UITP ADVANCING PUBLIC TRANSPORT

e·lobster

PROJECT BRIEF

REDUCING ENERGY LOSSES IN POWER DISTRIBUTION AND URBAN RAIL NETWORKS

DECEMBER | 2022

INTRODUCTION

European distribution and urban rail networks face common issues, as both have been developed as independent networks, relying on the resilience and robustness of existing power supplies. However, the progressive penetration of Renewable Energy Sources (RES) has introduced an increasing degree of uncertainty on the future nature of power flows.

*UITP participated in the EU-funded research project 'E-LOBSTER' (**E**lectric **LO**sses Balancing through integrated **ST**orage and power Electronics towards increased synergy between **R**ailways and electricity distribution networks), coordinated by RINA. This project aimed at developing an innovative R+G (Railway to Grid) management system which - combined with advanced power electronics - will be able to reduce electricity losses in both the power distribution network and the light railway network.*

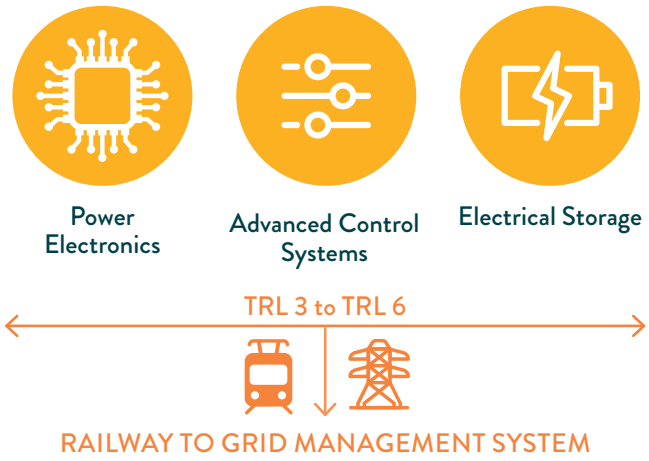
This project brief presents the main achievements and innovative solutions that were derived. It provides an overview of the methodology, findings and key takeaways from the E-LOBSTER project.

PROJECT OBJECTIVES

E-LOBSTER had the following objectives:

- To develop and validate a new, real-time-optimised Railway to Grid/Grid to Railway (R+G) energy management aiming to enhance the interaction between electrified transport and distribution networks.
- To develop storage systems and advanced power electronics as shared assets between the electrified transport and distribution networks, and allowing unique management of the energy between the two networks.
- To demonstrate E-LOBSTER's innovative solutions and technologies under real conditions in the Metro of Madrid at TRL 6, preceded by validation in the Smart Grid Laboratory at Newcastle University.

Figure 1: E-LOBSTER concept



To reach these objectives, a consortium of nine partners was built to participate in the project. These included public transport operators, original equipment manufacturers (OEMs), technology suppliers and services providers as well as research and academic institutes. The full list of members can be found on the E-LOBSTER website: **https://www.e-lobster.eu/**.

INNOVATIVE TECHNOLOGICAL SOLUTIONS OF E-LOBSTER

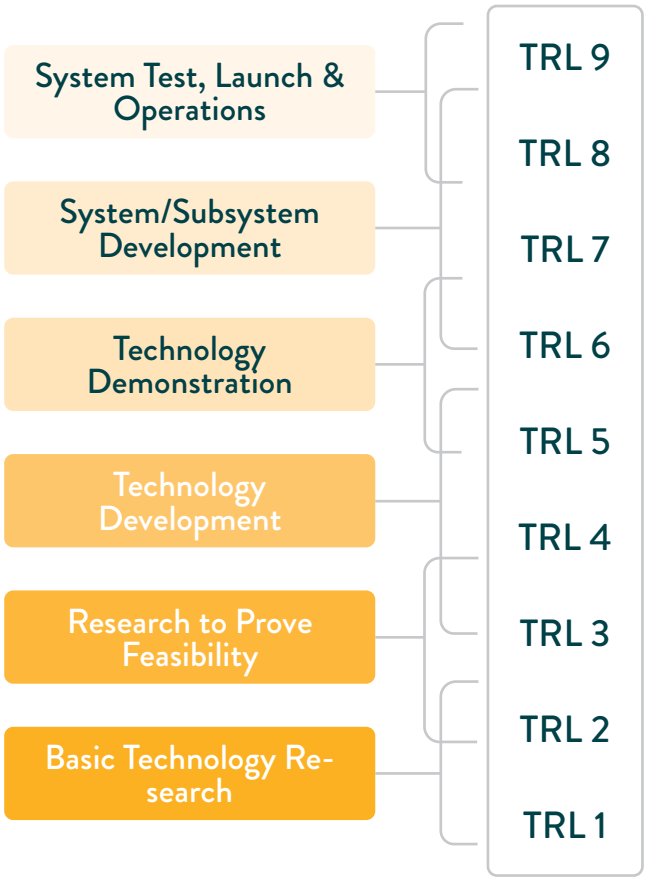
There is a global need to increase the penetration of low-carbon technologies (LCTs). At the same time, there is a growing requirement to provide people with sustainable form of transport such as electric vehicles (EVs) and trains, particularly in urban centres.

E-LOBSTER proposes, for the first time, a substantial integration of renewable sources, electrified road and rail transport with advanced power electronics technologies and energy storage. This will be managed by a unique control management system (namely R+G Management System), which will operate taking account of the mutual benefit of both transport and distribution network prioritising distribution losses reduction and allowing the recovery of braking energy from the train.

The overarching objective of the E-LOBSTER project was to create **synergies amongst the different actors of the energy sector**. Concretely, the project developed and demonstrated, up to TRL 6, in a relevant environment (a real underground railway in Madrid, connected to a local power distribution network) an innovative, economically viable and easily replicable Electric Transport-Grid Inter-Connection System. Properly managed, it was able to establish synergies between power distribution networks, electrified urban transport networks (such as metros, trams and light railways) and charging stations for electric vehicles.

"The overarching objective of the E-LOBSTER project was to create synergies amongst the different actors of the energy sector."

Figure 2: Technology Readiness Levels (TRLs)



The project developed innovative solutions and technologies, which have been validated and demonstrated in real conditions for the:

- Assessment of the source of losses
- Minimisation of electricity losses
- Maximisation of consumption of RES production through electric energy storage
- Recovery of braking energy.

E-LOBSTER is built around the following innovative technological solutions:

- Smart Soft Open Point (sSOP)[1]
- Battery Energy Storage System (BESS)
- Railway to Grid/Grid to Railway (R+G) energy management.

1 Soft Open Points (SOPs) are power electronic devices placed at open points on electricity distribution networks to provide flexible power control to the network.

TECHNOLOGICAL INNOVATIVE SOLUTIONS

Smart Soft Open Point

The project developed and validated a smart Soft Open point (sSOP) based on back-to-back power converters. The project proposed a new three-way sSOP to interface with the power distribution network and the railway electrification system (a two-stage DC/AC power converter with an intermediate and regulated accessible DC link). This allows the unique management of the energy flow between the traction substation and the distribution network.

Battery Energy Storage System

In a second innovation, the project developed and validated suitable storage technologies for creating synergies between the electrified transport networks and the power distribution networks by increasing the penetration of renewable energy sources. Together with the sSOP, these represent the two shared assets between power distribution network and transport network.

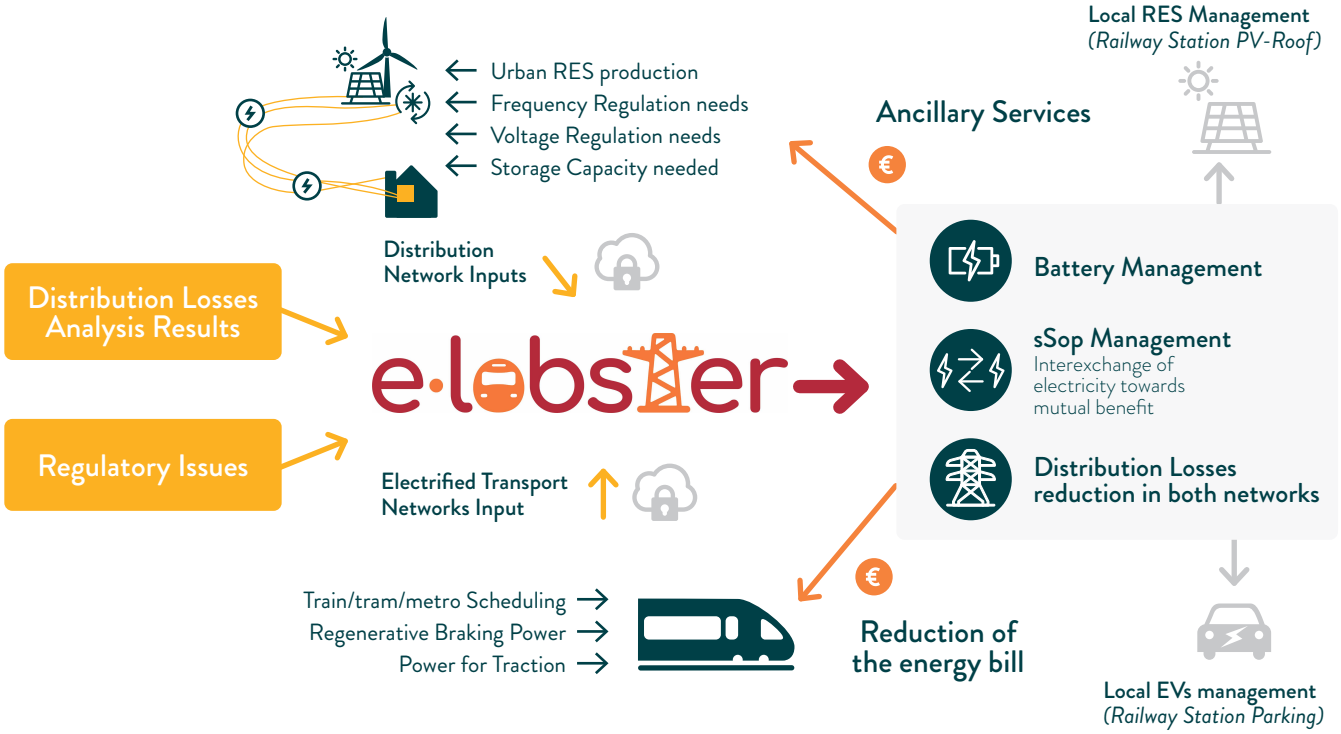
E-LOBSTER R+G Management System

E-LOBSTER developed and validated a **new and innovative real time R+G management system capable of optimising the interaction between the two grids**. The E-LOBSTER management system provided a unique platform for real-time energy flow management between rail, the grid and the energy storage system.

The system also takes into account the road electric vehicles, aiming at the optimisation of the interaction amongst the three energy networks. The system increases the sub-consumption of the renewable energy locally connected to the distribution grid and the sub-consumption of the energy breaking of the vehicles. In this way, the system analyses the optimal charging strategy for electric vehicles.

Ultimately, the R+G Management system made the optimum use of the available energy of both grids. This unique innovative tool for assessing losses and energy consumption of power distribution networks and railway electrification networks has been validated through real data.

Figure 3: E-LOBSTER concept



As well as the aforementioned technical objectives, the E-LOBSTER projects also included the following steps:

- Designing the scale-up of the E-LOBSTER concept (feasibility studies) and defining a roadmap for the marketability and exploitation of the E-LOBSTER results through suitable business models.
- Analysing the current regulatory, standards and policy framework to identify measures for replication.
- Preparing a "Best Practice" handbook, to guarantee the appropriate cybersecurity required to protect the data.
- Creating a unique network of stakeholders and project supporters to help foster the marketability of E-LOBSTER solutions.

MAIN FINDINGS AND RESULTS

The project developed and validated - at TRL7 - a **smart Soft Open Point (sSOP)**. The system is mainly comprised of the following enclosures:

- Rail DC-DC converter 200kW rating
- Energy Storage System (ESS) DC-DC converter, 200kW rating
- Low-Voltage (LV) Grid, DC-AC converter 80kVA rating
- Low-Voltage (LV) Isolating Transformer AC-AC, 80kVA rating.

The second hardware element developed is the **Battery Energy Storage System (BESS)**, with a total maximum power of 200kW. The system has the following specifications:

- Technology: Lithium-ion NMC
- Number of racks: Three
- Total max power: 200kW
- Theoretical max energy: 237 kWh.

XOLTA (the battery systems department of Lithium Balance) has developed a unique, cost-and-energy efficient battery storage system that is fully outdoor-capable without the need to install bulky, air-conditioned and expensive containers.

The system was developed for harsh environmental conditions (high or low temperatures). The battery system was integrated with sSOP and it was managed by the R+G management system.

In addition, XOLTA also developed an intelligent method of battery energy management, which not only meets the needs of the E-LOBSTER project requirements but also extends battery system life.

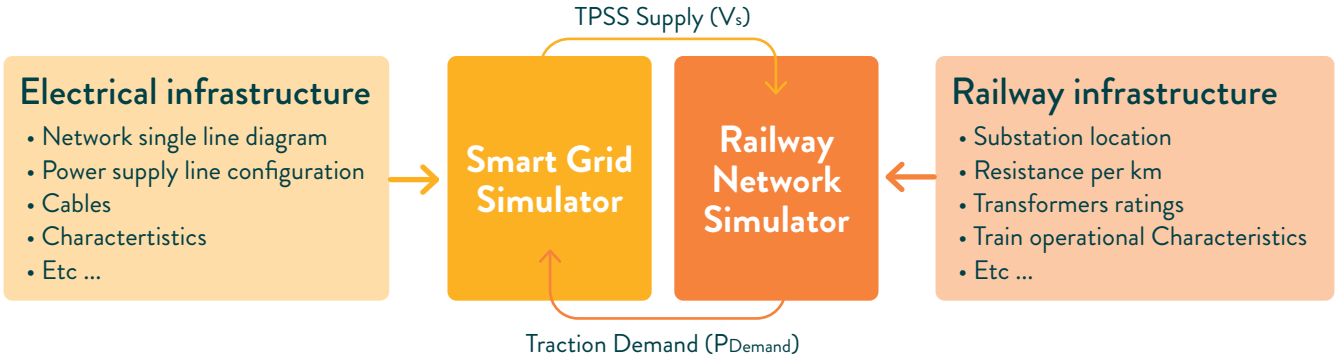
The **R+G Management System** can be divided into a hardware component based on an industrial PC, and a software component that allows the control of E-LOBSTER and to monitor the parameters through a dedicated graphical user interface.

Last, an **innovative tool** was developed for assessing the losses and the energy consumption in power distribution network and the railway electrification network. The tool has been validated through real data supplied by Metro de Madrid.

The **tool developed** can identify the highest source of losses in the network, via the data provided by the users, the equipment or the electronics installed in the line and other characteristics. The idea is to extract any excess of regenerative power from the railway that would be otherwise wasted.

Figure 4: Lithium Balance (XOLTA) modular battery system

Figure 5: Integrated distribution losses monitoring and simulation tool



From the E-LOBSTER system, the following features are possible:

- Increasing the efficiency of the breaking energy. It is possible to improve the recovery of braking energy by 10%.
- Depending on the frequency of services, the energy stored in the battery can be up to 4-5 MWh/day.
- This energy can charge, from empty, 40-50 large EVs (assuming 100kWh battery) or 100-125 smaller (hatchback) EVs (assuming 40kWh battery).

VALIDATION IN THE LABORATORY OF NEWCASTLE UNIVERSITY AND METRO OF MADRID DEMONSTRATION

The Smart Energy Lab located in the Urban Science building at Newcastle Helix has been used to validate and demonstrate the innovation technologies in the E-LOBSTER project. The Smart Energy Laboratory at University of Newcastle provides a connection to the physical electrical distribution Low Voltage (LV) network. The physical grid network, battery energy storage system and sSOP components have been combined with emulated behaviours for rail network using real-time data measured in Sacedal substation in Metro de Madrid to demonstrate the applicability of the solution in different cases.

The main objective of the **embedded R+G Management System is to increase regeneration braking efficiency in railway network and to support the LV grid in accommodating excess generation from, for example, renewable resources and excess consumption from EV charging points**. In this concept, the energy management strategy in the E-LOBSTER project has been designed to distribute energy between three systems – grid, railway and battery storage.

The R+G Management System determines whether there is available braking power on the rail network, as well as whether excess consumption is demanded, for example from EVs, from the LV grid or whether renewable resources are generate a surplus of energy. It means that the R+G Management System has been developed to switch intelligently between the following two modes, based on availability of braking energy:

1. **Rail + Grid mode**: Rail provides regenerative braking power to BESS and the LV grid (depending on if the LV grid requires power).
2. **Grid mode**: Power is exchanged between BESS and the LV grid, according to the consumption and generation power levels on the grid side. In this condition, there is no braking power available.

The effectiveness of the E-LOBSTER solution for accommodating excess demand such as EV charging stations, and to support grid while excess energy from renewable energy resources, has been demonstrated in the tests conducted in the Newcastle Lab. These successfully validated the system and provided good insights into the E-LOBSTER solution for the next phase of project.

METRO DE MADRID DEMONSTRATION

The demonstration of the E-LOBSTER innovation technology took place in the Metro de Madrid[2] premises, where optimisation of the energy distribution network is vital. Specifically, the E-LOBSTER system was installed in the Sacedal substation, where the traction power supply serves two sections of Line 9 and also the Sacedal depot.

For testing purposes, the output of the E-LOBSTER system was connected to the local Low Voltage (LV) grid system of the substation. The main goal was to use the excess of energy generated when the train is braking to feed the internal LV grid of the Metro de Madrid. In practice, the E-LOBSTER systems transforms a conventional substation into a reversible one.

2 Madrid Metro statistics: more than 300 stations, almost 300 kms of rail network with an average of 14 million passengers per year

The demonstration consisted of a smart Soft Open Point (sSOP) with the rail converter connected to the rail network, the grid converter connected to a local low-voltage grid and the ESS battery converter connected to the battery storage system. During the demonstration, the project team undertook measurements to assess the operation of the system. The team captured the input voltage to the rail converter, the input DC current to the grid converter (Ig DC) and the input current to the battery converter (Ib DC). The conditions for testing were set with a power rail reference up to 50kW, grid reference power up to 10KW and chose a setpoint for the rail voltage at 652V.

The system was also demonstrated with testing conditions set with a power rail reference up to 100 kW, Grid Reference power up to 10KW and chose a setpoint for the rail voltage at 655V.

REPLICATION OF THE SYSTEM

During the project, a preliminary design for a full-scale application of E-LOBSTER was performed. E-LOBSTER can be adapted to substations and lines with different features, not only where it has been demonstrated but also in many other situations. In addition to being deployed in metro lines in Europe and beyond, the whole concept can be replicated, if the necessary modifications to adapt the system to local specificities are applied.

Preliminary designs of full-scale E-LOBSTER deployment have been carried out by considering the following cases:

- Other metro locations
- Tramways
- Regional trains
- High-speed railways

REPLICATION IN OTHER METROS

The E-LOBSTER system can be replicated on other lines of Metros de Madrid lines operating at 600V without any major modifications. The replication of E-LOBSTER in metro in the range 600 - 750V nominal does not require major changes, and can be carried out by fine tuning the system installed on Line 9 of Metro de Madrid.

Situations where modifications may have to be made are as follows:

- Where changes to the number of carriages per train occur
- Where there are changes to the power flow to the external grid.

If the E-LOBSTER system is to be replicated on other lines of the Metro de Madrid operating at 1500V, modifications to the original system will be needed. The voltage of the DC-link in the sSOP can be kept at 750 V but the following aspects are expected to be modified:

- Rail Converter
- BESS Rating: The power and capacity rating of the BESS would need to be modified according to two factors:
  a. The regenerative power/energy expected from the train
  b. The requirements for power flow between sSOP and the local grid
- Grid Converter: Rated in line with rail and BESS-rating deltas.

REGIONAL TRAINS

Regional trains in most of the European countries operate at 1.5kV or 3 kV DC. Therefore, if the E-LOBSTER system is to be replicated for the regional train lines, certain modifications are needed:

- Rail converter
- BESS rating
- Grid converter (if rail/BESS deltas differ)

To be also taken into account:

- Number of carriages per train consist
- Power flow to the external grid.

TRAMS

Trams around the world operate at either 600V DC or 750V DC, with 750V being more prevalent in the modern system. If the E-LOBSTER system is to be replicated to a tram operating at 750V, no specific changes will be needed.

Figure 6: The E-LOBSTER system in real operation

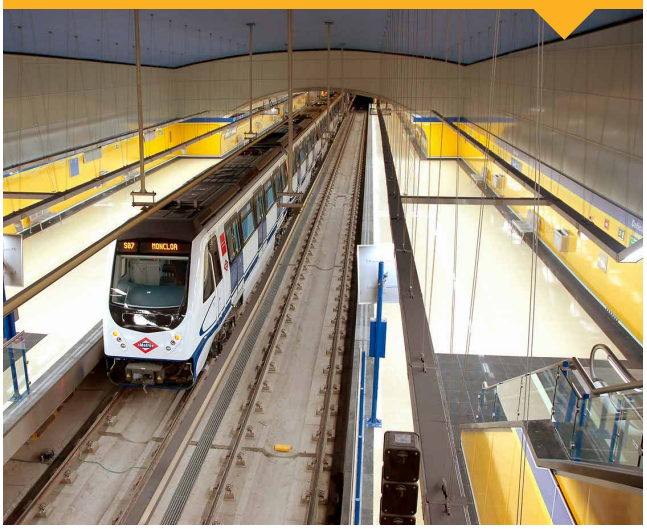
SPECIFICATIONS AND DEMONSTRATABLE BENEFITS OF THE SYSTEM:

Line 9 of Metro of Madrid is 39.4 km long, with 29 stations from Paco de Lucia to Arganda del Rey. The operating voltage of this line is 600V DC.

The benefits of the use of the E-LOBSTER system demonstrated in Madrid were:

- Electrical energy produced during braking, which is not being used by another train, can be used to feed other equipment.
- Energy consumption overall is reduced.
- Greenhouse gas emissions and the carbon footprint are reduced.
- Braking resistors use is reduced as tunnel temperature and ventilation required are reduced.
- The infrastructure of the station does not need to be modified, the normal functioning and operation of the substation is not affected and the system can be connected and disconnected as and when required.
- System operation does not interfere with the installation, with the capacity to disconnect automatically if required, guaranteeing the current reliability and availability ratios of the traction substation.

It should be noted that E-LOBSTER can also be used for **EV charging stations**, as the **battery can also support EV charging, while being replenished by train braking**.



CONCLUSION

The E-LOBSTER system has been successfully validated and demonstrated in real-world condition at TRL6 by proving the potentialities of the overall system that - through some shared assets (sSOP and BESS) between the power distribution grid and the transport network - is able to reduce energy losses both at distribution network level (currently around 5%) and at railway electricity level (currently around 8%). This is thanks to a proper R+G Management System that is capable of exchanging electricity between the two grids. This sees mutual benefits of a reduction in losses and increased grid stability.

Some technical and non-technical achievements should be highlighted following the conclusion of the project:

- *Optimal energy management, able to drive synergies among the power distribution and transport grids.*
- *Demonstration of the stable and secure operation of smart grids integrating variable energy sources, with a high potential for integrating larger shares of renewables in the future EU market.*
- *Reductions in losses.*
- *High potential for replicability in different contexts (such as metros, trams, regional railway, high-speed railways).*
- *Support to ongoing policy developments in the field of the design of the internal electricity market. Also, supporting energy efficiency policies in electrified transports and demonstrating new schemes for their 'local smart' contribution to the power distribution network management.*

Among the major lessons learned from the project, for the last item it is worth mentioning the importance of the policy framework and the need to pay particular attention to the authorisation process for installing the system, according to the specificities of the local contexts.

VALUE PROPOSITION OF THE SYSTEM

- Enhances network resilience, capacity and power quality
- Enables the connection of EV charging infrastructure
- Enables the integration of sources of renewable energy generation
- Reduces the cost of energy consumed to charge EVs
- Provides real-time optimal management of the energy flows through the controlling platform
- Reduces power losses and subsequently overall costs
- Provides opportunities for decarbonising urban and extra-urban mobility.

THANK YOU TO OUR PROJECT PARTNERS

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Find out more at https://www.e-lobster.eu/

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UITP ADVANCING PUBLIC TRANSPORT

Rue Sainte-Marie 6, B-1080 Brussels, Belgium | Tel +32 (0)2 673 61 00 | info@uitp.org | www.uitp.org