Artificial intelligence, energy infrastructures and climate change. Vulnerabilities and impact in the Italian context

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Abstract

Artificial intelligence (AI) is increasingly intertwined with energy and infrastructure systems. On the one hand, the expansion of data centers and computationally intensive applications creates additional electricity demand, often concentrated in locations where grid capacity is already constrained. On the other hand, AI-based applications can support forecasting, renewable integration, congestion management, predictive maintenance and operational resilience. Assessing these effects separately may therefore provide a misleading picture of AI's overall relationship with the power system. This article develops a conceptual and policy-oriented analysis of this dual relationship, with specific reference to the Italian electricity system. Building on, but substantially extending, the interdisciplinary work of the Working Group on Artificial Intelligence and Climate Change of the Associazione Italiana esperti in Infrastrutture Critiche (AIIC), it integrates evidence from scientific literature, institutional and technical reports, and the Italian infrastructure context within a common analytical framework. The analysis focuses on the feedback between four interacting dimensions: AI-related electricity demand, physical power-system constraints, AI-enabled operational capabilities, and climate-related stress. The Italian case illustrates how geographical mismatches between renewable generation and demand, transmission bottlenecks, the localization of new digital loads, and long infrastructure development times can condition both the costs and the potential benefits of AI deployment. The paper argues that AI should be understood neither simply as an additional electricity load nor as an autonomous technological solution to energy-system challenges. Rather, it acts as a capacity multiplier whose effects depend on the resilience and adequacy of the physical infrastructures in which it is embedded. This perspective provides a transferable framework for assessing AI-energy interactions while identifying the infrastructure and policy conditions under which AI can contribute positively to power-system resilience.

Keywords: artificial intelligence, power systems, critical infrastructures, climate change, data centers.

JEL classification: Q48, Q41, O33, Q54

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1. Introduction

The relationship between artificial intelligence and energy has gained intense public and political scrutiny in recent years. The rapid proliferation of large-scale machine learning models, the expansion of advanced digital services, and the emergence of generative applications have spotlighted the inextricable links between AI development, energy consumption, and environmental impact. Meanwhile, climate change is placing unprecedented stress on critical infrastructures, especially power systems, which are required to guarantee continuity of service under increasingly variable and stressful operating conditions.

The chief risk lies in fragmented, single-issue analyses. Public discourse and accounts by early adopters – including some participants in the initial phases of the AIIC Working Group – often portray AI as an "immaterial" technology, capable of dematerializing processes, converting resource-intensive workflows into digital and knowledge-based equivalents. Examples abound in consumer applications like digital media distribution, remote services, smart home management, or the substitution of physical documentation and on-site operations with data-driven platforms. These processes reduce consumption, primarily in terms of final or mechanical energy use, while often implying a shift toward higher electricity demand ± in the process generally known as the electrification of society and the economy. Conversely, AI is presented by other analysts as a direct threat to energy sustainability, driven by the speedy growth of data centers and computational loads, and the consequent power consumption needs. Both views capture partial truths, but falter without a broader systemic framework (World Economic Forum, 2025).

AI is neither monolithic nor homogeneous. It comprises diverse statistical and computational methods that interact with complex physical systems: power grids, industrial plants, transport infrastructures, and urban systems. In this sense, speaking of "AI and climate" thus demands dealing with the impact on infrastructures – how they are designed, operated, and adapted within the context of the energy and environmental transitions. More AI infrastructure can be directly translated into more environmental and climate impact – but the net effect hinges on balancing its energy demands against the energy efficiency gains, emissions reductions, and mitigated externalities.

Italy offers a stark illustration. Its power system has to cope with entrenched asymmetries: a growing share of new wind and solar generation is concentrated in the South and Islands, while electricity demand remains clustered in the North, and transmission deals with bottleneck North-South corridors. Hydroelectric generation, by contrast, remains predominantly located in the North. This northern hydroelectric resource is itself climate-sensitive: Alpine water availability depends in part on snow accumulation and seasonal snowmelt, so declining snow cover and changing runoff regimes can affect hydropower availability. Reinforcing this grid entails protracted permitting, construction timelines, and territorial compromises. Introducing electricity-intensive AI loads – like data centers – thus demands granular spatial and infrastructural scrutiny, not mere aggregate projections (ISPRA, 2026; EEA, 2025).

This article therefore aims to clarify three pivotal points:

- Distinguishing AI's abstract technological evolution from operational, short to medium term applications, eschewing speculative forecasts that risk obscuring the analytical picture;

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- Revealing AI's multifaceted power system impacts beyond the energy demand from data centers, and thus considering AI applications to grid management, demand forecasting, renewable integration, peak-load response and beyond;
- Underscoring Italy's power system vulnerabilities as structural constraints that both limit AI expansion and amplify AI's potential as a tool for climate resilience.

2. Technological framing of artificial intelligence

To assess AI's role in energy and climate contexts, we must first delineate its scope. Contemporary AI spans a broad family of machine-learning techniques, including – but not limited to – deep learning. These methods discern patterns from vast datasets to enable forecasting, classification, optimization, and, more recently, content generation.

These methods are neither autonomous nor disembodied. They hinge on high-quality data, physical/digital infrastructures, and embedded reference models/assumptions. In practice, AI augments – rather than supplants – established physical, engineering, statistical models and human operators. In power systems, it bolsters state estimation, digital twins for scenario analysis, and anomaly detection in noisy data, while physics-grounded models validate outputs (ENEA, 2022; ETIP-SNET, 2024; Ciapessoni et al., 2026).

Public discourse often overlooks AI's operational realities. While training complex foundational models demands immense compute, the load demands of the energy-sector AI applications result from their use for *inference* – the ongoing deployment of adapted models. This nuance is vital for gauging true power-system impacts, avoiding overgeneralization from extreme cases or experimental outliers.

In the energy sector, AI applications already in operation or under active development span several functions (Yao et al., 2025; Zhang et al., 2026), including:

- Demand forecasting;
- Renewable generation forecasting;
- Dispatch optimization;
- Predictive maintenance of plants;
- Management of grid congestion;
- Decision support under conditions of climatic uncertainty.

These applications do not require massive foundational LLMs, but rather an accurate integration of operational data, grid models, and regulatory constraints.

From this perspective, AI not only introduces new opportunities, but also new infrastructural dependencies. The growing reliance on advanced digital systems makes the operation of the power system increasingly sensitive to the availability of computational capacity, reliable connectivity, and continuity of power supply. This creates a circular dependency that must be carefully managed: AI contributes to optimizing the power grid, yet critically depends on it.

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3. Artificial intelligence and the power system: structural impacts and vulnerabilities in the Italian case

The interaction between artificial intelligence infrastructure and applications, and the power system serving them, cannot be analyzed by the mere aggregate assessment of the associated energy consumption. It is well known that the physical layout of the power grid, and the geographical location of generation plants and main loads, have a major impact on the operational capabilities and the grid reliability, affecting its exposure to hazards, congestion and losses. In Italy, the AI-power system interaction advances in a structurally fragile system, characterized by geographical asymmetries, infrastructural bottlenecks, and protracted adaptation timelines. Rather than introducing a novel set of challenges, AI acts as a catalyst that amplifies pre-existing tensions, making them more visible and, in some cases, increasingly difficult to manage (ENTSO-E, 2023; AIIC, 2026).

3.1. Territorial asymmetries and grid constraints

The Italian power system operates under a persistent geographical imbalance:

- The South and Islands host a growing share of renewable generation (wind and solar) and have the potential for further major plants;
- The North contains the main industrial, logistics, and urban hubs, driving the electricity demand.

While this asymmetry is not new, it has intensified in recent years due to the rapid deployment of renewable installations in southern regions. Transmitting electricity from South to North relies on a limited number of major backbone corridors. Constructing or reinforcing high-voltage lines involves long and complex institutional negotiations and environmental assessments, comparable to the construction of large transportation infrastructures. Each new line requires the involvement of local authorities, environmental agencies, affected communities, and regulatory bodies, with timelines that are rarely compatible with the speed of technological innovation. These constraints are consistent with European-wide assessments highlighting transmission availability as a critical bottleneck for system evolution (ENTSO-E, 2023; ETIP-SNET, 2024).

To address these constraints, the Italian TSO Terna has adopted a major network development programme. The 2025 Development Plan foresees more than EUR 23 billion of investment over 2025-2034 and an increase in interzonal exchange capacity, while explicitly identifying the rapid growth of data-centre connection requests as a new planning driver (Terna, 2025). In addition, the placement of substations near industrial and urban areas faces land-use and permitting restrictions. The effective impact of these investments will nevertheless depend on permitting timelines, social acceptance, and synchronization between grid expansion and the spatial concentration of new electricity-intensive loads.

Recent assessments within the AIIC Working Group highlight how these structural asymmetries already constrain operational choices. In Northern Italy and along the Alpine corridor, connection requests for new electricity-intensive facilities in-

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creasingly face delays not because of generation shortages, but due to limited transmission margins and substation saturation. Similar patterns have been observed in other European regions, where grid availability has become a binding constraint for industrial and digital investments.

In this context, the spatial distribution of new loads becomes a decisive variable. AI-related infrastructure, particularly data centers, tends to cluster in areas with high connectivity and established industrial ecosystems – often the same areas where grid expansion faces the strongest territorial and social opposition. Thus, the infrastructural nature of Italy's challenges can be characterized by the following factors:

- Operational constraints: In Northern Italy and the Alpine corridor, connection requests for new facilities are increasingly delayed. These delays are not caused by generation shortages, but by limited transmission margins and substation saturation;
- A shift in focus: The challenge has shifted from a purely technological issue to one of spatial planning and long-term network development;
- The localization factor: The primary issue is not the total volume of consumption, but rather the geographic location of loads and their interaction with a grid that is already operating near its limits.

The problem thus becomes primarily infrastructural and territorial, rather than purely technological.

4. Data centers, AI, and grid congestion: European evidence

Recent European analyses clearly show that data centers are already a critical factor for power grid planning. According to Ember, in the main European hubs – the so-called FLAPD markets (Frankfurt, London, Amsterdam, Paris, and Dublin) – data centers have already reached a very significant local impact on electricity demand. In 2023, they accounted for between 33% and 42% of electricity consumption in cities such as Amsterdam, London, and Frankfurt, reaching nearly 80% in the case of Dublin (Ember, 2024; IEA, 2024).

More recent evidence confirms the speed of this trend. The IEA estimates that global data-center electricity consumption rose to about 485 TWh in 2025 and could reach around 950 TWh by 2030, while electricity use by AI-focused data centers is projected to roughly triple over the same period (IEA, 2026). In Italy, Terna reported about 30 GW of data-center connection requests at the end of 2024, concentrated overwhelmingly in the North, including ca. 18.6 GW in Lombardy; by June 2025, requests had already exceeded 50 GW nationwide (Terna, 2025). These are connection requests rather than realized loads, but they provide a quantitative indicator of the pressure that prospective digital demand is placing on grid planning.

These figures indicate not only a rapid growth in demand, but above all a localized pressure on distribution and transmission networks, resulting in congestion, connection queues, and delays in grid investments. Ember highlights how the availability of grid capacity is becoming a determining factor in the choice of locations for new data center investments and, more broadly, for the development of AI applications.

Evidence collected within AIIC also points to a rapidly evolving role of data centers, which are no longer passive loads but increasingly active grid participants.

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While today less than 15% of European facilities operate with significant on-site renewable generation or storage, this share is expected to rise to around 30% by the late 2020s, driven by hybrid solar-battery systems, waste-heat recovery, and long-term power purchase agreements.

Nevertheless, these "prosumer" configurations do not eliminate the need for grid reinforcement. Even when data centers partially self-generate electricity, their peak demand, cooling requirements, and reliability standards continue to rely on transmission and distribution networks. As a result, local congestion remains a critical issue, particularly in regions where renewable generation, industrial demand, and digital infrastructure growth converge spatially.

Although Italy does not yet exhibit concentration levels comparable to those of Dublin or Amsterdam[1], the risk of replicating similar dynamics is concrete, especially in northern areas characterized by high industrial density and limited room for grid expansion. In the absence of proactive planning, the economic attractiveness of territories for AI-related investments may come into direct conflict with existing infrastructural constraints (AIIC, 2026; European Commission, 2023).

5. AI as a stress factor and as a management tool

It is important to emphasize that AI does not act solely as a stress factor on the power system. The same technologies that generate new loads can also be used to improve grid management and enhance resilience. As already mentioned, AI applications are already employed for demand forecasting, estimation of renewable generation, early detection of congestion, and management of flexibility (ENEA, 2022; ETIP-SNET, 2024).

Practical applications discussed in the AIIC report confirm this dual role. AI-based forecasting and predictive control systems are already used to mitigate short-term imbalances by anticipating drops in renewable output or surges in demand and activating storage or flexible loads in advance. In pilot environments, such approaches have reduced renewable curtailment and reliance on spinning reserves, particularly at the distribution and sub-transmission levels.

At the same time, these applications operate within a clearly defined operational envelope. When congestion becomes structural – due to persistent north–south imbalances or concentration of new loads in already stressed nodes – digital optimization alone cannot restore system margins. In these cases, AI acts as a buffer rather than a solution, extending but not redefining the physical limits of the network.

In this sense, AI can contribute to a more efficient use of existing resources, reducing the need for immediate infrastructural interventions. However, this contribution does not eliminate the structural constraint represented by the transmission capacity and insufficient local generation. Algorithmic optimization can delay or mitigate the problem, but it cannot replace the construction of new infrastructures when the mismatch between generation and consumption becomes systemic.

[1] It should be noted, however, that over 74 Data Centers are already operating in Lombardy (Milan Data Centers, in DATA CENTER MAP, https://www.datacentermap.com/italy/milan/.

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Recent contributions in emerging literature have begun to question the implicit assumption that the expansion of artificial intelligence can be accommodated without major systemic consequences for energy infrastructures (IEA, 2024). While AI is often framed as a tool for efficiency and optimization, its rapid diffusion – particularly through large-scale data centers – may itself become a structural driver of electricity demand growth.

In this perspective, the issue is not limited to aggregate consumption levels but concerns the temporal and spatial mismatch between the pace of digital expansion and the slower dynamics of infrastructure development. Power grids require long planning and implementation cycles, whereas AI-related loads can scale within much shorter timeframes. This asymmetry may result in localized congestion, delayed connections, and increasing competition for grid capacity.

A potential paradox thus emerges: the same technologies that are expected to improve system efficiency and support renewable integration may simultaneously intensify the structural constraints they are meant to alleviate. This tension is particularly relevant in contexts such as the Italian one, where network capacity is already limited and geographically uneven. Under these conditions, AI should be interpreted not only as an enabler of system optimization, but also as a factor that can amplify underlying infrastructural fragilities if not properly aligned with grid development and spatial planning strategies.

The Italian experience shows that flexibility – demand response, storage systems, intelligent load management – can offer significant margins of maneuver, but only within certain limits. When demand growth concentrates in already critical nodes of the grid, the cumulative effect risks exceeding the compensatory capacity offered by digital tools.

6. Energy efficiency and the role of AI: the ENEA contribution

The work carried out by ENEA (ENEA, 2022). on artificial intelligence for energy efficiency provides a complementary perspective, less focused on data centers and more attentive to distributed applications. In a 2022 case study on the Umbrian building stock, ENEA used an artificial neural network to compare retrofit strategies over a 25-year horizon. Targeting the most energy-intensive buildings on the basis of AI-supported forecasts increased the achievable energy saving to as much as 23%, with an estimated 13% reduction in the sector's overall energy demand. This example does not imply that comparable gains can be generalized to all power-system applications, but it provides a quantified illustration of AI as a decision-support tool for energy-efficiency planning.

This approach is particularly relevant for the Italian context, where the potential for improving overall system efficiency remains substantial. However, even in this case, the potential benefits of AI depend on the availability of adequate infrastructures and on a regulatory framework that promotes the adoption of advanced solutions without creating new bottlenecks.

AI can therefore be seen as an efficiency multiplier, but not as a self-sufficient solution. Without structural interventions on the grid and without coherent planning

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of energy-intensive facilities, there is a risk that downstream benefits will be offset by upstream inefficiencies.

AIIC findings further suggest that efficiency gains achieved through AI-enabled asset management and predictive maintenance can be significant at the component level, yet modest at the system scale if upstream bottlenecks persist. Improvements in transformer lifetime, loss reduction, or maintenance scheduling may delay investments, but they do not offset the cumulative effects of growing demand and limited transmission capacity.

This reinforces a key message: efficiency-oriented applications of AI deliver their full value only when embedded in a coherent infrastructure strategy that aligns grid development, load localization, and regulatory incentives within a broader infrastructure strategy (AIIC, 2026).

7. Implications for climate resilience

A distinction should be made between traditional digital control systems and AI-based approaches. Conventional digital tools are typically rule-based and deterministic, operating within predefined thresholds and programmed responses. AI systems, by contrast, rely on adaptive learning from data, probabilistic pattern recognition, and continuous model updating. In the context of climate-related stress – where non-stationarity, extreme events, and evolving risk profiles challenge historical assumptions – this adaptive capacity may enhance preparedness and resource allocation. At the same time, AI inherits the limits of data availability, model validation, and computational dependency. Its contribution therefore lies not in replacing established control systems, but in augmenting them with adaptive analytical capabilities under changing environmental conditions.

Climate change introduces further layers of complexity. Extreme events, heatwaves, and variations in the availability of renewable resources place stress on the power system precisely at a time when demand associated with digital services and AI tends to grow. In this context, system resilience cannot be entrusted exclusively to targeted technological solutions. Resilience is typically described as the ability of the system and its components (technical equipment and human operators) to prepare for, anticipate, absorb, adapt to and recover from non-routine disruptions, including high impact-low frequency (HIF) events (NATF/EPRI 2025). Therefore, the abilities and capacities that a resilient power system must present span along all technical, organizational and human dimensions.

Water availability is an additional source of climate-related stress. During the exceptional 2022 drought, very low river flows and reservoir levels in Northern Italy sharply constrained hydroelectric generation; national hydro production fell by 37.7% compared with 2021, illustrating how prolonged water scarcity can reduce available generation precisely when the electricity system is under additional stress (Terna, 2022).

AI can support the forecasting of critical events and emergency management, but resilience remains an emergent property of the entire infrastructural system. In this perspective, critical infrastructures should be understood not as isolated technical assets but as embedded ecosystems. Climate resilience depends not only on the ro-

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bustness of the core facility, but also on the reliability of its energy supply chains, connectivity networks, and supporting logistics. Recent extreme events have shown that failures often originate outside the physical perimeter of the infrastructure, affecting fuel supply, transport corridors, or upstream grid nodes. Designing for climate resilience therefore requires an ecosystem approach that integrates infrastructure planning, supply-chain validation, and emergency continuity frameworks.

It depends on network redundancy, diversification of sources, coordination capacity among operators, and the coherence of public policies. In the absence of these elements, the adoption of AI solutions risks producing marginal benefits or even exacerbating existing vulnerabilities (AIIC, 2026; ENTSO-E, 2023).

8. The energy trilemma under climate stress

In the current context, the power system can no longer be interpreted solely as a service infrastructure tasked with balancing generation and consumption. It has effectively become one of the main sensors of climate stress, as three structurally conflicting objectives converge upon it simultaneously: system security, environmental sustainability, and cost containment. This "energy trilemma," already well known in the sector literature, now assumes a new configuration, in which climate change acts as a multiplier of existing criticalities (IEA, 2024; ENTSO-E, 2023, Vivoda Vlado et al., 2026).

A first dimension concerns the integration of renewable sources and energy storage, marking the transition from a system based on dispatchable generation to one dominated by volatility (when sufficient energy accumulation is not available). In the past, grid operators could modulate supply by adjusting thermal power plants to follow demand profiles. Today, with a growing share of non-dispatchable renewable generation, the system is increasingly driven by meteorological conditions. This leads to well-known operational paradoxes: during hours of maximum solar irradiation, the grid may experience local overproduction that existing infrastructures are unable to absorb or transmit to consumption centers, generating congestion and curtailment. This is compounded by the reduction of system inertia, as inverter-connected renewable plants do not provide the "rotating mass" typical of large synchronous machines, making grid frequency more sensitive to rapid variations induced by climate events, even at regional scale. For that reason, there are multiple applications of synthetic inertia in power grids[2].

Storage is therefore not a marginal complement but a structural flexibility resource. Storage is a central enabler for connecting large, flexible, and highly dynamic AI data centers to the grid while maintaining reliability and security of supply. It acts both as a local buffer for the data center and as a system resource for the operator. From the grid operator's perspective, storage can make the net load profile more predictable and controllable, which is critical in congested areas. The objectives should be: 1) to enable a secure grid connection of the AI data center, able to absorb variability; and 2) to potentially take advantage of AI data centers as provid-

[2] See Wikipedia, Inertial response, https://en.wikipedia.org/wiki/Inertial_response.

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ers of valuable ancillary services, including peak shaving, congestion relief, and frequency and voltage control.

In its 2025 Development Plan, Terna estimates that 71.5 GWh of new storage capacity will be required in Italy by 2030, net of existing pumped-hydro plants, to support the effective market integration of renewable generation. Storage can absorb surplus production during high-renewable hours and release it when renewable output is insufficient, thereby reducing curtailment and easing short-term congestion. It cannot, however, substitute for transmission reinforcement where geographical imbalances are persistent (Terna, 2025).

A second dimension concerns the electrification of final consumption, which transfers climate risk directly onto the demand curve. The diffusion of heat pumps, electric vehicles, and cooling systems intensifies the dependence of the power system on environmental conditions. Prolonged heatwaves translate into simultaneous load peaks, which may coincide with reductions in renewable generation or with increased auxiliary consumption by data centers, required to ensure cooling of digital infrastructures. Under such conditions, system reserve margins shrink rapidly. Moreover, high temperatures produce direct physical effects on grid assets, reducing cable transmission capacity due to thermal derating: precisely when demand increases, the infrastructure is able to carry less energy.

The third dimension concerns infrastructural constraints and the growing reliance on advanced digital tools for system management. In such a complex context, the use of artificial intelligence for forecasting, dispatch, and real-time control becomes indispensable. However, this dependence introduces a new form of systemic risk. The digital infrastructure hosting these systems – data centers, telecommunications networks, control platforms – is itself exposed to the effects of climate change and to power supply disruptions. In the event of widespread failures or local blackouts, operators may lose not only operational capacity but also "visibility" over the system, compromising rapid restoration functions and black-start capabilities.

For Italy, the scale of the required physical adaptation can be expressed more directly through current network planning. Terna's 2025 Development Plan foresees more than EUR 23 billion of investment over 2025-2034 and projects a 6.8 GW increase in strategic interzonal exchange capacity by 2030. These figures illustrate the magnitude and long lead times of the physical infrastructure that must accompany electrification, renewable integration and new digital loads (Terna, 2025).

This creates a paradox at the heart of the energy trilemma: reinforcing the grid to accommodate renewable generation and AI-driven demand is essential for system security, yet the physical expansion of infrastructure may itself generate new environmental and social tensions. AI, in this setting, becomes both a necessary enabler of operational resilience and a catalyst that exposes unresolved structural trade-offs.

A further dimension of the energy trilemma concerns capital allocation. The transition towards a low-carbon system involves competing investment priorities: renewable generation, grid reinforcement, large-scale storage, energy efficiency measures, and digitalization, including AI-enabled applications. These domains are interdependent but draw from overlapping financial resources. While digital tools may improve operational efficiency, they do not substitute for physical infrastructure expansion. In contexts where transmission reinforcement, storage deployment, and renewable integration already require substantial capital, the allocation of additional

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resources to AI-based optimization must be evaluated within a broader systemic framework. The key issue is not whether digitalization is beneficial, but how investment priorities are sequenced and financed without disproportionately increasing end-user costs or delaying essential infrastructure upgrades.

A vicious circle thus emerges: climate stress puts pressure on the power grid; the grid supplies digital infrastructures and AI systems called upon to govern it; but if the grid fails, AI systems also shut down, making stability recovery more difficult. In this sense, AI is neither a panacea nor a neutral factor, but an element that reinforces the need for a systemic vision of infrastructural resilience (AIIC, 2026; ISO, 2023).

As discussed in Chapter 6 of the AIIC Report, AI enhances climate modelling primarily when embedded within physics-based frameworks, notably through surrogate modelling, data assimilation, and regional downscaling. European programmes such as Destination Earth illustrate this integration of AI, HPC, and digital twins at systemic scale. However, AI does not eliminate structural uncertainties nor the intrinsic limits of atmospheric predictability. Its value lies in refining long-term risk assessment rather than replacing established climatological methodologies.

9. Policy options

When facing the trade-offs deriving from the upcoming massive adoption of AI, and having to balance the reliability, efficacy and efficiency of the power system with its sustainability, and the affordability of investments and that of energy bills, authorities confront pressing and unavoidable decisions. On the one hand, authorities should prioritize policies that balance AI data center growth with grid stability, as this defines the only feasible while narrow path forward. On the other, authorities should spur harnessing AI's potential in power systems through targeted incentives and safeguards. This appears as the only workable trajectory to ensure energy security amid surging demand projections (e.g., data centers driving 25% of new EU load by 2030).

At the European level, the policy framework has advanced substantially since the first version of this paper. On 3 June 2026 the European Commission published its Strategic Roadmap for Digitalisation and AI in the Energy Sector (European Commission, 2026). The Roadmap addresses both sides of the relationship analyzed here: the sustainable integration of data centers into the energy system and the acceleration of AI and digital solutions for grids, buildings, industry and demand-side flexibility. The Commission estimates that demand-side digital flexibility could reduce EU consumers' electricity costs by more than EUR 71 billion per year, while AI-based operation and maintenance optimization could generate savings of up to EUR 94 billion annually by 2035. Concurrently, it also launched the AI.grids initiative[3] and a framework for tripartite cooperation among data-center operators, energy stakeholders and public authorities.

The following are the main policy points being considered in Europe for shaping the connection of AI data centers to the power grid:

[3] https://energy.ec.europa.eu/news/flagship-projects-ai-grids-and-data-centre-sustainability-2026-06-04_en.

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- New kinds of data on AI data center integration are required and national, regional and pan-European sharing frameworks must be created or adapted to this new reality;
- Common data saving practices and unified data models would be useful. Having ready access to these data is essential for supporting prompt policy and business decisions;
- Cooperation structures including all relevant actors are fundamental for trust building, defining common goals and a governance framework including TSOs and DSOs;
- Skills and education are generally considered as a challenge. The rapid evolution of technology requires a swift adaptation of human capabilities by all operators;
- The biggest risk for Al use in the energy sector is the risk of not acting. AI applications will be implemented and used, and the lack of awareness regarding their impact is a major vulnerability;
- Systemic testing and validating are key in risk mitigation strategies. Standardized metrics will facilitate the development of a common understanding among the industrial actors and with the policy makers;
- Sharing of best practices should inform risk mitigation strategies, contributing to community building through continuous discussion. This also will have to be implemented at the national, regional and European levels;
- There is a need for further guidance specific to the energy sector as the existing framework of the Al Act lacks sectoral clarity. Given that the use of AI applications will give place to new vulnerabilities and threats, their employment in grid control, dispatch, protection, forecasting and market operation should be treated as entailing high risk. By definition, the AI Act considers as "high-risk" any AI system used as a safety component in the management and operation of critical infrastructure, which comprises the supply of electricity;
- Under the Al Act, Al regulatory sandboxes can provide the right environment to experiment, a contact point to speak with authorities and a place to meet other businesses (either users of AI data centers or affected by their integration in the power grid).

It is clear from these points that the effort towards the development of AI applications for the power sectors and the benefits deriving from them are a blend of individual ventures of the various actors in the power sector, and of joint endeavors motivated by the realization that inescapably there are common issues and common goals.

The obligations foreseen by the AI Act are: i) build an inventory of all AI systems (Annex III, Section 2) used in operations and classify each one according to the norms; ii) implement a lifecycle risk-management system (Article 9) for the identified components; iii) put in place a robust data governance system (Article 10); iv) ensure human oversight and clear instructions for use (Articles 13 and 14); v) produce evidence concerning the technical robustness, accuracy and cybersecurity of the components (Article 15); vi) ensure the availability of technical documentation, automatic logging of inputs, outputs and context, and the post-deployment monitoring of performance degradation, unexpected behavior or incidents (Articles 11, 12 and 72); vii) produce a conformity assessment before deploying any high-risk AI system; viii) establish an AI governance framework with appropriate policies, roles,

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approval processes and audit mechanisms, including the procurement and contract processes for AI, and their compliance with other relevant frameworks (such as NIS2 for network security, the 2022 CER Directive on the resilience of critical entities, and any other applicable sectoral code).

Moreover it will be necessary to establish clear mandatory grid integration mandates for preventing gridlocks deriving from the connection of AI data centers (Lo Schiavo 2025). This will entail demand response obligations, location in low carbon and/or uncongested zones, time-to-use tariffs, and use-it-or-lose-it connection queues. In other terms, data centers will have to be designed as grid-interactive dispatchable assets, able to defer or shift non-critical jobs, reduce consumption, and agree in advance on ride-through, curtailment and contingency-response obligations. For satisfying these conditions, AI data centers will benefit from Behind-the-Meter (BTM) assets and storage (such as grid-interactive UPS, on-site or collocated generation, and microgrid and hybrid control.

For the allocation of AI in power systems, crucial items to consider are:

- Cybersecurity and safety standards, as power grids are critical infrastructures. This requirement could involve specific robustness testing, adversarial training, and checking of the efficacy of human oversight;
- Audit trails for decisions (e.g. dispatch), and general transparency and explainability of inputs/outputs of AI applications and the management of uncertainty;
- Strict standards regarding data management, and the sharing of information among the operators and with the authorities (including forecasts);
- Regulated auditable platforms for AI experiments and training (including dedicated sandboxes for AI pilots), aiming at accelerating the adoption of trusted applications;
- Incentives for beneficial AI applications (such as subsidies and tariffs rewarding AI that boosts flexibility and resilience).

In addition, the creation of trust among all actors in the power system and market will profit from dedicated actions by both authorities and private actors. The European legal and regulatory framework will have to be adopted, customizing it to the Italian reality. An emergent need is to establish a continuous dialogue between the regulator (ARERA), the TSO (Terna); the DSOs, the constructors and operators of large data centers (mainly the hyperscalers), and the developers of AI applications for the power sector.

10. Conclusions

The analysis developed in this contribution shows how artificial intelligence already exerts a concrete impact on the power system, not so much as a single technology but rather as a systemic factor interacting with infrastructures, markets, and territories. The Italian case highlights this dynamic with distinct clarity: the growing adoption of AI-based solutions is embedded in a power grid characterized by long-standing geographical asymmetries, limited transmission capacity, and structurally long adaptation timelines.

Data centers and, more broadly, the digital loads associated with AI do not currently represent the dominant share of overall energy consumption. Nevertheless,

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their spatial concentration, continuity of demand, and requirement for high levels of reliability make them a critical element for grid planning. European evidence shows that, in the absence of anticipatory action, the availability of grid capacity rapidly becomes a constraint on investment, with direct effects on the economic competitiveness of territories.

In the Italian context, this issue cannot be addressed separately from the structure of the national power system. The growing renewable generation located in southern regions and consumption concentrated in the North impose a physical constraint that no algorithmic optimization can eliminate. The construction or reinforcement of transmission backbones remains an unavoidable step, with political, environmental, and social implications that require complex decision-making processes and long timelines. In this sense, AI does not replace infrastructure: at best, it delays saturation points or temporarily improves asset utilization.

At the same time, AI offers concrete tools to improve power system management. Forecasting applications, advanced control, predictive maintenance, and flexibility management are already capable of increasing operational efficiency and grid resilience. As emphasized by ENEA, these applications can contribute significantly to loss reduction and consumption optimization, particularly when integrated into a systemic vision of energy efficiency.

The crucial point is that such benefits are not automatic. Without coordination among energy planning, industrial policies, and the spatial localization of digital infrastructures, AI risks becoming an additional source of pressure on an already fragile system. Climate resilience, in particular, cannot be entrusted exclusively to digital solutions: extreme events, thermal stress, and renewable variability require robust and redundant networks governed by long-term criteria.

In conclusion, artificial intelligence should be interpreted as a capacity multiplier rather than as a technological shortcut. It can amplify both the strengths and the weaknesses of the power system. In the Italian case, its positive contribution will depend on the ability to address structural – both infrastructural and territorial – constraints that precede the very adoption of AI technologies. Only by recognizing the power system as a critical infrastructure exposed to climate stress, rather than as a mere service platform, can AI support a credible, resilient, and socially sustainable energy transition.

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