Feasibility and Sustainability Analysis: A Geothermal-Powered AI Data Center in Băile Felix, Romania

Executive Summary

This report presents a comprehensive feasibility and sustainability analysis for the development of a state-of-the-art, geothermal-powered Artificial Intelligence (AI) data center in the Băile Felix / 1 Mai region of Bihor County, Romania. The project is conceived as a direct and timely response to the European Union's most critical strategic imperatives: securing technological sovereignty in the digital era and accelerating the transition to a green, carbon-neutral economy. By synergistically pairing a high-demand AI facility with a 24/7, baseload, zero-carbon energy source, this initiative offers a scalable and replicable model to resolve the inherent tension between the EU's Digital Decade ambitions and its Green Deal commitments.

The technical architecture is founded on a dual closed-loop system, representing a paradigm shift in sustainable digital infrastructure. Power will be generated via an advanced Closed-Loop Geothermal System (CLGS) that harnesses heat from the region's deep Triassic reservoir (2,200-3,200 meters) without extracting or consuming geothermal fluids. This approach fundamentally differs from the historical open-loop exploitation of the shallow aquifer that led to ecological damage in the area, demonstrating a design philosophy rooted in learning from the past to ensure future sustainability. The data center itself will utilize a closed-loop liquid cooling system, which dramatically improves energy efficiency (PUE) and virtually eliminates water consumption (WUE), setting a new benchmark for AI infrastructure.

The environmental benefits are profound and quantifiable. The project will provide a source of clean, resilient power, insulated from the climate-change-induced volatilities (droughts, altered river flows) that threaten Romania's significant hydropower capacity. By avoiding reliance on the national grid, which remains partially dependent on fossil fuels, the facility will achieve a net annual CO_2 abatement of significant magnitude. Furthermore, by integrating waste heat recovery for local district heating

or agricultural use, the project embeds itself within the local community as an energy asset, championing the principles of a circular economy.

Socio-economically, the project will serve as a powerful catalyst for regional development. It represents a major capital injection into Romania's burgeoning data center market and is projected to create a substantial number of high-value jobs during both its construction and long-term operational phases. More strategically, it establishes a critical piece of high-tech infrastructure currently absent in Romania—a major hyperscale-ready facility. This will act as an anchor for a broader technology ecosystem, attracting further investment, fostering local innovation, and providing compelling career opportunities for Romania's skilled IT workforce, thereby helping to counter the national "brain drain."

While the project faces risks, primarily related to subsurface exploration and an outdated national regulatory framework for geothermal energy, these have been thoroughly assessed and are met with robust mitigation strategies. A phased exploration approach, leveraging modern geophysical techniques and existing data, will de-risk drilling. Proactive and collaborative engagement with Romanian authorities, supported by the EU's strategic push for geothermal energy, will transform the regulatory challenge into an opportunity to pilot a modern legal framework for the entire country.

This analysis concludes that the proposed geothermal-powered AI data center is not only technically feasible and environmentally sustainable but also strategically vital. It offers a unique opportunity to advance Europe's digital and green ambitions in parallel, create a model for sustainable AI development, and foster significant economic growth in Southeastern Europe. It is therefore recommended that this project receive full funding consideration as a flagship initiative aligned with the core objectives of the European Union.

I. The Strategic Imperative: Aligning with Europe's Digital and Green Future

The proposed geothermal-powered AI data center in the Băile Felix region is more than an infrastructure project; it is a strategic initiative designed to address two of the most pressing and interconnected challenges facing the European Union today. On one hand, the EU is pursuing an ambitious agenda for digital leadership and technological sovereignty. On the other, it is bound by the urgent necessity of the green transition. This project is conceived at the very intersection of these two imperatives, offering a tangible, scalable, and innovative model that demonstrates how digital ambition and climate action can be mutually reinforcing rather than conflicting goals.

The Core EU Dilemma: Digital Ambition vs. Energy Reality

The European Union's strategic direction for the coming years is clearly articulated in its "Digital Decade" policy programme.[1] This framework sets ambitious targets for 2030, aiming to propel the EU to the forefront of the global digital economy. Key objectives include fostering the widespread adoption of transformative technologies like Artificial Intelligence (AI), cloud computing, and big data among European businesses, with a target of 75% uptake.[3] The ultimate goal is to enhance the EU's global competitiveness and establish a robust "technological sovereignty" that reduces dependence on external actors.[2]

However, this digital ambition is colliding with a formidable physical constraint: energy. The European Commission's own analysis, presented in the 2025 State of the Digital Decade report, identifies a critical and burgeoning structural challenge. The exponentially rising energy demands of the digital transformation, driven particularly by the computational intensity of AI, are rapidly outpacing the development of clean, reliable, and sufficient energy supplies across the Union.[1] This growing chasm between digital demand and green energy supply is no longer a peripheral concern; it is emerging as a "potential significant barrier to the scaling of key digital technologies".[1] This discrepancy threatens to delay the EU's ability to fully leverage AI and data-driven innovation for economic competitiveness, creating a new and profound strategic vulnerability.[1]

This situation presents a core strategic paradox for the EU. The Digital Decade and the European Green Deal are the twin pillars of its long-term strategy, yet the success of one appears to be creating a critical bottleneck for the other. The global investment in data centers nearly doubled between 2022 and 2024, with AI being a primary driver, and their electricity consumption is projected to more than double by 2030.[4] This trajectory puts immense pressure on national grids, which are simultaneously undergoing the complex and capital-intensive process of decarbonization.

It is precisely this paradox that the Băile Felix project is designed to solve. By directly co-locating a high-demand AI data center with a dedicated, baseload, zero-carbon geothermal power source, the project creates a symbiotic system that decouples critical digital infrastructure growth from the constraints of the public grid and the intermittency of other renewable sources. It provides a concrete, replicable blueprint for how the goals of the Digital Decade and the Green Deal can be pursued synergistically. This initiative moves beyond policy rhetoric to offer a physical demonstration that Europe's digital future can, and must, be powered by a sustainable and sovereign energy foundation. It elevates the project from a simple infrastructure proposal to a strategic pilot for resolving one of the EU's most significant long-term challenges.

Achieving True Technological Sovereignty

The concept of "technological sovereignty" has moved from the periphery to the forefront of the EU agenda.[3] It reflects a growing recognition that dependence on foreign technology providers for critical infrastructure constitutes a strategic liability in an era of increasing geopolitical shifts. The EU's reliance is stark: a staggering 92% of European data resides in the clouds of U.S. technology companies, and the Union depends on external providers for over 80% of its digital products, services, and infrastructure.[2] The 2025 State of the Digital Decade report is unequivocal, stating that these "persistent strategic dependencies threaten the EU's economic security and technological sovereignty".[1]

In response, the EU is actively pursuing a suite of policies and legislative measures aimed at building a more resilient and sovereign digital ecosystem. Upcoming initiatives such as the Digital Networks Act, the Quantum Strategy, and the Cloud and AI Development Act are designed to bolster the security and sovereignty of the EU's technological base, particularly in the foundational realms of connectivity, cloud, and data infrastructure.[1] These policies aim to foster the development of a "EuroStack"—a complete, EU-controlled technology stack from the physical infrastructure layer up to platforms and applications.[3]

The Băile Felix project represents a direct and practical implementation of this "EuroStack" concept at its most fundamental layer. It addresses the critical need for sovereign, EU-based, high-performance compute infrastructure. By creating a facility that is physically located within the EU, powered by a local European energy resource, and aligned with EU data protection standards, it provides a secure and credible alternative to relying on non-EU hyperscalers for sensitive AI and data processing workloads. This is particularly relevant as a substantial portion of governmental digital infrastructure across the EU continues to depend on service providers from outside the Union.[1]

The project therefore serves as a physical manifestation of the policy goals articulated in the Digital Decade reports. It contributes directly to the objective of reducing strategic dependencies and building the secure digital infrastructure necessary for the EU to assert its autonomy in the digital age. By providing a state-of-the-art, sustainably powered platform for AI innovation on European soil, it helps ensure that the future of this transformative technology can be shaped by European values and interests.

II. The Geothermal Resource of the Băile Felix / 1 Mai Hydrothermal System

The viability of the proposed project rests on the geological endowment of the Băile Felix / 1 Mai region. A thorough understanding of the area's complex hydrogeology is paramount, not only to confirm the availability of a sufficient energy resource but also to address the sensitive environmental legacy of past geothermal exploitation. This analysis establishes the robust potential of the deep geothermal reservoir while explicitly differentiating the project's approach from historical practices that led to ecological degradation.

Geological and Hydrogeological Context

The geothermal anomaly in the Băile Felix / 1 Mai area is a surface expression of a large and complex hydrothermal system. It is not an isolated phenomenon but is hydrodynamically connected to the geothermal aquifers exploited in the nearby city of Oradea and is part of a regional water circulation system.[6] The ultimate source of the thermal water is meteoric, originating as precipitation in the higher-altitude karst landscapes of the Pădurea Craiului Mountains.[6]

From this recharge zone, water infiltrates deep into the Earth's crust through an intricate network of fractures, faults, and karst conduits within thick layers of Mesozoic limestones and dolomites.[6] The region's tectonic history, characterized by the overthrust of the Codru Nappe System over the Bihor Autochthon, has created a highly fractured and permeable subsurface.[8] A key feature is the Galbena Fracture System, a major crustal fault zone that acts as a primary hydrogeological drain, collecting and channeling underground water in a rapid regional flow from the mountains northwest towards the Pannonian Basin and the project area.[8]

As this water descends to depths of several kilometers under the insulating sedimentary layers of the Pannonian Basin, it is heated by the Earth's natural heat. The region exhibits an unusually high geothermal gradient, estimated at 45-55°C per kilometer of depth, which is significantly above the global average.[6] This process thermalizes the water before it rises back towards the surface along fault lines and uplifted geological blocks in the Băile Felix / 1 Mai area.[6]

Crucially, geological and drilling data reveal the existence of two distinct and largely separate geothermal reservoir systems, differentiated by depth, temperature, and host rock formation:

1. **The Shallow Cretaceous Reservoir:** This is a fissural geothermal system hosted within Lower Cretaceous limestones at relatively shallow depths, ranging from 45 to 500 meters.[10] The water temperatures in this system are moderate, typically varying between 33°C and 49°C across different wells.[10] This shallow, easily accessible reservoir has been the exclusive source for the region's historical balneological and spa-related activities for over a century.[7]
2. **The Deep Triassic Reservoir:** Situated at much greater depths, between 2,200 and 3,200 meters, is a higher-temperature geothermal reservoir located within Triassic-age limestones and dolomites.[6] This system is hydrodynamically connected with the deep aquifers that supply the geothermal heating system of Oradea.[6] Temperatures in this deep reservoir are substantially higher, with surface expressions reaching up to 85°C and a thermal gradient capable of supporting efficient electricity generation.[6]

A Legacy of Over-Exploitation: The Case of Lacul cu Nuferi

Any development proposal in the Băile Felix / 1 Mai region must confront the area's well-documented and tragic history of environmental mismanagement. For decades, the **shallow** geothermal aquifer was subjected to what has been described as "irrational and excessive use" to supply the burgeoning spa tourism industry.[12] A proliferation of wells, both legal and illegal, extracted thermal water at unsustainable rates, far exceeding the natural recharge of the system.[10]

The consequences were catastrophic. Long-term hydrogeological monitoring has shown a direct and undeniable correlation between the intensification of water extraction from the shallow wells and a severe decline in the aquifer's piezometric surface (the water table level).[13] This pressure drop caused the natural artesian springs, which had fed the local ecosystem for millennia, to cease flowing.[12] The most visible and devastating result was the complete drying of the "Ochiul Mare" lake within the Pețea Creek Nature Reserve.[12]

The loss of this unique thermal habitat led to the local extinction of several endemic and relict species of immense conservation value, most notably the thermal waterlily (*Nymphaea lotus var. thermalis*), the thermal snail (*Microcolpia parreyssii*), and Racoviță's rudd (*Scardinius racovitzai*).[12] The destruction of this one-of-a-kind ecosystem represents a significant loss for Romania's and Europe's natural heritage.[12] This legacy of over-exploitation underscores the extreme sensitivity of the shallow aquifer and serves as a critical lesson in the necessity of sustainable resource management.

The Strategic Pivot: Targeting the Deep, Unstressed Reservoir

The core sustainability principle of this project is founded on a deliberate and complete separation from the historically mismanaged shallow aquifer. The project's design explicitly learns from the ecological mistakes of the past to forge a new model of responsible geothermal development. This is achieved by targeting the distinct, deeper, and higher-temperature Triassic reservoir for energy extraction.[6]

This strategic pivot is fundamental to the project's feasibility and environmental integrity. The deep reservoir is not the source that was over-exploited; it is a separate hydrogeological unit with different characteristics. Furthermore, as will be detailed in

Section III, the project will employ an advanced Closed-Loop Geothermal System (CLGS). This technology does not consume or extract any geothermal water; it simply circulates a self-contained working fluid through a deep borehole to absorb heat via conduction from the rock mass.[14]

This technological choice ensures that the project will have no hydraulic interaction with or impact on the fragile, shallow Cretaceous aquifer. It will not contribute to any further lowering of the piezometric surface, nor will it place any demand on the water resources that once sustained the Lacul cu Nuferi ecosystem. This approach reframes the project narrative. It is not another geothermal development in a sensitive area; it is a technologically superior and environmentally benign initiative that actively avoids the practices of the past. By doing so, it turns a major potential reputational risk into a compelling story of responsible innovation and sustainable progress.

Feature	Shallow Reservoir (Cretaceous)	Deep Reservoir (Triassic)
Dominant Geology	Fissured Lower Cretaceous limestones [10]	Karstified Triassic limestones and dolomites [6]
Depth	45 – 500 meters [10]	2,200 – 3,200 meters [6]
Temperature Range	33 – 49 °C [10]	Surface expression up to 85°C; high gradient (45-55°C/km) [6]
Historical Use	Extensive exploitation for balneology, spas, local heating [10]	Limited exploitation, primarily for Oradea district heating [7]
Current Status	Stressed; documented over-exploitation leading to ecosystem collapse [12]	Largely unstressed in the Băile Felix area; high potential [6]
Proposed Project Interaction	**None.** The project will not drill into, extract from, or inject into this aquifer.	**Heat exchange only.** A closed-loop system will circulate fluid to absorb heat without extracting geothermal water. [14]

Table II.1: Hydrogeological Characteristics of the Băile Felix / 1 Mai Reservoir Systems

III. Technical Feasibility: A Symbiotic Architecture for Geothermal Power and AI Computation

The technical viability of this project is rooted in a symbiotic architecture that integrates two advanced, highly efficient, and environmentally sustainable technologies: a closed-loop geothermal system for power generation and a closed-loop liquid cooling system for the AI data center. This "dual closed-loop" design creates a self-sufficient and resilient infrastructure model that sets a new standard for green computing.

Power Generation: Advanced Closed-Loop Geothermal System (CLGS)

The project will harness the Earth's heat using an advanced Closed-Loop Geothermal System (CLGS), also known as an Advanced Geothermal System (AGS). This technology represents a significant evolution from conventional geothermal power generation and is uniquely suited to the environmental context of the Băile Felix region.[14]

Unlike traditional open-loop or hydrothermal systems, which function by drilling into an aquifer and extracting large volumes of hot water or steam to the surface, a CLGS operates on a fundamentally different principle.[15] It functions like a massive, deep-earth heat exchanger. The system consists of a sealed, continuous loop of underground pipes through which a working fluid (such as water or a specialized heat-transfer fluid) is circulated.[14] This fluid travels down to the hot rock strata of the deep Triassic reservoir, absorbs thermal energy via conduction through the well casing, and then returns to the surface. At the surface, the heat is transferred to a secondary fluid in a binary cycle power plant, causing it to flash into vapor and drive a turbine to generate electricity. The original working fluid, now cooled, is then pumped back down into the loop to repeat the cycle.[17]

The advantages of this approach are manifold and directly address the primary environmental concerns associated with geothermal energy:

- **Zero Water Consumption:** The system is entirely self-contained. It does not extract or consume any water from the underground geothermal reservoir. The same working fluid is continuously recirculated, eliminating any impact on the local water table or aquifer pressure.[14] This is the single most important technical feature that ensures the project will not repeat the ecological damage caused by past open-loop exploitation in the region.

- **No Aquifer Contamination:** Because there is no mixing of fluids between the closed loop and the surrounding geology, there is no risk of contaminating groundwater aquifers with the highly mineralized or saline brines often found at depth.[18]
- **Minimal Surface Footprint:** Binary cycle power plants are compact, and the CLGS requires no large-scale surface infrastructure like steam separators or cooling towers that rely on water evaporation.
- **Elimination of Induced Seismicity Risk:** The risk of induced seismicity in geothermal projects is primarily associated with the large-scale injection and extraction of fluids, which can alter pore pressures along existing fault lines.[18] The CLGS, by not engaging in such activities, effectively eliminates this risk, a crucial advantage in a tectonically complex area.[15]
- **Baseload Reliability:** Geothermal energy is not dependent on weather conditions or time of day. It provides a constant, reliable, 24/7 source of baseload power, which is an absolute requirement for data centers that must operate continuously without disruption.[17]

The feasibility of implementing such a system in Romania is enhanced by the country's existing industrial capabilities. The Oil and Gas Employers' Federation (FPPG) has explicitly endorsed the development of CLGS technology, highlighting that Romania's long history and deep expertise in the oil and gas sector provide a ready-made workforce and technical know-how for the precision deep-drilling operations required.[15]

Data Center Cooling: Optimizing for PUE and WUE

The computational workloads associated with Artificial Intelligence are characterized by extremely high power density, which in turn generates immense heat within a small physical space. Traditional data center cooling methods, which rely on circulating large volumes of cold air (air cooling), are inefficient and often inadequate for these demands. This project will therefore employ an advanced **closed-loop liquid cooling** solution, a technology that is rapidly becoming the standard for high-performance computing.[19]

In a closed-loop liquid cooling system, a coolant (typically a water-based mixture) is circulated in sealed pipes directly to the heat-generating components of the servers, such as CPUs and GPUs, or to heat exchangers integrated into the server racks.[19] The liquid absorbs the heat much more efficiently than air and transports it away from the IT equipment. This heat is then transferred to a secondary loop, which can be cooled by various means, including ambient air or, in this project's case, potentially integrated with the geothermal system's cooling cycle.

This choice of cooling architecture has a profound and positive impact on the two most critical sustainability metrics for data centers:

- **Power Usage Effectiveness (PUE):** PUE is the ratio of the total energy consumed by a data center to the energy delivered to the IT equipment (PUE=Total Facility Energy/IT Equipment Energy). A PUE of 2.0 means that for every watt delivered to the servers, another watt is used for cooling, lighting, and power distribution. The ideal PUE is 1.0. Because liquid is a much more effective medium for heat transfer than air, liquid cooling systems require significantly less energy to operate than large-scale air conditioning units. This dramatically reduces the "overhead" energy consumption, driving the facility's overall PUE much closer to the ideal 1.0 and making it exceptionally energy-efficient.[20]
- **Water Usage Effectiveness (WUE):** WUE is the ratio of the data center's water consumption to the energy consumed by its IT equipment (WUE=Annual Water Consumption [Liters]/IT Equipment Energy [kWh]).[21] Many conventional data centers, especially in warmer climates, rely on evaporative cooling, where water is evaporated to dissipate heat. This process consumes enormous quantities of water and can strain local resources.[19] By utilizing a **closed-loop** liquid cooling system, the project avoids any water loss through evaporation. The coolant is continuously recycled within a sealed system, resulting in a WUE metric that approaches zero.[19] This is a critical advantage in a region where water resources and their ecological importance are a primary concern.

The symbiotic combination of a closed-loop system for power generation and a closed-loop system for server cooling creates a "dual closed-loop" architecture. This integrated design establishes a world-class standard for sustainable AI infrastructure. It ensures that the facility's core operations are almost entirely decoupled from local water consumption and have an exceptionally low energy overhead. This approach proactively addresses the data center industry's most significant sustainability challenges—energy and water consumption—from the initial design phase, making it a powerful model for future AI deployments across the EU.

Parameter	Open-Loop System (Conventional Geothermal)	Closed-Loop System (CLGS - Proposed)
Operating Principle	Extracts hot water/steam from an underground aquifer to drive a turbine. [18]	Circulates a working fluid in a sealed pipe to absorb heat via conduction from deep rock. [14]
Water Consumption	High. Requires extraction of large volumes of geothermal fluid; some is lost to steam and must be replaced. [18]	**Zero.** The working fluid is continuously recirculated in a closed system. No geothermal water is extracted. [14]
Aquifer Interaction	Direct. The system is designed to produce fluid from the aquifer, impacting its pressure and volume. [18]	**None.** The sealed well casing prevents any fluid exchange with the surrounding aquifer. [14]
Surface Footprint	Larger. May require steam separators, scrubbers, and large evaporative cooling towers. [18]	**Smaller.** Compact binary power plant with no need for large-scale fluid processing. [15]
Induced Seismicity Risk	Moderate. Large-scale fluid extraction and re-injection can alter subsurface pressures and trigger minor seismic events. [18]	**Negligible.** No large-scale fluid extraction or injection occurs, eliminating the primary trigger mechanism. [15]
Waste/Brine Disposal	A significant challenge. Extracted fluids can be highly saline and contain dissolved minerals/gases requiring treatment or disposal. [18]	**None.** No fluids are brought to the surface, so there is no waste stream to manage. [14]
Suitability for Băile Felix	**Unsuitable.** The history of aquifer depletion and ecosystem damage makes any technology involving fluid extraction extremely high-risk and irresponsible. [12]	**Highly Suitable.** The zero-consumption, zero-interaction design is the only responsible technological choice for this environmentally sensitive region. [15]

Table III.1: Comparison of Geothermal System Technologies

IV. Environmental Sustainability and Ecosystem Stewardship

This project is conceived not merely to be less harmful than conventional alternatives, but to be a positive contributor to environmental sustainability. Its design incorporates quantifiable CO2 abatement, inherent resilience to climate change, circular economy principles through waste heat reuse, and a firm commitment to the stewardship of the local ecosystem.

CO2 Emissions Abatement

The primary environmental benefit of the project is the provision of clean, carbon-free electricity for a highly energy-intensive application. Romania's national electricity grid, while possessing a commendable share of renewables, remains significantly reliant on fossil fuels for firm, dispatchable power.[25] In 2023, coal and natural gas together accounted for nearly 30% of total electricity generation.[25] More critically, these sources were responsible for over 95% of the power sector's greenhouse gas emissions in 2022, with coal alone contributing two-thirds of the total.[25]

This reliance results in a notable carbon intensity for the Romanian grid. While figures vary by year and calculation methodology, recent credible estimates place the grid's emission factor between 232 gCO2eq/kWh and 261 gCO2eq/kWh.[27] An older, but officially cited, figure from the European Environment Agency is as high as 461 g/kWh.[29] In contrast, geothermal energy, particularly when generated via a closed-loop binary plant, has near-zero operational emissions and very low lifecycle emissions, estimated to be around 0.1 to 0.2 pounds of CO2 equivalent per kilowatt-hour (approximately 45-90 g/kWh), which is a fraction of even the cleanest fossil fuel plants.[18]

By powering the AI data center directly from the dedicated geothermal source, the project avoids drawing this substantial and continuous power load from the national grid. This act of "load displacement" results in a direct and significant abatement of

CO2 emissions that would have otherwise been generated. The following table provides a conservative estimate of this annual environmental benefit.

Parameter	Value/Calculation	Source(s)
Projected Data Center Annual Energy Consumption (MWh)	438,000 MWh	(Assuming a 50 MW facility operating at 100% capacity)
Romanian Grid CO2 Emission Factor (tCO2e/MWh)	0.232 tCO2e/MWh	[27] (Conservative 2024 average)
Projected Annual Grid Emissions (tonnes CO2e)	438,000 MWh * 0.232 tCO2e/MWh = 101,616	Calculation
Project Geothermal Lifecycle Emissions (tonnes CO2e)	438,000 MWh * 0.090 tCO2e/MWh = 39,420	[18] (Using high-end estimate for EGS)
Net Annual CO2 Abatement (tonnes CO2e)	**101,616 - 39,420 = 62,196**	**Calculation**

Table IV.1: Estimated CO2 Emissions Abatement Analysis

This net abatement of over 62,000 tonnes of CO2 equivalent per year represents a substantial and ongoing contribution to Romania's and the EU's climate targets. It is a direct, quantifiable outcome of the project's core design philosophy.

Climate Change Resilience

A critical aspect of long-term sustainability is resilience to the impacts of climate change. The Carpathian region, including the Apuseni Mountains that form the recharge zone for the Băile Felix aquifer, is projected to experience significant climatic shifts throughout the 21st century. Regional climate models, under both moderate (RCP 4.5) and high-emission (RCP 8.5) scenarios, consistently project a robust warming trend, with mean temperature increases of up to 4.5°C by 2100.[30]

These rising temperatures will have profound effects on the regional hydrological cycle. Projections indicate more irregular rainfall patterns, with a decrease in summer precipitation and an increase in the frequency and severity of droughts.[30] At the same time, when rain does occur, it is expected to be more intense, leading to a higher risk of pluvial and fluvial flooding.[33] Winter precipitation is expected to increase, but higher temperatures mean more of it will fall as rain instead of snow, leading to a decline in snowpack duration and earlier spring melts.[31]

These projected changes pose a direct and significant threat to water-dependent infrastructure, most notably hydropower, which is a cornerstone of Romania's renewable energy mix, accounting for 32.2% of electricity generation in 2023.[25] Reduced snowmelt, lower summer river flows, and more frequent droughts will inevitably impact the reliability and output of the nation's hydroelectric dams.[30]

In this context, the choice of deep geothermal energy offers a superior level of climate resilience. The heat source for the project is the Earth's internal, stable thermal gradient, which is entirely insulated from surface weather patterns and climatic shifts.[17] Unlike hydropower, its performance is not dependent on annual precipitation, snowpack levels, or river flow rates. Unlike wind or solar, it is not subject to the intermittency of weather. This makes deep geothermal a uniquely stable and resilient source of baseload power, ensuring the 99.999% uptime required by critical AI infrastructure, even in the face of the predicted climatic changes.[4] This inherent resilience is a crucial factor in the project's long-term sustainability and strategic value.

Climatic Driver	Projected Change (Carpathian Region)	Impact on Hydropower (Vulnerable)	Impact on Deep Geothermal (Resilient)
Mean Temperature	Increase of 2-5°C by 2100 [30]	Increased evaporation from reservoirs; reduced efficiency.	**None.** Heat source is deep underground, unaffected by surface temperatures.
Summer Precipitation	Decrease; increased frequency and severity of droughts [30]	**High impact.** Reduced river flows directly decrease power generation capacity during peak demand season.	**None.** System is independent of surface water availability.
Winter Snowpack	Strong declines in snow cover extent and duration [33]	**High impact.** Reduced snowpack leads to lower and earlier spring melt, diminishing a key source of reservoir	**None.** Heat source is geological, not hydrological.

		recharge.	
Extreme Rainfall	Increased frequency and intensity of heavy rain events, leading to higher flood risk [33]	**High impact.** Risk of damage to dam infrastructure; altered sediment loads; operational challenges.	**None.** Power plant is engineered to withstand surface weather events.

Table IV.2: Projected Climate Change Impacts (RCP 4.5 & 8.5) on Regional Water Resources and Power Generation Resilience

Circular Economy: Waste Heat Reuse

Modern data centers are powerful engines of computation, but they are also enormous sources of waste heat.[36] Traditionally, this thermal energy—a direct byproduct of electricity consumption—is simply vented into the atmosphere, representing a massive inefficiency. The principles of a circular economy, however, reframe this waste product as a valuable resource.[37]

This project is designed from its inception to embrace this principle. The closed-loop liquid cooling system is exceptionally efficient at capturing the waste heat generated by the AI servers. Instead of being discarded, this captured low-grade heat (typically in the range of 30-50°C) can be repurposed for a variety of local uses. This practice of cogeneration, or combined heat and power, is strongly encouraged by European policy, and the EU's Energy Efficiency Directive (EED) now requires large data centers (over 1 MW) to conduct a cost-benefit analysis for waste heat recovery.[36]

Potential applications for the recovered heat in the Băile Felix / Sânmartin area are numerous and align well with the local economy:

- **District Heating:** The recovered heat can be supplied to a local district heating network, providing low-carbon warmth to nearby residential buildings, hotels, and public facilities. This model is being successfully deployed across Europe, with data centers providing heat to municipal utilities.[36]
- **Agriculture and Aquaculture:** The heat can be used to warm greenhouses, enabling year-round cultivation of crops and extending the local growing season. It could also support aquaculture operations, such as the fish farming enterprises

that have historically existed in the area.[10] This creates a direct link between the digital economy and local food production.[37]

- **Balneological Pre-heating:** The waste heat could be used to pre-heat water for the local spas, reducing their own energy consumption and operational costs.

By integrating a waste heat recovery module, the data center transforms from a simple energy consumer into a community energy asset.[36] This creates a powerful symbiotic relationship with the local community, improves the overall energy efficiency of the entire system, generates a potential new revenue stream from the sale of heat, and greatly enhances the project's social license to operate. It is a tangible application of circular economy principles that adds a compelling layer to the project's comprehensive sustainability credentials.

V. Socio-Economic Impact and Regional Development

The establishment of a geothermal-powered AI data center in the Băile Felix region will serve as a significant engine for economic growth and technological advancement, not only for Bihor County but for Romania as a whole. The project's impact extends beyond the direct capital investment to encompass substantial job creation, GDP contribution, and the catalytic effect of anchoring a high-tech ecosystem in a developing region of the EU.

Direct, Indirect, and Induced Economic Contribution

The Romanian data center market is already on a steep growth trajectory, with the colocation segment alone projected to nearly double in value from USD 530.2 million in 2024 to over USD 1.045 billion by 2030, reflecting a compound annual growth rate of 12.2%.[39] This project represents a major injection of foreign direct investment into this expanding sector, accelerating its development and increasing its sophistication.

To quantify the potential economic ripple effects, it is instructive to examine established case studies of similar large-scale investments across Europe. In Ireland, a leading data center hub, the industry supports an estimated 5,700 full-time equivalent (FTE) roles annually through direct, indirect, and induced employment.[41]

The construction of a single large data center campus in the United Kingdom was estimated to support over 10,000 job-years of employment and contribute over £1 billion in GVA during its build-out phase.[42] Google's extensive investments in its European data center fleet supported an average of 16,700 jobs per year between 2015 and 2018 and are projected to support over 27,000 jobs annually from 2019-2021, while contributing billions of euros to the European GDP.[43]

The project's impact is twofold, stemming from both the geothermal power plant and the data center itself. Geothermal projects are inherently significant job creators. A typical 50 MW geothermal plant can generate up to 1,000 jobs during its multi-year construction and drilling phase, and create 50-100 highly skilled, permanent jobs for its 30-50 year operational lifespan.[44] These are stable, well-paid positions in engineering, geology, and plant operations, often located in rural or remote areas with fewer employment opportunities.[46]

By adapting economic impact models like the NREL's JEDI (Jobs and Economic Development Impact) model and benchmarking against these European precedents, it is possible to project the significant contribution this project will make to the Romanian economy.[48]

Impact Category	Construction Phase (Cumulative Total)	Operational Phase (Annual)
Direct Employment (FTEs/Job-Years)	900 - 1,200	100 - 150
Indirect & Induced Employment (FTEs)	2,000 - 3,000	250 - 400
Total Employment Supported	**2,900 - 4,200**	**350 - 550**
Direct Contribution to GDP (€ million)	€150 - €200	€20 - €30
Total Contribution to GDP (€ million)	**€350 - €450**	**€45 - €60**

Table V.1: Projected Socio-Economic Impact (Job Creation & GDP Contribution)
Note: Projections are estimates based on comparative analysis of case studies 41 and adapted for the Romanian economic context. Construction phase impacts are cumulative over the build period; operational impacts are annual.

Catalyzing a High-Tech Hub and Countering Brain Drain

Beyond the direct financial metrics, the project's most profound strategic value lies in its potential to act as a catalyst for a durable, high-value technology ecosystem in Northwestern Romania. Romania has successfully cultivated a robust and rapidly growing ICT sector, which has become a cornerstone of the country's service exports and a significant contributor to private sector R&D spending.[49] However, the sector faces two critical challenges: the persistent "brain drain" of highly skilled graduates to opportunities in Western Europe, and the risk that its strong position in IT outsourcing could be eroded by the very AI technologies this project seeks to enable.[50]

This project provides a powerful, strategic response to both challenges. A significant impediment to Romania's ascent in the digital economy is the current lack of a major hyperscale cloud operator presence on its soil.[51] The proposed facility, with its secure, green, and abundant power, creates precisely the kind of anchor infrastructure that attracts such global players, as well as a constellation of other technology firms, software developers, and innovative startups.[52]

This creates a virtuous cycle. The presence of a world-class AI facility generates demand for advanced digital skills, moving the local labor market up the value chain from basic IT services to more complex and resilient fields like AI infrastructure management, data science, cybersecurity, and geothermal engineering.[53] This, in turn, creates high-value, well-paid, and long-term domestic career paths that provide a compelling alternative to emigration for Romania's talented youth, directly addressing the brain drain phenomenon.[50]

By investing in this critical piece of physical capital, the EU is also making a strategic investment in Romania's human capital. The project will help the country improve its standing in the EU's Digital Economy and Society Index (DESI), where it has historically lagged.[53] It is not merely about importing a data center; it is about seeding a domestic innovation ecosystem, fostering local entrepreneurship, and ensuring that Romania can become not just a consumer, but a key contributor and beneficiary of Europe's digital future.

VI. Market and Regulatory Landscape

The commercial viability and successful implementation of the project depend on a clear understanding of the European data center market dynamics and a proactive strategy for navigating Romania's regulatory environment. The analysis indicates a strong market opportunity driven by macro-level shifts in the industry, coupled with a manageable regulatory challenge that presents an opportunity for strategic leadership.

Market Opportunity: The Shift to Europe's Emerging Hubs

The European data center market is undergoing a period of explosive growth, with total investment projected to more than double from USD 47.23 billion in 2024 to USD 97.30 billion by 2030.[55] This expansion is fueled by the relentless growth of cloud computing, 5G deployment, and, most significantly, the massive computational demands of Artificial Intelligence.[55]

However, this growth is not evenly distributed. The traditional, dominant data center markets of Frankfurt, London, Amsterdam, Paris, and Dublin (collectively known as FLAP-D) are facing critical bottlenecks that are beginning to constrain their expansion.[58] These mature hubs are grappling with severe limitations on power availability from congested grids, a scarcity of suitable land for large-scale development, and increasingly stringent regulations.[51] For new projects, securing a grid connection in these markets can now take between seven and ten years, a timeline that is untenable for the fast-moving technology sector.[58]

This reality is forcing a strategic geographical realignment of the industry. Data center operators and hyperscale investors are increasingly shifting their focus towards secondary and emerging markets, particularly in Central and Southeastern Europe, where power is more readily available, land is less constrained, and grid connection times are shorter.[55] Countries like Romania, Bulgaria, Hungary, and Serbia are consequently gaining significant traction as the new frontier for data center development.[55]

Romania is exceptionally well-positioned to capitalize on this strategic shift. The country offers a compelling combination of advantages for data center developers [51]:

- **Energy Diversity:** A resilient energy mix with a high share of renewables, including significant hydro and nuclear capacity, and untapped geothermal potential.[25]

- **Robust Connectivity:** Significant investment in fiber optic networks has resulted in high-quality, high-speed internet infrastructure.[51]
- **Skilled Workforce:** A large pool of skilled and competitively-priced IT professionals.[49]
- **Favorable Climate:** A temperate climate that allows for the efficient use of cooling technologies, improving energy efficiency.[51]
- **Land Availability:** Opportunities to secure large plots of land suitable for data center development at competitive prices, in contrast to the scarcity in Western Europe.[51]

This project, with its unique proposition of 100% green, baseload power, is perfectly timed to meet the market's pivot towards sustainable and resilient infrastructure in these emerging European hubs.

Regulatory Framework: A Challenge and an Opportunity

The primary non-technical hurdle for the project lies in Romania's current regulatory framework for geothermal energy. The governing legislation, Mining Law No. 85/2003, was enacted two decades ago and is primarily designed to regulate the exploration and exploitation of mineral resources, including the consumptive use of geothermal waters in traditional, open-loop systems.[15]

This existing law presents significant legal gaps and uncertainties when applied to a modern, non-consumptive technology like a Closed-Loop Geothermal System (CLGS).[15] The key ambiguities are:

1. **Legal Definition of Geothermal Heat:** The law treats geothermal resources as "mineral resources" to be extracted. It does not have a clear classification for the in-situ heat harnessed by a CLGS, which is a "characteristic of the earth" rather than a substance to be mined. This distinction is fundamental for establishing property rights and the appropriate regulatory, authorization, and monitoring framework.[15]
2. **Lack of a Specific Authorization Process:** The current permitting process is tailored for projects that extract fluids. There is no clear, streamlined pathway for a project that simply exchanges heat without any extraction, which can lead to

bureaucratic delays and uncertainty for investors.[15]

While this legal ambiguity constitutes a risk, it also presents a unique strategic opportunity. For a flagship project with strong backing from the European Union, this challenge can be transformed into a chance to act as a regulatory pathfinder. The project can work proactively and collaboratively with the key Romanian authorities—namely the Ministry of Energy and the National Agency for Mineral Resources (ANRM)—to co-develop and pilot the necessary updates to the legal framework.[15]

This endeavor is strongly supported by political momentum at the EU level. In 2024, the European Parliament passed a resolution calling for the establishment of a comprehensive European strategy on geothermal energy, signaling a high-level political will to remove barriers and accelerate deployment.[15] This provides powerful political top-cover for Romanian authorities to modernize their national legislation to align with EU best practices and technology neutrality principles.[15]

By successfully navigating this process, the project will not only secure its own legal standing but will also create a clear, modern, and predictable regulatory pathway for all future CLGS investments in Romania. This act of de-risking the entire sector would be a significant contribution to the national economy, turning a potential bureaucratic hurdle into a lasting strategic achievement.

VII. Comprehensive Risk Assessment and Mitigation Matrix

A thorough and transparent assessment of potential risks is essential for ensuring project success and securing stakeholder confidence. The following matrix identifies the principal risks across geological, technical, environmental, regulatory, and market domains, and outlines clear, data-driven strategies for their mitigation. This demonstrates a comprehensive due diligence process and a proactive approach to risk management.

Risk Category	Specific Risk	Probability	Impact	Mitigation Strategy	Relevant Sources
Geological / Exploration	High upfront investment in	Medium	High	Employ a phased	62

	exploration and drilling fails to identify a commercially viable geothermal resource (insufficient temperature or flow potential).			exploration strategy to minimize at-risk capital. **Phase 1:** Reprocess existing 2D seismic data from Romania's extensive oil and gas archives to create initial subsurface models. **Phase 2:** Conduct new, targeted 3D seismic and deep-electromagnetic surveys to precisely map the deep Triassic reservoir, identify fracture networks, and optimize drilling targets. This data-driven approach significantly increases the probability of success before committing to the high cost of drilling.	

Technical / Operational	Underperformance of the geothermal power plant; corrosion, scaling, or biofouling within the closed-loop system compromises efficiency and lifespan.	Low	Medium	Utilize proven, off-the-shelf binary cycle power plant technology from reputable suppliers. Implement a comprehensive water treatment and real-time monitoring program for the circulating fluid based on the "three-legged stool" approach: **1) Chemical:** Use of corrosion inhibitors and biocides. **2) Operational:** Ensure continuous fluid circulation to prevent stagnation. **3) Mechanical:** Install robust side-stream filtration to remove particulates.	14
Environmental /	The project is publicly	Medium	High	Launch a proactive,	12

Reputational	and politically conflated with the historical over-exploitation of the shallow aquifer, leading to local opposition, protests, and permitting delays.			transparent, and sustained public communications and stakeholder engagement campaign from the project's outset. The campaign will clearly and repeatedly emphasize the fundamental technological distinctions: **Deep vs. Shallow** and **Closed-Loop (heat exchange) vs. Open-Loop (water extraction)**. Highlight the project's zero-water-consumption design and its commitment to ecosystem stewardship, framing it as a solution that learns from, and will not repeat, past mistakes.	

Regulatory / Political	Project timelines are significantly delayed by bureaucratic hurdles arising from the lack of a clear and specific legal framework for closed-loop geothermal systems in Romania.	High	Medium	Initiate early and collaborative engagement with the National Agency for Mineral Resources (ANRM) and the Ministry of Energy. Position the project as a national pilot initiative to help co-develop the necessary regulatory clarifications. Leverage the project's alignment with EU strategic goals (Digital Decade, Green Deal) and the European Parliament's resolution on geothermal energy to secure high-level political support for expediting the modernization of the legal framework.	15

Market / Financial	Fluctuations in national energy prices impact project economics; competition from other emerging data center locations in Europe attracts the anchor tenant away.	Low	High	Secure a long-term, fixed-price Power Purchase Agreement (PPA) between the geothermal plant and the data center, insulating the project from market volatility and guaranteeing a stable revenue stream. Emphasize the unique and superior value proposition of the site: 100% green, 24/7 baseload, climate-resilient power with a near-zero water footprint. This is a significant competitive advantage over locations reliant on intermittent renewables or operating on power-const	4

				rained grids.	

Table VII.1: Comprehensive Risk Assessment and Mitigation Matrix

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VIII. Conclusion and Strategic Recommendations

This comprehensive analysis demonstrates that the proposed geothermal-powered AI data center in the Băile Felix / 1 Mai region is a project of exceptional strategic importance, technical viability, and long-term sustainability. It represents a forward-looking investment that aligns perfectly with the paramount objectives of the European Union, offering a powerful synthesis of digital advancement and environmental responsibility.

Synthesis of Findings

The project's strengths are robust and multifaceted, addressing key challenges at the European, national, and regional levels:

- **Strategic Alignment:** The initiative provides a direct, tangible solution to the EU's core strategic paradox, demonstrating that the immense energy demands of the Digital Decade can be met sustainably in line with the goals of the European Green Deal. It is a practical step towards achieving true European technological sovereignty by building a secure, green, and EU-based foundation for the future of Artificial Intelligence.
- **Technical Viability:** The "dual closed-loop" architecture, combining an advanced geothermal system for power with a liquid cooling system for the data center, is technologically sound, highly efficient, and innovative. It leverages proven technologies in a synergistic design that sets a new global benchmark for sustainable digital infrastructure.
- **Environmental Sustainability:** The project offers profound and quantifiable environmental benefits. It will deliver a significant annual abatement of CO_2 emissions, provide a source of clean power that is uniquely resilient to the projected impacts of climate change in the region, and champion circular

economy principles through the reuse of waste heat. Critically, its design consciously and completely avoids the environmentally harmful practices of the past by targeting a deep, unstressed reservoir with a zero-consumption technology, thereby ensuring the protection of the local hydro-ecological system.
- **Socio-Economic Benefit:** The project will act as a powerful engine for economic growth in Northwestern Romania and a catalyst for the country's technological advancement. It will generate substantial GDP contribution and create hundreds of high-value, long-term jobs. More importantly, it will establish an anchor for a high-tech ecosystem, helping to transition the regional economy up the value chain and providing the kind of advanced career opportunities that can help reverse the national "brain drain."

Strategic Recommendations for the EU Funding Body

Based on the exhaustive analysis presented in this report, the following strategic recommendations are put forward:

1. **Grant Full Funding Approval and Designate as a Flagship Initiative:** It is recommended that the project be granted full funding approval and designated as a **Flagship Project for the EU Digital Decade and Green Deal**. This designation would recognize its unique potential to serve as a highly visible, replicable model for aligning digital and green policy objectives across the Union.
2. **Facilitate Regulatory Modernization in Romania:** It is recommended that the European Commission actively facilitate high-level dialogue between the project proponents and the relevant Romanian national authorities (Ministry of Energy, ANRM). The objective of this facilitation would be to support the swift clarification and modernization of Romania's regulatory framework for closed-loop geothermal systems, leveraging the political momentum from the European Parliament's 2024 resolution on geothermal energy. This would unlock not only this project but the entire geothermal sector in Romania.
3. **Establish as a "European Geothermal-AI Pathfinder":** It is recommended that the project be established as a formal **"European Geothermal-AI Pathfinder"** initiative. Under this framework, its development progress, technical performance, regulatory navigation, and socio-economic impacts would be systematically monitored, documented, and disseminated as a public set of best practices. This would maximize the return on the Union's investment by creating an invaluable knowledge base to inform and de-risk similar strategic projects in

other EU member states, thereby accelerating the deployment of sovereign and sustainable AI infrastructure across Europe.

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