

LIAISON

Making transport infrastructure
climate-neutral, sustainable and circular

INFOPACK - MAY 2026

SECTOR 3 OF 5

ENERGY EFFICIENCY

Energy Efficiency & Generating infrastructure Adaptive Tunnel Ventilation Control System

SMARTER, SAFER AND MORE
SUSTAINABLE AIRFLOW MANAGEMENT
FOR EUROPE'S TUNNELS

SECTOR 3 of 5
ENERGY EFFICIENCY



Ventilation is one of the most energy-intensive and safety-critical components of any road tunnel. Traditionally, tunnel fans operate in a simple on/off mode, running at full speed even when demand is low. While effective in emergencies, this approach wastes significant energy, increases noise and vibration, and accelerates equipment wear — all of which translate into higher costs and reduced reliability.

ZITRÓN is developing an Adaptive Control System for Tunnel Ventilation that redefines how fans operate in both normal and emergency conditions. The system introduces Variable Frequency Drives combined with sine-wave filters, enabling precise fan speed control and dramatically improving energy efficiency. Early measurements confirm up to 40% energy savings thanks to optimized airspeed control and reduced power consumption.

Beyond efficiency, fan speed regulation brings a series of operational and environmental benefits. Lower speeds reduce mechanical stress, decreasing vibration and noise levels — a major advantage for tunnels located in urban or residential areas. Reduced vibration also extends equipment lifetime and lowers maintenance needs, contributing to safer long-term operation. In fire scenarios, lower background

noise allows emergency announcements and alarms to be heard more clearly, improving evacuation and response conditions. Central to the innovation is ZITRÓN's ZJET electronic card, installed directly on each fan. It gathers signals from accelerometers, temperature sensors, heaters, and other components, enabling real-time health monitoring. Integrated vibration spectrum analysis helps detect anomalies early, supporting predictive maintenance and reducing the risk of unexpected failures. The cards also simplify installation by arriving fully wired from the factory.

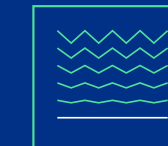
The system is managed through ZVM control software, which streams data to the cloud, where ZCARE performs advanced diagnostics and analyses environmental sensor inputs such as airflow and smoke behaviour. Together, these tools allow operators to continuously optimise airflow, improve energy performance, and test fire-control strategies under different scenarios.

The adaptive ventilation system is being validated in Spain's Mamariga Tunnel, where upgraded control cabinets, ZJET units, and monitoring software are now operating across both tunnel tubes. Performance will continue to be assessed through 2026, delivering real-world evidence of energy savings, safety improvements, and circularity benefits.

BENEFITS



UP TO 40% ENERGY SAVINGS THROUGH PRECISE, VARIABLE-SPEED FAN CONTROL



LESS NOISE AND VIBRATION, IMPROVING USER COMFORT, EXTENDING EQUIPMENT LIFESPAN



LOWER MAINTENANCE AND OPERATIONAL COSTS THANKS TO LESS MECHANICAL STRESS



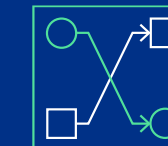
ENHANCED SAFETY WITH CLEARER EMERGENCY COMMUNICATION



SMART, REAL-TIME MONITORING VIA ZJET SENSORS AND CLOUD-BASED DIAGNOSTICS



MORE RELIABLE TUNNEL OPERATION THROUGH ADAPTIVE AIRFLOW MANAGEMENT



EASY INTEGRATION WITH PREWIRED UNITS AND UPGRADED CONTROL SYSTEMS

ROADMAP TO IMPLEMENTATION

Definition of adaptive tunnel ventilation system, identifying inefficiencies

Development of smart components, control software and cloud integration

Deployment, commissioning in a real tunnel, with system calibration and training

Monitoring & validation of energy savings, safety, performance

Optimisation of performance, development of guidelines for replication

Deployment across EU infrastructures, integrating with other smart systems

Energy Efficiency & Generating infrastructure Intelligent Tunnel Lighting System

AI-ENHANCED OPTIMISATION FOR
SAFER, CLEANER AND
MORE ENERGY-EFFICIENT TUNNELS

SECTOR 3 of 5
ENERGY EFFICIENCY

Every day, thousands of drivers enter tunnels experiencing the so-called “black hole effect” — a momentary loss of visibility caused by the contrast between bright daylight and the darker tunnel entrance. This phenomenon can compromise safety, especially in high-traffic tunnels. To address this, international standards such as CIE 88:2004 define precise lighting levels for each tunnel section, ensuring visibility and comfort for all users. Yet current lighting systems often rely on static configurations or simple expert rules that cannot adapt to changing outdoor conditions or optimise energy consumption.

The Intelligent Tunnel Lighting System, developed by TECNALIA within the LIAISON project, introduces an intelligent tunnel lighting control system designed to meet safety requirements while drastically reducing energy use. The system continuously adjusts light levels based on real-time luminance measurements (L20 readings) and traffic conditions, ensuring compliance with the CIE curve while avoiding the unnecessary over-lighting that increases electricity demand and CO₂ emissions. The goal: a 30% reduction in electricity use for tunnel lighting. At the heart of the tunnel lighting system is a meta-heuristic optimisation algorithm. Unlike traditional Expert Rule Systems, this AI-

driven approach evaluates live tunnel conditions, identifies the most suitable luminance profile, and calculates energy-cost implications using electricity price data from the Spanish grid (ESIOS). A dynamic cost function guides the system toward the optimal balance between safety and efficiency.

The solution is being validated in the Mamariga Tunnel on Spain’s N-644 road — a 320-metre twin-tube tunnel linking the A-8 motorway to the Port of Bilbao. Its diverse traffic patterns and geometry provide an ideal testbed to demonstrate energy savings, reliability, and visibility improvements under real operational conditions.

Aligned with the LIAISON Dynamic Multi-Infrastructure Governance Framework (DMIGF), The intelligent tunnel lighting system contributes to technical, environmental, circularity, and social KPIs, including reduced energy demand, lower emissions, optimised resource use, and enhanced driver safety.

By combining advanced optimisation, LED and DALI technologies, and dynamic control, the intelligent tunnel lighting system forms a cornerstone of smart tunnel infrastructure — and offers strong bundling potential with Adaptive Ventilation for integrated, energy-efficient traffic tunnels.

BENEFITS



UP TO 30% ENERGY SAVINGS, LESS ELECTRICITY CONSUMPTION AND OPERATIONAL COSTS



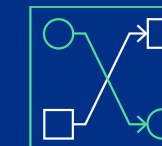
IMPROVED SAFETY AND VISIBILITY COMPLIANT WITH CIE TUNNEL LIGHTING STANDARDS



LOWER CO₂ EMISSIONS THANKS TO REDUCED ENERGY DEMAND



EXTENDED EQUIPMENT LIFETIME DUE TO OPTIMISED, DEMAND-BASED LIGHTING LEVELS



AI-BASED OPTIMISATION BRINGS INTELLIGENCE AND ADAPTABILITY TO PUBLIC INFRASTRUCTURE

ROADMAP TO IMPLEMENTATION

Define lighting system addressing inefficiencies, ensuring safety standards

AI-based optimisation, validate performance through simulations

Deploy in real tunnel, install hardware, calibrate controls, train operators

Monitor performance, energy savings, ensure safety and environmental benefits

Refine for scalability, standardisation, economic viability across use cases

Scale to market, integrate with smart infrastructure, improve via data insights

Guardrails are essential elements of road safety, designed to protect drivers and motorcyclists by reducing the severity of roadside accidents. Traditionally, they have served a single purpose: impact protection. The Photovoltaic (PV) Guardrail concept developed within the LIAISON project transforms guardrails into dual-function infrastructure that improves safety while generating renewable energy.

The core idea is simple yet innovative: integrate photovoltaic modules into standard guardrail structures so they can harvest solar energy throughout the day. This allows roads to contribute directly to sustainability goals without requiring additional land or altering the road layout. The PV guardrail becomes a compact, efficient solar installation embedded in existing transport networks.

Assessing how the PV guardrail performs in real operational conditions includes evaluating its energy generation capacity, analysing how different orientations (north, south, east, west) affect performance, and studying the guardrail's durability and safety behaviour through virtual impact tests and structural monitoring. Continuous data collection—covering sunlight intensity, temperature, rainfall, shading patterns, and performance ratio—helps build a complete picture of how the

system behaves across seasons and weather conditions.

Beyond energy production, the solution enhances safety by enabling powered safety functions. Electricity generated by the guardrail can feed roadside LED lighting for improved night visibility or support sensors for hazard detection, fog monitoring, or emergency alerts. These features can help reduce accident risk and increase driver awareness, especially in challenging environments.

Feedback from road authorities, users, maintenance personnel, and local communities helps assess acceptance and identify potential barriers to deployment. Cost and environmental analyses further examine the long-term value of PV guardrails, including their recyclability and potential for reducing carbon emissions.

The demonstration on VITA premises, alongside real-world testing, will provide insights into scalability and replicability and will inform guidelines for future installations, supporting wider adoption across Europe.

The Photovoltaic Guardrail represents a new generation of multifunctional infrastructure combining road safety, renewable energy, and sustainable design into one innovative solution.

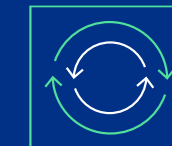
BENEFITS



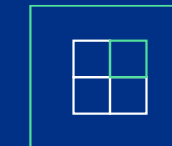
MORE ROAD SAFETY, IMPROVED IMPACT PERFORMANCE, POWER LIGHTING/SENSORS



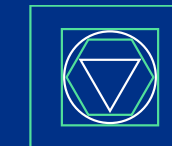
CLEAN ENERGY PRODUCTION INTEGRATED DIRECTLY INTO EXISTING GUARDRAILS



TURNING EXISTING SAFETY INFRASTRUCTURE BECOME DUAL-PURPOSE SOLAR ASSET



SCALABLE AND ADAPTABLE TO DIFFERENT ROAD TYPES, CLIMATES, AND ORIENTATIONS



DATA-DRIVEN PERFORMANCE WITH ENERGY AND ENVIRONMENT MONITORING



LOWER IMPACT THROUGH RENEWABLE GENERATION AND RECYCLABLE MATERIALS



REDUCED ENERGY COSTS AND POTENTIAL ACCIDENT-RELATED COST SAVINGS

ROADMAP TO IMPLEMENTATION

Demonstration in VITA premises: energy and performance

Durability and safety behavior through virtual impact tests and monitoring

Demonstration in real-world testing site (Italian Highway)

Stakeholders engagement: authorities, users, communities, maintenance personnel

Key inputs for market scalability: PV provider agreement

Market Uptake: standardization

Transport infrastructure is expected to do more than provide structural support. Alongside durability and safety, modern assets must enable monitoring, digitalisation, and energy efficiency, often in locations where grid access is limited. At the same time, the construction sector faces growing pressure to reduce resource consumption and environmental impacts by adopting circular and low-carbon materials.

Within the LIAISON project, an innovative thermoelectric concrete transforms conventional cement-based materials into functional, energy-harvesting infrastructure elements capable of converting naturally occurring temperature differences into electrical energy through the Seebeck effect, enabling concrete components to act as passive power sources for embedded monitoring and sensing systems.

The approach builds on circular economy principles by enhancing thermoelectric performance using secondary raw materials and industrial by-products. Materials such as red mud, copper slag, mine residues, and recycled graphite are incorporated into the cement matrix to increase electrical conductivity and thermoelectric response while preserving the inherently low thermal conductivity of cementitious materials. In this way, waste-derived

materials are reused and re-activated with new energy-related functionalities. Extensive laboratory testing has demonstrated that selected mixtures can achieve order-of-magnitude improvements in thermoelectric properties compared to conventional cement pastes, while maintaining mechanical performance. Rather than targeting high-efficiency power generation, the solution is designed for distributed, low-power energy harvesting, where robustness, durability, and large surface areas are key advantages.

Based on these results, optimised mixtures incorporating graphite and red mud have been selected for field validation in Slovenia. Thermoelectric concrete elements are integrated into secondary-raw-material-based infrastructure components and equipped with electrodes and monitoring systems to assess voltage output and thermal response under real operating conditions.

By enabling self-powered monitoring systems and reducing dependence on external energy supply, thermoelectric concrete opens new possibilities for smart, low-maintenance transport infrastructure.

BENEFITS



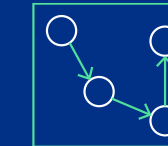
ENERGY FROM WASTE HEAT, ENABLING SELF-POWERED SENSORS AND MONITORING



CIRCULAR ECONOMY INTEGRATION THROUGH USE OF INDUSTRIAL BY-PRODUCTS



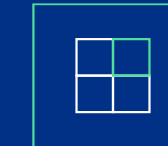
LOW-CARBON SOLUTION WITH MINIMAL OPERATIONAL ENERGY FOOTPRINT



IMPROVED INFRASTRUCTURE AUTONOMY, LESS CABLING AND MAINTENANCE NEEDS



STRONG INTEGRATION POTENTIAL WITH SMART MONITORING AND DIGITAL SYSTEMS



TRANSFERABLE CONCEPT FOR RAIL, ROAD, INFRASTRUCTURE, FAÇADES, AND PAVEMENTS

ROADMAP TO IMPLEMENTATION

Pilot validation: demo in Slovenia to validate usability and energy harvesting performance in real conditions

Gradual market outreach: expand across EU, starting with rail, then road and urban sectors

Licensing and integration: partners will license the technology and support industrial adaptation

Support and knowledge transfer: guidance on material formulation, installation, and monitoring



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