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## Sustainability-Driven Energy and Environmental Optimization in High-Power Laser Facilities: ELI ERIC's Approach

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In response to evolving European and global climate commitments, including the EU Green Deal and related environmental accountability frameworks, ELI ERIC is actively advancing sustainability-focused measures across its operations. The organization is currently developing an ESG roadmap to systematically integrate sustainability into both its operational and technological planning.

A cornerstone of this effort is ELI ERIC's participation in the Horizon Europe-funded FlexRICAN project, which aims to demonstrate scalable energy flexibility solutions for electro-intensive research infrastructures. ELI leads the development of integrated frameworks focused on intelligent building management systems (BMS), precise environmental condition maintenance and battery array optimization—enabling adaptive energy behavior and grid-interoperable operations.

To ensure environmental stability within high-power laser zones—where even minor thermal or humidity deviations can compromise performance—ELI Beamlines is in a process of deploying a dedicated digital twin (DT) architecture. This system supports real-time facility modeling and predictive control using a suite of advanced tools: Mixed-Integer Linear Programming (MILP) via OMEGAlpes for energy dispatch, machine learning for anomaly detection, Gaussian process regression for uncertainty quantification, and greedy algorithms for local load optimization.

These capabilities enable precise environmental regulation while supporting real-time energy responsiveness. With an annual demand of 15 GWh (11 GWh electricity, 4 GWh gas), energy use represents the primary contributor to the facility's carbon footprint.

To address this, ELI Beamlines has invested in renewable energy systems. A 530 kW combined heat and power (CHP) unit with 630 kW thermal output has reduced energy consumption by 7,600 GJ annually, avoiding 1,550 tCO<sub>2</sub>e. Complementing this, a 312.8 kWp photovoltaic plant composed of 665 panels contributes an additional 125 tCO<sub>2</sub>e in yearly savings.

By integrating digital control systems, advanced energy modeling, and local renewables, ELI ERIC exemplifies how scientific facilities can actively support Europe's green transition. The long-term vision is to align frontier laser science with environmental responsibility—achieving operational excellence that is both technologically and ecologically resilient.

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