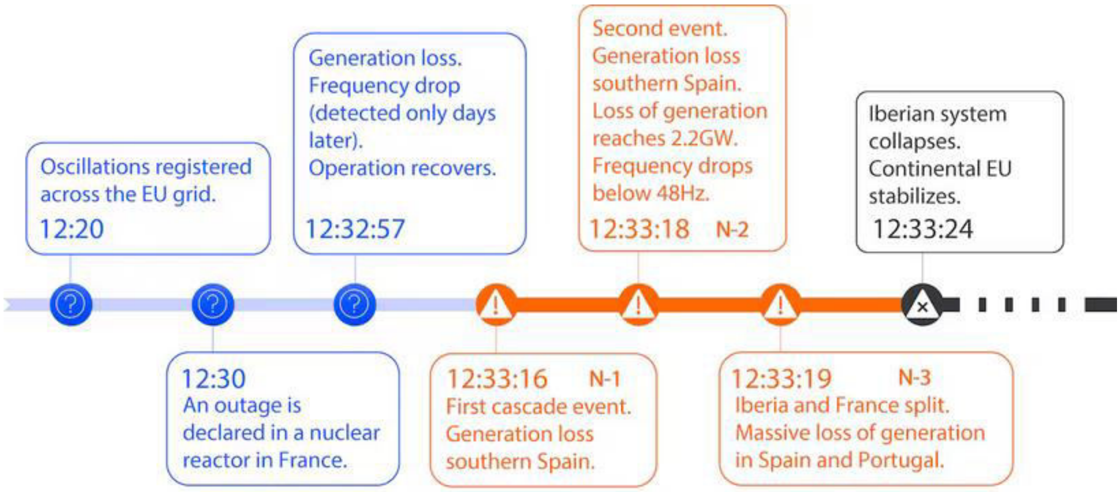

FIG.3 Timeline of events at the power outage in Spain *(Source: RaboResearch 2025)*

Preliminary investigations, carried out by entities such as ENTSO-E [10], indicate that the incident was triggered by a series of disconnections of generation units, in particular in south-west Spain. A major factor contributing to this instability was the lack **of mechanical inertia** specific to traditional rotary generators (such as those in thermal or nuclear power plants), inertia that contributes to the stability of the grid frequency in the event of rapid fluctuations. Photovoltaic and wind systems, due to their electronic nature, do not offer the same inertia, which can amplify grid instability in stressful situations.

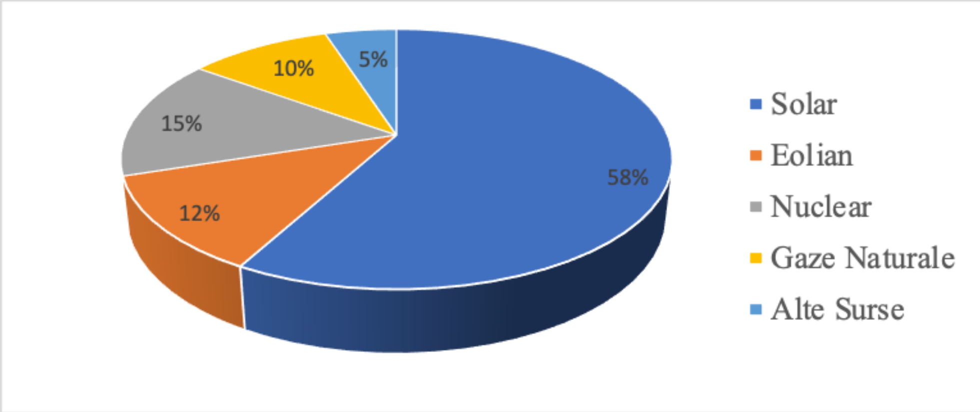

FIG.4 The energy mix of the Iberian Peninsula at the time of the power outage (April 28, 2025)

For example, at the time of the incident, the Iberian system had a very high share of renewable generation, with solar energy accounting for almost 60% of the energy mix (Figure 3) and wind power for about 12% [11][12]. This technological gap highlights a major challenge of the energy transition: ensuring grid stability as the share of intermittent renewables increases exponentially.

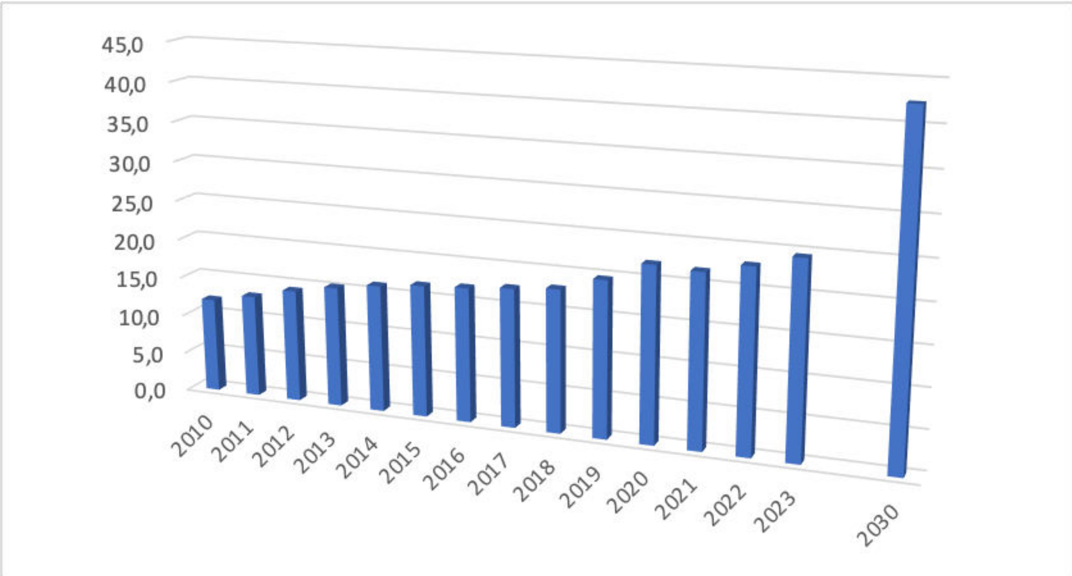

FIG.5 Share of renewables in EU gross final energy consumption (%)

The impact of this power outage (Table 1) on **critical infrastructure** was considerable. Airports were forced to suspend operations, hospitals switched to emergency generators, public transport networks and communications were significantly disrupted, and ATMs and electronic payment systems became inoperable [13][14]. This incident clearly demonstrates the degree of interdependence of modern societies on a continuous and stable power supply. In the specific context of defence systems, such a disruption could substantially affect the air and maritime surveillance capability, the functionality of command and control systems, as well as the operationality of military units that depend on the civilian network for supply. It underlines the need to develop autonomous and resilient energy solutions for these infrastructures [15].

Table 1: Impact of the power outage of April 28, 2025

Critical Infrastructure Sector	Observed Impact
Airports	Suspended operations; Rerouted/delayed air traffic
Hospitals	Switching to emergency generators; Potential risk for patients dependent on appliances
Public Transport Networks	Total stop (metro, trams); Extensive roadblocks
Communications	Significant disruptions to voice and data networks; difficulties in calling emergency services
Financial Systems	Inoperable ATMs; blocked electronic transactions; impact on trade
Defense Systems (Radar)	Risk of loss of surveillance and detection capability; Compromise of C2 (Command and Control) functionality

3. VULNERABILITIES OF CRITICAL INFRASTRUCTURE IN THE CONTEXT OF THE ENERGY TRANSITION

Critical infrastructure is the set of systems and assets, physical or virtual, whose malfunction or destruction would have a debilitating impact on the security, economy, public health or safety of citizens. This includes sectors such as health (hospitals, clinics), transport (airports, ports, railways), communications (data and voice networks), financial systems and, obviously, the **energy sector** itself, alongside **defence systems** such as radar and surveillance [16]. The continued functioning of these sectors is a key element for social cohesion and the state's ability to react in crisis situations.

The massive integration of **renewables**, although a necessary step towards sustainability, introduces new **risks and vulnerabilities** in the stability of energy grids. The intermittent nature of solar and wind energy, dependent on weather conditions, imposes complex grid balancing requirements. Without adequate **energy storage** measures and advanced **grid stabilization** solutions, rapid fluctuations in production can generate frequency and voltage instabilities, culminating in the risk of cascading disconnections. The incident in Spain is illustrative of this: at the time of the power outage, Spain generated a significant proportion of its electricity from solar (53%) and wind (11%) sources, along with nuclear and gas (15%) [9]. Reliance on low-inertia sources can amplify the speed and severity of a network collapse in the absence of robust response systems.

For **radar systems**, which are important components of defense infrastructure, these vulnerabilities are amplified. A radar system, whether dedicated to aerial, sea or ground surveillance, requires a **continuous, stable and high-quality power supply**. Outages, even of short duration, can lead to loss of detection and tracking capability, equipment reset, or even irreparable damage. This would seriously compromise the reaction capacity of the armed forces, from early warning to the guidance of defense systems. The exclusive dependence on the national grid, even in the presence of conventional backup generators, exposes radar systems to multiple risks: physical attacks on transmission lines, cyber attacks on the SCADA control systems of the civil network, or even extensive technical failures, as exemplified in the case of Spain. Therefore, energy autonomy and resilience become not only options, but strategic requirements for maintaining the operational capacity of defense systems.

4. STRATEGIES FOR STRENGTHENING ENERGY INDEPENDENCE AND CRITICAL INFRASTRUCTURE RESILIENCE

Ensuring **the energy independence** and **resilience** of critical infrastructure requires a multifactorial approach, which combines technological innovation with strategic planning and the implementation of appropriate public policies. A central element in this strategy is **the development of microgrids and energy storage systems**. Microgrids are localised energy systems capable of operating independently of the national grid (island mode) in the event of disruptions, ensuring continuity of supply for critical consumers. The integration **of** high-capacity batteries (such as Li-Ion or flow), alongside other storage solutions (thermal, mechanical or hydrogen-based), is useful to compensate for the intermittency of renewable sources and provide immediate backup power [5]. For radar stations, the development of hybrid microgrids (solar-wind-batteries, with diesel/gas backup) would ensure increased energy autonomy, reducing dependence on the centralized grid and, implicitly, the associated vulnerabilities.

Diversification of energy sources is another basic strategy. Reducing dependence on imports and a single type of fuel is achieved by increasing domestic energy production from multiple sources. This includes not only accelerating the deployment of renewable energies (solar, wind, small hydro, geothermal, biomass) [17], but also maintaining a balanced energy mix, which also includes basic capacities (nuclear, natural gas) capable of ensuring long-term stability. For defense infrastructure, especially for isolated or mobile units, the use of compact and easy-to-deploy renewable energy solutions (e.g. portable solar panels, small wind turbines) becomes a relevant aspect for reducing the logistical footprint and vulnerabilities related to fuel transport.

Investments in the modernisation and digitalisation of critical infrastructure are significant to enable smart and efficient management of energy resources. The implementation **of Smart Grids**, capable of monitoring and controlling energy flows in real time, optimizes distribution, minimizes losses and allows a better integration of distributed sources [18]. For radar systems, the modernization of the local energy infrastructure by integrating advanced monitoring and automated control technologies can prevent malfunctions and allow a rapid reaction in case of emergency.

Last but not least, **the cybersecurity** of the energy infrastructure of critical systems is an important aspect. As energy systems become more digitalised and interconnected, the risk of cyberattacks increases. The protection of industrial control systems (ICS) and SCADA that manage energy flows, including those of the microgrids that feed radar systems, is necessary to prevent sabotage, information gathering or disruption of operations [19][20]. An integrated approach, combining physical and cyber security, is needed to ensure the full resilience of critical infrastructure.

RECOMMENDATIONS AND CONCLUSIONS

Ensuring **energy independence** and strengthening **the resilience of critical infrastructure** are significant strategic objectives in the current global geopolitical and energy context. The case study of the power outage in Spain and Portugal on 28 April 2025 served as an illustration of the inherent vulnerabilities of centralised energy systems and the considerable impact on relevant sectors, including the potential impact on defence systems. The accelerated integration of renewable energy sources, while necessary to achieve decarbonisation goals, requires the adoption of robust technological and strategic solutions to manage intermittency and ensure grid stability.

Based on the analysis carried out, we formulate the following **key recommendations**:

- **Integrated Public Policies:** It is advisable to develop and implement coherent public policies that balance energy transition ambitions with security and resilience objectives. They must stimulate investment in energy storage technologies, the development of microgrids and the modernisation of existing infrastructure, with dedicated financing mechanisms for critical and military infrastructure.
- **Priority Investments in Microgrids and Storage:** Governments and entities responsible for critical infrastructure should prioritize investments in autonomous microgrids and advanced energy storage systems. They enable independent operation in crisis situations, ensuring the continuity of relevant services, including for defence and radar systems, which require exceptional reliability of supply.
- **Real Diversification of the Energy Mix:** Beyond the adoption of renewable energies, national strategies must aim at a broad diversification of supply sources and generation technologies, reducing excessive dependence on any single source or vulnerable import routes.
- **Strengthening Cybersecurity:** As energy infrastructure becomes increasingly digitized, investments in the cybersecurity of the control systems (ICS/SCADA) associated with it are necessary to prevent attacks that could compromise the power supply of critical infrastructure.
- **International and Regional Collaboration:** Cooperation between EU Member States and beyond is useful for developing interconnected, resilient and interoperable energy networks, as well as for sharing best practices and threat intelligence.
- **Education and Strategic Awareness:** An information campaign is needed for the general public and decision-makers on the strategic importance of energy independence and critical infrastructure resilience, in order to ensure the necessary support for the implementation of appropriate measures.

Therefore, energy independence is no longer just an economic option, but a strategic requirement of national and European security. By adopting an integrated approach, combining technological innovation with visionary public policies and a deep understanding of specific vulnerabilities, especially in areas such as defence and radar systems, an energy infrastructure can be built capable of sustaining the resilience of our societies in the face of present and future challenges.

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