FlexRICAN
Flexibility in RIs for global CArbon Neutrality

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Deliverable

D8.3: FlexRICAN Policy Brief

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List of Abbreviations and Acronyms

AL	Alfa Laval
BMS	Building Management System
CHP	Combined Heat & Power
CNRS	Centre National de la Recherche Scientifique
CO2	Carbon Dioxide
CZK	Czech Koruna
DA	Dieselaggregate
ELI	The Extreme Light Infrastructure ERIC
ELI Beamlines	The Extreme Light Infrastructure Beamlines
EMFL	European Magnetic Field Laboratory
EP	Energy Pool
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
ESS	European Spallation Source ERIC
EU	European Union
GA	General Assembly
GPPER	Global Plan for Potential Exploitable Results
HFML	High Field Magnet Laboratory
HFML-FELIX	High Field Magnet Laboratory - Free Electron Lasers for Infrared eXperiments
HVAC	Heating, Ventilation, and Air Conditioning
KER	Key Exploitable Result
LNCMI	Laboratoire National des Champs Magnétiques Intenses
MVA	Megavolt amperes
MW	Megawatt
PSEDER	Plan for stakeholder engagement, communication, dissemination and exploitation of results

PV	Photovoltaic Power
PVP	Photovoltaic Power Plant
RePowerEU	European plan to rapidly reduce dependence on Russian fossil fuels and accelerate the green transition
RI	Research Infrastructure
SB	Steering Board
SRU	Stichting Radboud Universiteit
RTE	Réseau de Transport d'Électricité (Electricity Transmission System Operator)
TG	Target Group
UPS	Uninterruptible Power Supply
WP	Work Package

Executive Summary

European Research Infrastructures (RIs) are essential drivers of scientific discovery, but their increasing energy demands and carbon footprints present a challenge to the EU's climate and energy goals. The **FlexRICAN** project explores how RIs can actively contribute to a more sustainable, flexible, and resilient European energy system. This policy brief presents findings from **five thematic case studies**, based on pilot actions at major RIs within the FlexRICAN consortium. These case studies demonstrate diverse opportunities for reducing environmental impact while unlocking value for local and regional energy systems. The themes include:

- **On-site Renewable Energy Integration**: Deploying solar PV, thermal storage, and hybrid systems to reduce grid dependency.
- **Demand Management Strategies**: Adapting RI operations through load shifting and flexible scheduling.
- **Operational Energy Efficiency**: Implementing retrofits, system upgrades, and process optimisation.
- **District Energy & Resilience**: Enabling local energy exchange and microgrid configurations for greater autonomy.
- **Digitalisation & Smart Control**: Leveraging advanced monitoring, automation, and predictive analytics.

Together, these cases illustrate that RIs can offer significant flexibility services to the energy system, provided they are supported by appropriate policy and technical frameworks.

Key policy recommendations include:

1. **Enable flexibility participation** by adapting regulatory frameworks to RI contexts.
2. **Mobilise financial and technical support** for sustainable infrastructure investments.
3. **Foster cross-sector collaboration** between RIs, energy system actors, and local authorities.
4. **Advance data-driven strategies** to assess, track, and scale flexibility potential.

FlexRICAN shows that RIs can move from being passive energy consumers to **active contributors in Europe's clean energy transition,** enhancing both scientific missions and societal impact.

Opening Section: EU Policy Scene on Energy Sustainability

Policy Context: Why FlexRICAN Matters Now

Europe is at a pivotal moment in its energy and industrial transition. With the launch of the Clean Industrial Deal [1], the REPowerEU roadmap [2], and the Action Plan for Affordable Energy [3], the EU has made clear its intention to lead the world in achieving a secure, sustainable, and competitive clean energy future. These initiatives set forth concrete targets:

- 100 GW of renewable electricity capacity installed per year to power Europe's clean industrial base.
- Full phase-out of Russian fossil fuels by 2027 to enhance energy security.
- Affordable, flexible, and resilient energy systems to support European industry and public services.

Thanks to its high-quality unified European Electrical Grid with a high dynamic of integration of Renewable European RI produce State of the Art research mission with a much lower carbon footprint than its main competitor.

However, RIs are largely overlooked in existing energy policy. FlexRICAN responds directly to this gap by turning RIs into testbeds and showcases for multi-energy flexibility, renewable integration, and energy efficiency to contribute to the global EU carbon-neutral policy.

FlexRICAN's Role in Meeting EU Goals

FlexRICAN delivers:

- Optimised solar power and waste heat recovery to improve local renewable integration.
- Advanced energy storage systems and real-time operational flexibility to support energy grid stability and minimise carbon footprint.
- Implementation of tested solutions at three ESFRI landmarks—ESS, ELI, and EMFL—each with distinct energy use patterns.
- Capacity building through training RI staff in energy-smart operations.
- Structured dissemination to municipalities, grid operators, and the wider RI ecosystem.

Together, these innovations directly support the EU's policy goals by:

- Reducing dependency on imported fuels.
- Contributing to the grid stability in a critical phase of rapid integration of Renewables.
- Contributing to circular and competitive energy use.
- Ensuring affordability and flexibility in large public infrastructures.
- Strengthening industrial decarbonization efforts through public-private cooperation.

Building on this strategic context and the project's alignment with EU policy, Section 1 provides a detailed overview of the FlexRICAN project itself. They describe how FlexRICAN addresses the Horizon Europe call by deploying innovative solutions, delivering exploitable results, and creating impact across multiple dimensions. The analysis is further supported by insights from five detailed case studies that exemplify practical applications and policy lessons from diverse RI settings.

Section 1: FlexRICAN Project, what is it and how it addresses the Call and its objectives

FlexRICAN Project Overview

FlexRICAN (*Flexibility for Research Infrastructures for global CArbon Neutrality*) is an EU-funded initiative under the HORIZON-INFRA-2023-TECH-01-01 “New technologies and solutions for reducing the environmental and climate footprint of RIs” Call (from now on will be referred as ‘Call’), designed to help European RIs reduce their environmental and climate footprint through integrated, tested, and transferable energy solutions.

The project is implemented at three leading ESFRI facilities — ESS (Sweden), ELI (Hungary/Czech Republic), and EMFL (France/Netherlands/Germany) — each representing different and complex energy usage patterns and depending on various electricity mixes. This diversity makes FlexRICAN a robust testbed for real-world deployment and methodological transferability across the EU RI landscape.

Table 1: Alignment with INFRATECH 2023-01 Objectives

HORIZON-INFRA-2023-TECH-01-01 Call - Expected Outcome	FlexRICAN Contribution
Reduction of environmental and climate-related impacts	Deployment of solar, energy storage, waste heat recovery, and energy flexibility systems
Optimization of resource and energy consumption through the full RI lifecycle	Tools and reports guiding energy efficiency, thermal management, and operational flexibility

Increased long-term sustainability of European RIs	Staff training, decision support tools, and planning frameworks that can be scaled across the RI ecosystem

FlexRICAN also delivers common methodologies, as required by the Call, by working across different types of infrastructures and generating replicable insights and tools.

Exploitable Results Supporting Call Alignment

The project has identified nine Key Exploitable Results (KERs) that will directly support EU goals for clean and efficient research infrastructure operations:

- Open-source software tools for PV performance, energy storage planning, flexibility analysis, and climate control.
- Open-source building management systems (BMS) and decision support systems for broader adoption and transparency.
- Technical reports on waste heat, helium usage, and quality labelling for energy-flexible operations of RIs.

These results address not only the technical side of energy and resource optimisation, but also the decision-making, standardisation, and upskilling needs across Europe's RI landscape — in full alignment with Call's ambitions.

Target Stakeholder Relevance of FlexRICAN's Exploitable Results

The nine Key Exploitable Results (KERs) identified at the mid-term point of the FlexRICAN project and described in Global Plan for Potential Exploitable Results (GPPER, i.e. this document) are strategically aligned with the needs of a wide spectrum of stakeholders – TGs identified in PSEDER. Each result is designed to maximise its value beyond the immediate project partners by contributing to broader EU policy, research, and societal goals. A full list of KERs has been added as Appendix 1 and a full list of Target Groups has been added as Appendix 2.

Policymakers and funding bodies (TG1) benefit from tools like the **flexibility analysis software** and the **flexibility quality label report**, which provide evidence-based input for policy design and evaluation. These tools also support the development of standards and funding criteria around energy-flexible infrastructure.

National and local authorities (TG2) are direct beneficiaries of technical insights provided by the **waste heat valorisation report**, **high-temperature cooling report**, and the **helium usage report**, which align with urban development and sustainability priorities, including circular economy principles and integration with district energy systems.

Research Infrastructures (TG4) and the broader **RI ecosystem (TG3)** are central to the uptake of results such as the **PV performance prediction tool**, **energy chain and battery planning tool**, and **open-source intelligent BMS**. These innovations help RI managers make informed decisions on clean energy upgrades, while ensuring that sustainability goals are met across the infrastructure lifecycle.

Industry partners (TG6) stand to benefit from collaboration, adaptation, or market adoption of the developed tools, particularly those relating to energy storage, building automation, and HVAC systems. The project offers a valuable testbed for validating innovative technologies within operational scientific environments.

Meanwhile, the **academic community (TG5)** gains access to practical case studies, modelling tools, and environmental data sets, such as those generated by the **helium usage** and **waste heat** studies, supporting further research and teaching in the fields of energy systems, sustainability, and infrastructure operations.

Finally, the **general public (TG7)**, while not a direct user of technical outputs, is an indirect beneficiary through improved environmental performance of public research facilities, transparent reporting, and contribution to local sustainability goals.

FlexRICAN's approach ensures that each KER is actionable, scalable, and positioned within an ecosystem of users and decision-makers, enhancing its value and uptake across the EU.

Section 2: Impact Analysis of FlexRICAN

The FlexRICAN project represents a significant step forward in advancing energy flexibility and sustainability within Europe's RIs. By developing innovative tools and methodologies, FlexRICAN not only delivers direct economic and ecological benefits but also fosters human capital development, local community integration, and a positive transformation of RIs as climate actors. This section outlines the multifaceted socioeconomic impacts of the project in four dimensions, highlighting its contribution to the EU's Green Deal and digital transition objectives.

A- Innovation & Scalability

FlexRICAN delivers nine KERs combining technological innovation with strong scalability. Software tools from WP3, WP4, WP6, and WP7 (See Appendix 3 to view the list of WPs) aiming PV Plant performance prediction, energy chain optimisation, battery storage, indoor climate, and flexibility decision support, designed for replicability and positioned at mid to high TRLs for rapid deployment across diverse range of RIs. Open-source solutions and data repositories enhance accessibility and transferability beyond RIs. Complementary reports on waste heat valorisation, helium use, and flexibility evaluation inform policy and operations, supporting wider adoption. Together, these innovations position FlexRICAN as a catalyst for energy-smart transformation aligned with the EU's green and digital transition goals.

B - Ecological Value

FlexRICAN advances environmental sustainability by reducing CO2 emissions and optimising resource use within energy-intensive RIs. The project's tools improve the integration of renewable energy sources, such as PV, optimise battery storage and energy dispatch, valorise waste heat, and maintain efficient indoor climate control. These innovations collectively reduce energy waste and lower the carbon footprint of RIs.

Positioning Research Infrastructures as proactive climate actors, showcasing them as innovative institutions committed to decarbonization. This enhances public trust and stakeholder engagement by demonstrating how high-tech facilities can reduce their environmental impact and contribute to climate goals.

Key ecological contributions in terms of project results include the following:

Table 2: Key Exploitable Results with ecological value

WP	Output	Type
WP3	KER#1 Software Tool for Predicting PV Plant Performance at RIs	Software tool
WP4	KER#2 Software Tool for Optimising Energy Chain and Battery Storage Planning	Software tool
WP5	KER#4 Waste Heat Valorisation Report	Report
WP6	KER#7 Analysis Tools and Methodology to Optimize Energy Management for Flexibility and Sustainability	Software tool
WP7	KER#5 Source Data Repository of Program Blocks for Intelligent Building Management Systems	Software tool
WP7	KER#7 Cleanroom-Oriented Technological Chain Optimisation Tool	Software tool

These outputs align with the EU Green Deal goals by enabling RIs to operate more sustainably, reducing emissions, and improving resource efficiency.

C - Economic Value

FlexRICAN creates economic value by helping RIs reduce energy costs and generate new revenue through flexibility markets and services. FlexRICAN integrates RIs into local energy networks, aligning scientific research with community energy transition goals. For example, waste heat from RIs is repurposed to supply local heating, reducing fossil fuel use and boosting energy resilience. These direct and indirect benefits, combined with technology spillovers and enhanced market readiness, contribute to economic growth and value creation across Europe's energy landscape. Case studies 2, 3, and 5, presented in Section 3 of this report, demonstrate tangible economic value creation.

D - Human Capital and Upskilling of Competencies

FlexRICAN significantly builds human capital within the consortium by engaging approximately 40 researchers, engineers, project managers, and students, gaining hands-on experience in renewables and energy flexibility. Gender equality is actively promoted to ensure balanced representation and equal opportunities.

Tailored training for RI staff, the first one already held in April 2025, attended by 71 trainees with 34 physically and 37 remotely from RIs within the FlexRICAN Consortium, enhancing skills in energy flexibility, renewables integration, waste heat recovery and energy storage, with a second training planned later in the project. Knowledge transfer between RIs and partners encourages human and technological spillovers, strengthening institutional capacity beyond the project's duration.

It supports the creation of high-skilled jobs within the consortium, investing in researchers and technical experts whose work drives innovation in the green energy sector while fostering a motivating work environment that supports staff well-being and commitment to sustainable practices.

Section 3: Policy Recommendations from Case Studies

Case Study 1: Energy Generation, Energy Efficiency & Storage at ELI

Key message: **Energy Efficiency Starts with Data-Driven Control**

As part of FlexRICAN's intelligent infrastructure management stream, the ELI Beamlines facility serves as a pilot site for the development of a next-generation BMS. The system is based on open-source code, using normed programming languages and standards, and enables full user-side control over all building functionalities, eliminating vendor lock-in and supporting seamless integration with heterogeneous hardware and visualisation platforms. The BMS prototype at ELI has already yielded measurable results: by identifying system inefficiencies and optimising control logic at the code level, heating demand decreased by 27% and electricity demand by 9%—without requiring hardware replacement. The system is now being structured into a modular, reusable code library, designed to help research infrastructures across Europe implement transparent, flexible, and cost-effective control solutions.

In parallel, FlexRICAN develops tools to support decision-making in the design of energy supply chains for scientific facilities. The exploitable result is an optimisation model for technological chain design—covering cogeneration, photovoltaic production, and multi-layered backup systems—tailored to the specific operational demands of research infrastructures. At ELI, the deployment of such a prototype system led to a 90% reduction in grid-induced brownouts, demonstrating its potential to stabilise high-load scientific operations. This experience informs the creation of a web-based tool and knowledge resource, aimed at supporting RI planners in selecting resilient and emission-efficient configurations adapted to cleanroom-intensive environments. The approach strengthens the long-term energy autonomy of scientific infrastructures while minimising environmental and operational risks.

A further line of FlexRICAN innovation addresses the complex challenge of achieving energy-efficient and climate-resilient indoor environments. By developing a Cleanroom-Oriented Technological Chain Optimisation Tool (KER#6), the project supports both real-time control and future-oriented optimisation of climate control infrastructure. Pilot activities at ELI have already resulted in 22% heating savings and an 8% reduction in electricity demand, while maintaining stringent cleanroom standards. The tool will integrate short-term forecasts to inform operational control and long-term climate scenarios to support strategic investment planning, such as pre-conditioning energy storage or adapting building envelope design. These capabilities directly support the EU Taxonomy objectives by providing science-based recommendations for the sustainable construction and operation of future research infrastructures in a changing climate.

Case Study 2: Energy, CO2 Optimisation and Flexibility: Services to the Grid at ELI and LNCMI

Key message: **Energy flexibility is key for an efficient energy landscape, minimising CO2, energy cost and maximising the integration of renewables**

In order to minimise the CO2 impact of a research infrastructure, acting on the CO2 content of the consumed energy is a powerful lever that impacts the whole energy chain.
At ELI Beamlines (yearly electricity consumption 8,9 GWh with achieved power output of 1,7 MWthe integration of multiple on-site energy sources has created a robust technological chain that supports implicit energy flexibility while maintaining operational resilience. The site combines a 312 kWp photovoltaic power plant (PVP) (with 348 MWh expected annual output), a high-efficiency cogeneration unit (CHP, 530 kWe, 630 kWt, fuel: Natural gas, 85,4% total efficiency), a diesel generator (DA) for backup power (2000 kVA), and a layered uninterruptible power supply (UPS) system (Lead acid batteries, total output 837 kVA). This setup allows for internal reallocation of energy sources based on reliability and availability.

In the event of a power voltage sag (Brownout), the CHP unit helps stabilise the voltage. In the event of a power outage or other grid disturbances, the UPS provides an immediate, seamless power bridge, ensuring voltage stability and protecting sensitive equipment. Simultaneously, the DA is automatically started and takes over the load within minutes, maintaining safe shutdown of laser-class infrastructure and recharging the batteries to be ready for the next grid disturbance. Once the grid is stabilised, the generator shuts off.

A shift in consumption from the 250 most emissive hours (highest carbon content in national electricity production) to the 250 least emissive hours (assuming ELI Beamlines is 100% flexible during these hours, and all the electricity curtailed is deferred) gives the following results. Over the 250 most emissive hours, the emission factor is 0.461 tCO2/MWh compared with 0.129 tCO2/MWh during the least emissive hours and 0.323 tCO2/MWh on average. Shifting consumption over these 250 hours (i.e. 277 MWo) would therefore avoid 0.332tCO_2/MWh, or 92 tons of CO2 out of the total yearly emissions of 2,912tCO2.

Similar calculations carried out on the LNCMI infrastructure show even more impactful figures because the French mix during the lowest emission factor hours is totally covered by nuclear and renewables, so that it reaches values around 0.01tCO_2/MWh.

The following recommendations can thus be derived from the FlexRICAN project:

- Presently, transmission system operators activate balancing power based on the purely economic merit order. Introducing a proportion of CO_2 impact based merit order could impact greatly the balancing market outcome (therefore giving priority to flexible assets in comparison to fossil-based production, basing the arbitration not only on economic considerations).
- In case of arbitrage need, favour flexible assets for grid connection (priority access and financial advantages in terms of wheeling/grid fee rate).

Case Study 3: Heat Recovery at ESS & Lund Municipality and HFML & Nijmegen Municipality

Key message: **Recovery at research facilities as well as industries is an enabler for decarbonization, energy security & affordability**

Large-scale research infrastructures typically consume large amounts of electricity. Electricity, which to a large extent is converted into heat that is rejected to the ambient environment through the facility's cooling system. In many cases of research facilities, the equipment is sensitive to high temperatures and as such, the cooling water temperature is often not very high, i.e 25-50°C. Such low temperature heat is often considered not to be of interest for distributed heating networks, either internal hydronic heating networks or larger-scale district heating networks. However, three FlexRICAN partners have shown how this heat can be used efficiently for the heating of buildings, thus paving the road for similar heat sources to recover the heat they produce. And such sources are abundantly available in Europe today and in the future, one such heat source is data centres, which, together with other industries, represent an increasing demand for electricity all over Europe. Recovering heat from these sources has a monumental potential to reduce primary energy demand, to increase energy security of the region and at the same time support electrification of other sectors than heating.

In Lund, Sweden, the research infrastructure of the ESS is under construction and is scheduled to be operational in 2027. When running at full operation, the equipment and facilities will annually use approximately 180 GWh of electricity. The ESS site has a centralised cooling system where the heat which is cooled off from the equipment will be made available for different purposes, and at different temperature levels to optimise the total system efficiency [4]. Parts of the generated heat will be used locally within the ESS site to cover the heating demands of the facilities on the site. The location of ESS was chosen carefully from the perspective that there is already a district heating network covering the entire city, which has a demand for large volumes of heat. For the internal demand, ESS will capture and use heat at available, lower temperature levels and when supplying heat to the external district heating network, the temperature will be increased with large-scale, efficient, industrial heat pumps. At full operation, ESS will have a large demand for electricity, so capturing the excess heat and making it available for the city will be fundamental to the energy security of the local energy system. And the best thing, this concept can be applied to other sites and industries in Europe, achieving the same goals for decarbonization and energy security.

Another example can be found at the Radboud University in Nijmegen, the Netherlands. The High Field Magnet Laboratory (HFML-FELIX) at the university's campus consumes 5-10 GWh of electrical energy to provide scientists with some of the strongest magnetic fields available in Europe. The return water temperature of the magnet cooling lies in the 20-25°C range. This heat is transferred into a large water system to which most of the buildings on the university campus are connected. These buildings then use renewable energy sources to power heat pumps that transfer this heat into the building heating network. The surplus of heat is stored in large aquifers for use at a later time, which allows the system to compensate for the highly intermittent use of the magnets. Currently, this system allows the recovery of about 30% of the heat generated at HFML-FELIX, which translates to a reduction in the use of natural gas for the heating of buildings in the order of 4000 m^3 annually.

Case Study 4: District Energy & Resilience: local production, microgrid configuration at FlexRICAN facilities

Key message: **For long-term energy district planning towards carbon-neutral and resilient cities, it is needed to set new governance to integrate the needs of local players/producers/industries & communities**

The LNCMI currently operates with two separate electricity delivery points, each managed independently. One point serves the main buildings and general infrastructure, while the second is dedicated exclusively to the high-powered research instruments. These are covered under two distinct electricity supply contracts, with minimal overlap or coordination between them. This segmented approach limits the potential for energy optimisation and advanced energy management strategies.

By adopting a bundled or unified view of these two delivery points, LNCMI could unlock several important opportunities. First, there is the possibility to reduce the overall peak consumption across the site. By coordinating energy use between buildings and instruments, demand could be better distributed throughout the day, reducing stress on the grid and potentially lowering associated demand charges. Second, this unified management would facilitate the integration of services to the grid — such as demand response or flexibility services — by offering a more aggregated and controllable load profile to the network operators.

Third, it would prompt a reassessment of LNCMI's current energy management strategy, which is currently fragmented and not primarily designed for resilience. A more centralised, smart management system could significantly enhance the site's ability to handle disruptions, price volatility, or grid constraints, while aligning with broader energy transition goals.

Of particular interest is the site's direct connection to the French transmission grid (RTE) at a high voltage level (225 kV, 60 MVA), specifically for the research instruments. This powerful connection is utilised intensively but only about 30% of the time, typically during the day, when scientific experiments are run. During the remaining 70% of the time, the capacity of this grid connection remains largely underutilised.

This idle bandwidth presents a major opportunity for flexibility. For instance, a co-located battery energy storage system could be installed and operated on-site. During off-peak hours, especially at night when electricity prices are lower, the battery could charge from the grid. Then, during daytime experiments when demand from the instruments rises, the battery could discharge to support that load. Additionally, the battery could participate in ancillary services markets, providing frequency regulation, voltage support, or reserve capacity to the grid operator, generating revenue while improving the overall efficiency of the grid connection.

Overall, a more integrated and strategic use of LNCMI's electrical infrastructure could enhance sustainability, reduce costs, and contribute to grid stability — all while supporting the lab's scientific mission.

This example is one out of many, demonstrating the value of local/district-level coordinated energy management and mutualisation of energy infrastructure. This dimension is also supported by the following examples at additional research infrastructures:

- ELI Beamlines, for which brownouts and power quality issues are much improved when their local production is operating (CHP generation and PVP as described in Case Study 2 above)
- ELI Alps, where a multi-MW Photovoltaic Power Plant is being installed, shows efficient use of the surface on which the facility is deployed.
- ESS and HFML-FELIX share their thermal energy with their neighbourhood (as described in Case Study 3 above)

The following recommendations can be derived from the FlexRICAN project:

- Incentivise the deployment of renewable power generation/storage at the research facility level that benefits the facility but also its surroundings.
- Incentivise local/district level self-consumption that can solve local power quality/congestion issues, decrease the carbon footprint of the consumed energy and contribute to the national grid balance.
- Incentivise the most efficient use of a grid connection point/point of delivery by favouring the coupling of consumption with production and/or storage, even when belonging to a third party.

Case Study 5: Economic Impact of Load-Shifting at ELI Beamlines

Key message: **Minimise electricity purchase costs and minimise CO_2 emissions**

Based on the electricity supply contract provided by FlexRICAN partners, ELI Beamlines bought its electricity at a fixed price of 3.381CZK/kWh (0.14€/kWh) for the year 2024.

A fixed-price contract makes it impossible to take advantage of electrical flexibility, since shifting consumption from one hour to the next does not change the price (which is fixed). However, conducted simulations display a shift in consumption to see what the environmental and economic impacts of load-shifting would be if ELI Beamlines were 100% exposed to the Czech spot price.

It is very important to note that the tax and grid fees components have been neglected. In a study of the economic impact of load-shifting, these components should necessarily be included, but the modelling is still in its early stages.

Based on the information provided, estimations show that in 2024, ELI Beamlines's annual consumption amounted to 8.9 GWh, and its emissions to 2,912 tCO_2 (0.327 tCO_2/MWh associated with ELI Beamlines's consumption vs 0.323 tCO_2/MWh for the average Czech Republic's power system). The analysis correlated ELI Beamlines's consumption data with spot market prices to approximate the site's electricity purchase cost. If it were 100% exposed to Czech hourly spot prices (neglecting taxes and network charges), an average cost per kWh of 0.085[1] €/kWh (2.1 CZK/kWh) is found, i.e. an annual cost of 757,000 € (18,667,847 CZK).

Two types of situations have been simulated: one that seeks to minimise the cost of purchasing electricity, the other that seeks to minimise emissions from electricity consumption.

Simulations

[1] Since grid costs, taxes and supplier margins were not taken into account, it's normal to have an average spot price well below the contracted cost of supply.

Minimise electricity purchase costs (assuming 100% exposure to the spot market and excluding tax and grid fees).

One of the simulated cases exhibited a consumption shifted from the most expensive 250 hours to the cheapest 250 hours (assuming the site is 100% flexible and defers 100% of its consumption).

Over the 250 most expensive hours, the average electricity price is 0.25€/kWh or 6.16 CZK/MWh, compared with -0.01€/kWh during the least expensive hours, or -0.25 CZK/MWh.

Negative prices are observed in cases where nuclear power plants prefer to sell their electricity at a negative price, rather than shut down their plant and restart it later (which generates significant restart costs), or when electricity is imported from a country with a surplus of renewable energy production (which has no interest in shutting down if it is subsidized and therefore not exposed to the market price).

From an emissions point of view, during the 250 cheapest hours, the system's CO2 emissions factor is 0.159 kgCO2/MWh, compared with 0.404 kgCO2/MWh during the most expensive hours (See Figure 1). Low prices associated with low emission factors suggest that residual demand was low, and that most of the generation was low-carbon (probably baseload nuclear).

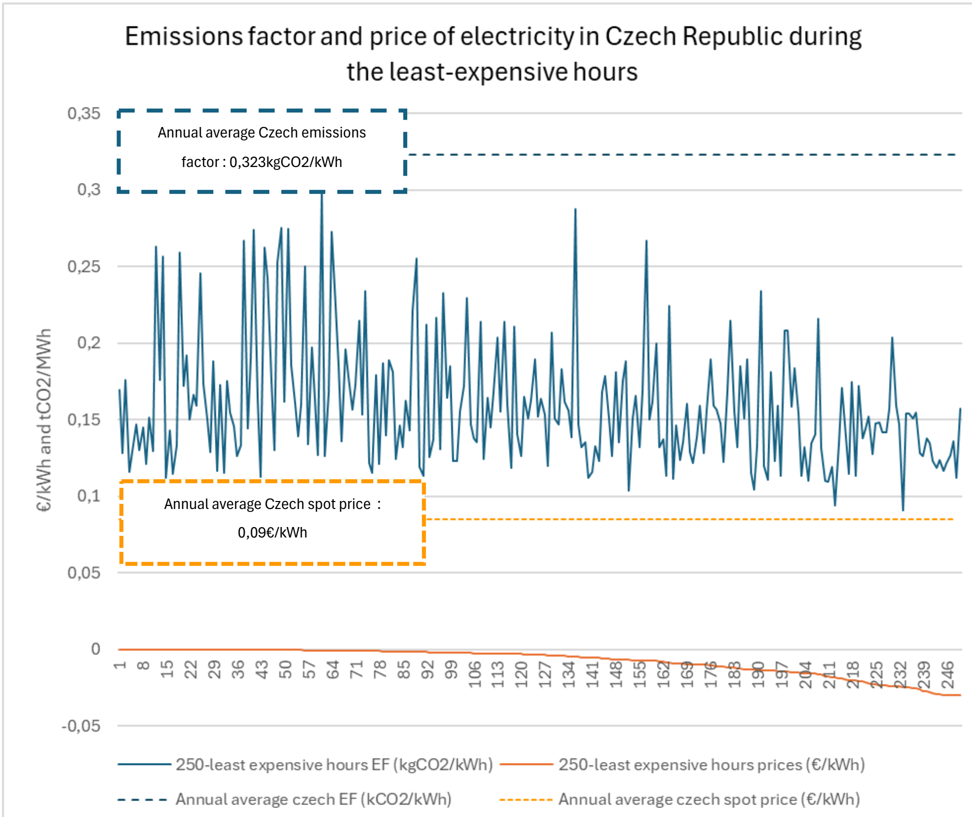

Figure 1: Lower CO2 Emissions Factor Observed During Low-Price Periods, Indicating a High Share of Low-Carbon Generation.

So, by shifting consumption from the most expensive 250 hours (267 MWh) to the cheapest 250 hours, it is possible to avoid 65 kg of CO2e and 65,444€ over one year (taking only the spot price into account), or 1,615,000 CZK.

Minimize CO_2 emissions

Simulation was conducted with a shift in consumption from the 250 most emissive hours (highest carbon content in national electricity production) to the 250 least emissive hours (assuming ELI Beamlines is 100% flexible during these hours, and all the electricity curtailed is deferred).

Over the 250 most emissive hours, the emission factor is 0.461 tCO2/MWh compared with 0.129 tCO2/MWh during the least emissive hours. Shifting consumption over these 250 hours (i.e. 277 MWh) would therefore avoid 0.332tCO_2/MWh, or 92 tons of CO2.

However, based solely on the Czech spot price (excluding network charges and taxes), the economic impact of this “emission-based” load-shifting is negative. The spot price over the 250 most emissive hours is only 0.07€/kWh (1.72 CZK/kWh) compared with 0.09€/kWh (2.22 CZK/kWh) during the least emissive hours.

In contrast to systems with large renewable capacities, power generation fleets with a significant proportion of carbon-based plants may see their spot prices rise as emissions are reduced, to the extent that gas power plants are introduced in addition to coal-fired plants when demand rises. It is believed that the 250 hours with the lowest emissions

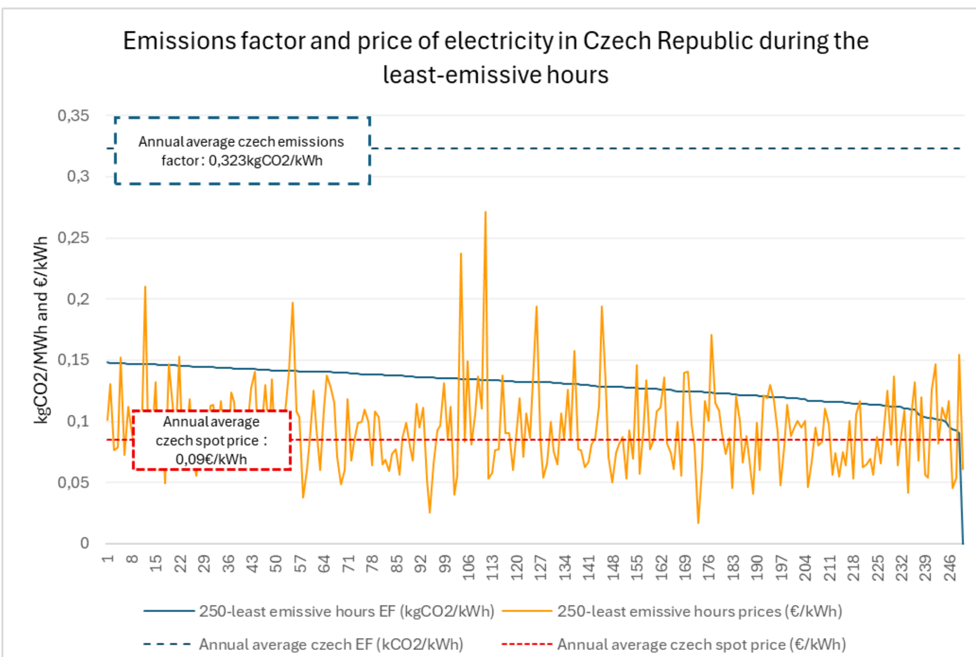

Figure 2: Economic Analysis of Emission-Based Load Shifting, Showing Higher Costs During Low-Emission Periods.

occur when gas-fired power plants are marginal (i.e. when the price of gas determines the price of electricity). Thus, although gas is less emissive than coal, it is more expensive, which implies that a drop in emissions factors is accompanied here by an increase in the spot price.

Thus, shifting this consumption would increase the purchase cost on the spot market by 0.02€/kWh (0.49 CZK/kWh), i.e. an additional cost of around 7,000€ over the year (173,000 CZK).

Considering only the spot price (grid fees and taxes are excluded), it seems more profitable to operate load-shifting on a "price-based" logic than on an "emissions-based" one. In this case, each kg of CO2 avoided coincides with a reduction in the spot electricity purchase price of 1.05€ (26 CZK), compared with an additional cost of 0.08€/kg CO2 avoided (2 CZK).

However, if ELI Beamlines does not change its contract modality and sees its electricity supplied at a fixed price, there will be no economic incentive to shift its consumption.

Closing section: Call to Action

To fully realise the potential of FlexRICAN's innovations and accelerate Europe's transition to a sustainable, resilient, and carbon-neutral energy future, coordinated action across policy, industry, and research sectors is essential. We recommend the following next steps:

1. Policy Support and Funding:

Prioritise funding for energy flexibility solutions in RIs and incentivise integration of renewable energy, energy storage, and waste heat recovery systems across public facilities.

2. Scaling and Exploitation:

Encourage exploitation of FlexRICAN's solutions and tools across Europe's broader RI ecosystem, promoting standardisation and interoperability to maximise impact.

3. Stakeholder Collaboration:

Foster multi-level cooperation among RIs, local authorities, grid operators, and industry partners to implement district-level energy management strategies and develop flexible energy markets.

4. Capacity Building:

Invest in continuous training programs to upskill RI staff and ensure long-term institutional capability in energy-smart operations and sustainability practices.

5. Regulatory Innovation:

Adapt regulatory frameworks to recognise and reward energy flexibility contributions, including revising grid tariffs, enabling participation in flexibility markets, and incorporating carbon impact in grid operation decisions.

6. Monitoring and Evaluation:

Establish robust monitoring mechanisms to track the deployment outcomes of flexibility measures, enabling evidence-based policy adjustments and further innovation.

By taking these concrete actions, the EU can leverage FlexRICAN's insights and tools to make RIs exemplars of energy efficiency and climate leadership, paving the way for a greener, more secure energy system across Europe.

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Appendices

Appendix 1 Table containing the Key Exploitable Results

KER Identifier	Name	Related WP	Type
KER#1	Software Tool for Predicting the Performance of a PV Plant at RIs	WP3	Software tool
KER#2	Software Tool for Optimising Energy Chain and Battery Storage Planning	WP4	Software tool
KER#3	High-Temperature Klystron Cooling Report	WP5	Report
KER#4	Waste Heat Valorisation Report	WP5	Report
KER#5	Open-Source Data Repository of Program Blocks for Intelligent Building Management Systems	WP7	Software tool
KER#6	Cleanroom-oriented Technological Chain Optimisation Tool	WP7	Software tool
KER#7	Analysis Tools and Methodology to Optimize Energy Management for Flexibility and Sustainability	WP6	Software tool and methodology
KER#8	Report on Flexibility Quality Label Initiatives	WP6	Report
KER#9	Report on Current and Future Usage of Helium - Sustainability and Costs	WP7	Report

Appendix 2: Table containing the Target Groups in PSEDER

Target groups	Relevance to the project

TG1: EU, Funding organizations, Policy-makers	Funding allocation, project compliance, policy development, further collaboration and exploitable results
TG2: National and local authorities in partner cities & regions	Economic growth, urban development, sustainability goals and alignment with EU directives.
TG3: Research Infrastructure networks and Policy ecosystem	Sustainability goals, efficient energy management, economic optimisation
TG4: Research Infrastructures	Innovation, new technology implementation
TG5: Academic and Scientific Communities	Research outcomes, innovation, technology transfer
TG6: Industry Partners	Technological innovation, market expansion, regulatory compliance Market opportunities, technology validation, innovation Industry standards, regulatory framework, market trends
TG7: General Public	Environmental impact, quality of life. Environmental protection, sustainable development, policy influence. Information dissemination, public awareness, project transparency

Appendix 3: Work Packages of the FlexRICAN Project

Work Package	**Name of the Work Package**
WP1	Project Management 1
WP2	Project Management 2
WP3	Renewable Energy Production at RIs
WP4	Efficient Use of Battery Arrays
WP5	Waste Heat Recovery
WP6	Energy Flexibility
WP7	Implementation of Flexibility & Carbon Reducing Solutions

WP8	Communication, Dissemination, Exploitation, Stakeholder Engagement and Training Activities 1
WP9	Communication, Dissemination, Exploitation, Stakeholder Engagement and Training Activities 2