Project Advances

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GRAVITEQA Advances Innovative Energy Technologies to Strengthen Europe's Clean Energy Transition.

The **GRAVITEQA project** continues to advance cutting-edge technological solutions designed to support the reliability, flexibility, and sustainability of future electricity systems. Funded under the Horizon Europe programme, the project integrates **gravitational energy storage, quantum computing technologies, and trustworthy artificial intelligence** to address emerging challenges in modern energy grids and accelerate Europe's transition toward climate neutrality.

As Europe moves toward its ambitious climate targets—including significant greenhouse-gas reductions and a rapidly increasing share of renewable energy in electricity generation—energy systems are becoming more decentralized, data-intensive, and complex to manage. GRAVITEQA aims to tackle these challenges by combining advanced computing and energy technologies to improve grid reliability, enable large-scale renewable integration, and support circular approaches in energy infrastructure.

Integrating Emerging Technologies for Next-Generation Energy Systems

A key ambition of the project is the synergistic integration of advanced technologies that can address the computational and operational challenges of future electricity grids.

At the core of the GRAVITEQA approach lies the development and validation of innovative methodologies combining:

1. Gravitational energy storage for abandoned mines repurposing

The project investigates **Gravitational Energy Storage (GES)** as a promising long-duration energy storage technology capable of supporting the increasing flexibility needs of RES-dominated energy systems. The technology operates by converting electrical energy into gravitational potential energy through the controlled lifting of a mass and releasing this stored energy by lowering the mass to drive a generator. Within the proposed methodology, different GES configurations, such as **shaft-based and piston-based systems**, are analysed by linking system geometry, material properties, and operational constraints to electricity market operation to estimate achievable storage capacity, operational performance, and financial viability. The approach incorporates techno-economic modelling, including CAPEX, OPEX, and revenue streams derived from energy arbitrage in day-ahead markets, enabling the comparative assessment of **alternative GES configurations and** their **hybridization with other storage technologies** such as Pumped Hydro Storage (PHS). This framework allows the identification of optimal design parameters and investment configurations while supporting the evaluation of gravity-based storage as a viable solution for large-scale energy flexibility and RES integration.

2. Quantum computing and quantum-inspired algorithms

Quantum computing (QC) and quantum-inspired (QIC) algorithms are explored as emerging computational paradigms that can address the growing complexity of large-scale combinatorial optimisation problems in energy systems. Many energy planning and flexibility estimation problems can be formulated as NP-hard (Non-deterministic Polynomial-time hard) combinatorial optimisation tasks, where classical optimisation approaches may face scalability limitations. In this context, the project investigates optimization methods based on Quadratic Unconstrained Binary Optimization (QUBO) formulations, which allow discrete decision variables and constraints to be encoded into quadratic objective functions that can be solved using different computational paradigms. These include classical optimisation solvers, quantum annealing approaches, and hybrid quantum-classical algorithms such as the Quantum Approximate Optimisation Algorithm (QAOA). While **current quantum hardware remains limited** by noise and scalability constraints, quantum-inspired optimisation methods implemented on classical hardware already provide practical solutions capable of handling large problem instances with thousands of binary variables and complex inequality constraints. These activities will focus on evaluating the applicability of QC and QIC optimisation methods for solving large-scale combinatorial problems

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in energy systems. In particular, the use cases will **investigate facility allocation problems and load flexibility management mechanisms**, assessing the scalability and performance of these approaches compared with state-of-the-art classical optimization techniques.

3. **Trustworthy AI and edge intelligence for grid operation and seaport electrification**

The innovations under the **"Trustworthy Artificial Intelligence and Edge Intelligence for Grid Operations and Seaport Electrification"** focus on enhancing the reliability, transparency, and deployability of AI-driven decision-support tools in energy systems. In the context of distribution grids, the project advances the **Network Operating Flexibility Envelope (NOFE)** estimation methodology by integrating machine learning with optimisation techniques to efficiently approximate network flexibility regions while preserving physical feasibility. The next development phase introduces mechanisms to improve the **robustness and explainability of the predict-and-optimise framework**, enabling system operators to better understand the drivers of flexibility estimates and increasing trust in the resulting operational recommendations. In parallel, for **seaport electrification planning**, the project introduces an integrated analytical platform that combines demand forecasting, infrastructure planning, and energy management modelling to support the large-scale deployment of cold ironing and other electrified port assets. The planning methodology evaluates the interaction between shore power demand, RES, storage systems, and flexible port equipment, enabling stakeholders to assess cost-efficient electrification pathways while maximising operational flexibility and emissions reductions. Together with **edge-intelligence architectures** designed for energy-domain applications, these innovations enable scalable, trustworthy deployment of AI-based forecasting, flexibility estimation, and planning services across distributed infrastructure such as ports and distribution grids.

Addressing Critical Challenges in the Energy Transition

GRAVITEQA focuses on several key application areas that are expected to play a major role in Europe's clean energy transition. These include:

- **Demand-side orchestration and distributed flexibility services**
- **Planning and integration of renewable energy sources**
- **Management of active distribution grids with high DER penetration**
- **Electrification strategies for green seaports and maritime transport**
- **Circular decommissioning and repurposing of fossil-fuel infrastructure**

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Among the project's innovations are tools for predicting electricity demand for ship electrification ("cold ironing"), optimization algorithms for coordinated charging of ships and electric vehicles in ports, and AI-based models capable of estimating grid flexibility in real time.

These solutions aim to enable more resilient, efficient, and sustainable energy systems, while supporting the electrification of new sectors such as maritime transport.

Project Progress and 3rd Plenary Meeting in Athens

On **20 January 2026**, project partner **FENTECH** hosted the **3rd Plenary Meeting** of the **GRAVITEQA** consortium in **Athens**. The meeting brought together representatives from research institutions, industry, and technology partners to review project progress, share updates on ongoing activities, and coordinate the next phases of research and development.

During the meeting, project partners evaluated the advancement of key technological components, including quantum-based optimization models, AI-based analytics for transmission and distribution (T&D) grid planning and operation, and innovative methodologies to support circular decommissioning of abandoned mines and conventional power plants through large-scale energy storage. The session also provided an opportunity to align on upcoming research milestones, validation activities, and collaborative initiatives planned for the coming months.

The meeting reinforced the consortium's commitment to delivering impactful technological innovations and strengthening collaboration among the participating research institutions, industry partners, and technology providers.

Looking Ahead

Over the coming phases of the project, GRAVITEQA will continue developing and validating its technologies through simulations and experimental environments, targeting **Technology Readiness Level (TRL) 4** validation for several core components.

By bridging advanced computing technologies with innovative energy storage and grid management solutions, GRAVITEQA aims to contribute to a **more resilient, flexible, and climate-neutral European energy system.**

Stay Connected with GRAVITEQA

As the project progresses, the GRAVITEQA consortium will continue sharing updates on technological developments, research milestones, and upcoming activities supporting Europe's energy transition.

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Stay in touch and join the conversation on #GRAVITEQA to learn more about how advanced technologies are shaping the future of sustainable energy systems.

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About us:

GRAVITEQA brings together ten (10) partners representing research institutes, technology providers and large companies from 3 EU countries, namely Bulgaria, Greece, and Spain. This international joint is necessary to implement the rising requirements of clean transitioning in the cross-sector coupled T&D grids utilizing the GRAVITEQA solutions.

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