ETALON

D6.1 Analysis of the Economic Models for for Energy Harversting System

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1 INTRODUCTION

1.1 BACKGROUND

The present document constituted the first and the only deliverable of the WP6 - D6.1 “Analysis of the Economic Models Energy Harvesting System” - in the framework of the project ETALON, which is a Shift2Rail project complementary to X2Rail-1 and X2Rail-2.

ETALON focuses on the adaptation of energy harvesting methodologies for trackside and on-board signalling and communication devices, being the project scope divided into two work-streams.

The WP6 and the D6.1 correspond to the second work-stream focuses on the development of competitive energy harvesting solutions for enhancing trackside object controller deployment, with the vision to minimizing trackside infrastructure, especially cabling. This work stream contributes to the X2Rail-1 WP7 “Smart wayside objects” that focuses on the development of autonomous, complete, intelligent, self-sufficient smart equipment (“boxes”) able to connect with control centres (e.g. interlocking) and wayside objects and communicating devices in the area (by radio or satellite), but also e.g. with on-board-units and traffic management systems (TMS).

One of the technical goals of the ETALON is to demonstrate the efficiency of proposed energy harvesting (EH) solutions for trackside Object Controllers, ensuring appropriate safety considerations.

As a result, ETALON will specify and develop energy harvesting solutions to support trackside object controllers which are economically viable and suitable for application, particularly considering modern radio communication requirements and safety critical aspects.

The D6.1 is an output of the Task 6.1 “Scenario Building for Economic Modelling” of trackside energy harvesting systems for object controllers and Task 6.2 “Economic Models for Energy Harvesting Systems”.

1.2 PURPOSE OF THE DOCUMENT

Rail transportation systems, including freight train, commuter rail and subways, play an important role in people’s daily life and also provide substantial supports for the economy (Lin et al., 2014). Relevant trackside infrastructures are fundamental both for the current and the future railway systems in order to improve the quality of services, the safety systems linked where the electric infrastructures are the core of the overall system and reliable and low-maintenance power supplies are essential prerequisites for several services (e.g. warning and signal lights, track switches, grade crossing signals, track-health monitoring systems, wireless sensors for monitoring and communication access points, bridge monitoring, positive train control systems and train position, etc.). Mainly in some remote (where electrical infrastructures are poor) or difficult to access area there is few deployments of because of lack of reliable power supply and low-maintenance battery[1]. For this reason, the increasing of demand for electronic trackside devices is an important driver for designing a cost-effective and reliable power supply solution for trackside devices themselves. Moreover, the EH systems will make the railroad more independent from national energy grid.

The present deliverable aims at (1) setting the basis for a well-grounded picture of the AS-IS market (i.e. status quo) and technical structure in the current European trackside energy systems, in particular energy supply of object controllers of field elements, in railway sector[2] for freight

[1] Some regions still only use railroad crossing signs at grade crossings and do not implement flashing lights, moving gates, or whistles (Lin et al. 2014).

[2] The Etalon project will analyse also the on-board systems, but according to the DoA the economic focus will be only on the trackside one.

and regional lines and at (2) identifying the possible options for future trackside energy harvesting (TEH) system by capturing the market trends acting as backdrop for the specification of a sound TO-BE market proposition (i.e. for TEH). Indeed, railways and wayside infrastructure are continuously exposed to train loads, making it possible to extract energy from them that, through specific technologies, can be transformed into electrical energy. This paper deals with the economic analysis of energy harvesting (EH)[3] technologies for railways, identifying the technologies that are being studied and developed and the cost functions for both AS-IS and TO-BE scenarios. By doing this, the deliverable investigates the opportunities to be seized by main stakeholders involved in the European railway ecosystem to implement in a fruitful energy harvesting system.

The main challenge of D6.1 is to analyse whether, when and how the existing trackside energy system with its infrastructure – which is costly for many EU countries – can be replaced by a more environmental friendly[4] and economically efficient technology by using renewable resources. Indeed, using cables and providing energy with the current systems has high costs for IMs due to several factors as cables theft[5], high cost of maintenance (e.g., high long run maintenance costs), high costs in some difficult to access area, etc. Due to these hurdles, railway enterprises that own the network infrastructure can be interested in the advent of new energy power solutions from renewable resources in order to obtain greater benefits, both in terms of cost reduction, savings, efficiency improving and reduction of pollution.

The methodological approach of the deliverable entails an initial identification of the current system of energy system and a market analysis of the main systems deployed in European countries. As second step, the document sheds light on the future candidate of TEH systems with their potential market driving forces enabling the migration in this new 'green' scenario. In addition, a first analysis of main external stakeholders has been conducted and some contacts with them could generate an added value to our extent to be as much as possible exhaustive in building the right infrastructure.

Finally, we build a theoretical virtual route where to simulate the results of the economic models and provide insights useful for the Partners and external stakeholders in depicting the pros and cons in the migration from current system to the new one. The final results of this model could be a functional form and not necessary a final figure with the exact cost of current and future solution. This WP and this deliverable, that will be concluded at M8 of the project, would provide more a sort of a financial methodological approach to be used for future computation, since at this stage of the project will be very difficult to get and have some real data as input of economic model, where the future solution for TEH are not still developed.

In doing this approach, useful and needed input will be the WP4 draft paper available at M4 that will provide insights of the state-of-the-art and of the future TEH. These will be inputs for building appropriate economic models.

With the intent to extensively cover the key aspects relevant to a successful development of the project, the present deliverable is structured into the following chapters. Chapter 2 sets the methodology approach we used for the project. Chapter 3 will draw the AS-IS scenario where the *status quo* of the current energy system is depicted and the main actors (i.e., suppliers of equipment, railway enterprises, etc.) are analysed to define the market dynamics. This chapter

[3] "In the area of renewable energies, besides the major energy sources (hydro, solar, wind, waves), energy harvesting has recently been considered on a micro scale, where it is possible to generate electricity from small energy variations, such as thermal gradients, pressure, vibrations, radiofrequency or electromagnetic radiation, among others" [30].

[4] Indeed, most electrical energy production uses fossil fuels as energy source, leading to increasing environmental effects, as well as making economies dependent on fuel costs.

[5] Cables can be of two types: copper cables and aluminium cables. The first are more attractive for thief and more costly. Today price of copper is quoted around 5,750 per ton, while for the aluminium is around 2,400 per ton.

will dive also into the identification of the gap analysis to depict market forces – either endogenous or exogenous to railway operators – triggering the migration towards THE. Chapter 4 will go in deep on the future TEH systems and their infrastructure and equipment. Chapter 5 provides a description of the architecture of the energy systems and the main scenarios selected for the economic analysis while chapter 6 highlights some qualitative economic insights of these selected scenarios through a SWOT analysis and a brief market analysis of the stakeholders involved in the migration towards a new energy system. Finally, chapter 7 contains the definition and the description of the techno-economic models where the counterfactual scenario (AS-IS) will be the basis for the economic analysis with respect to the TEH scenarios (TO-BE). A final guide book has been provided in the chapter 7 to be used together the spreadsheet as the final output generated by the WP6. Chapter 8 provides the conclusion.

1.3 Definitions and acronyms

Acronym	Meaning
CA	Consortium Agreement
CEN	European Committee for Standardisation
D#.#	Deliverable number #.#
EC	European Commission
EH	Energy Harvesting
FE	Field Element
GA	Grant Agreement
GSM-R	Global System for Mobile Communications-Railway
IXL	Interlocking
IM	Infrastructure Manager
LEC	Levelised Energy Cost
LCOE	Levelised Cost of Energy
MTB	Main Technical Building
mW	Mill watt
MW	Megawatts
M#	Month number #
OC	Object Controller
OCC	Overnight Capital Cost
PMO	Project Management Office

QM	Quality Manager
RU	Railway Undertakings
SC	Steering Committee (SC)
SWOC	Smart Wayside Object Controllers
TB	Technical Building
TCO	Total Cost of Ownership
TEH	Trackside Energy Harvesting
TMS	Traffic Management Systems
TMT	Technical Management Team (TMT)
W	Watts
Wh	Watts per hour
WP#	Work Package number #
WPL	Work Package Leader (WP Leader)
WSN	Wireless Sensor Network

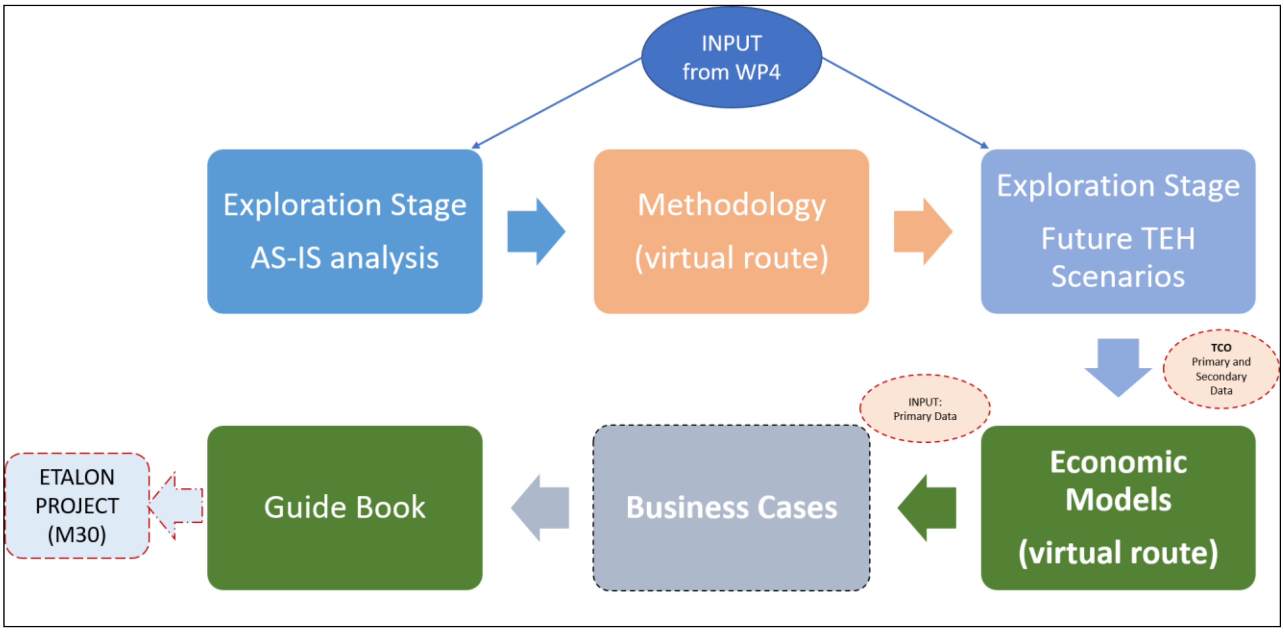
2 METHODOLOGY FOR ECONOMIC MODELLING

The present work would purpose to build some economic models for energy systems that would represent 'generic' examples to be exploited as in some more realistic cases. With the aim to reach this goal, our approach has been, first, to define a methodology for building the economic model and, as a consequence, to identify the appropriate functional forms to be implemented through a simulation approach in order to get generic results with implication of policy.

It should be important to underline that since our results has to be delivered by Month 8 (M8), that is in the initial part of a 2.5-year project, our model would not provide final results but, instead, a methodological approach that can be used during the following of the project when more information and more clearness will be reached mainly about the future TEH systems to be really implemented. Our approach has been consisted in performing the analysis including a wide range of possible scenarios in some cases making generic assumptions instead of analysing in detail a final candidate that will be chosen by the end of the project. In doing this, our aim was to define the main parameters and variables, inputs for the economic models, that will be stressed during the following period of the project. Technical feasibility and economic viability will be the basis for the model construction.

After a set of face to face (F2F) meetings with the Partners of the Etalon Consortium, we have defined the following 'logical flow' of steps that will be the basis for our work (Figure 1).

Figure 1. Logical flows for WP6 methodology



(*) Source: ETALON Consortium elaboration

The 'exploration' stages (AS-IS and TO-BE) have been the first step where we collected all the technical information about, the current energy systems with related infrastructure and the future THE systems. The output of this stage is a well-defined list of equipment, costs and technical requirements which are the essential basis to build an economic model with both primary and secondary data.

The 'methodology' step is to define the way to build a theoretical techno-economic model to be used in the future of the project by making empirical tests about the deployment of different energy harvesting systems compared with the current mains powered one. Hence, our approach has been to define a theoretical model based on some assumptions (i.e. technical hypothesis) with a selected number of variables and technical parameters useful to define a 'virtual route' where we can simulate the results of the model. This route will be constituted by a set of well-defined infrastructures and equipment in a specific area where geographical variables will be considered in order to adapt the model to different country characteristics.

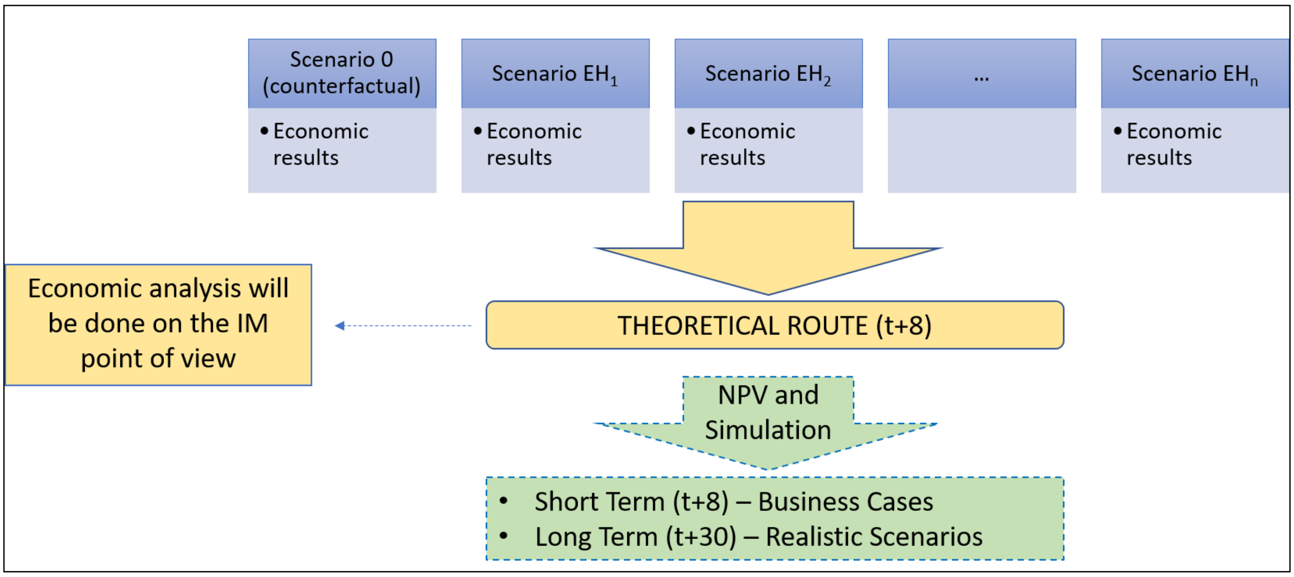
The 'economic models' step will provide our main results. Our economic model will be based on the side of costs and savings[6], because for trackside we did not identify any relevant revenue streams from the infrastructure managers (IM) point of view to be analysed with particular attention and that can affect the migration to a new paradigm of energy powering. In other words, the most important input for our analysis is to identify well-defined total-cost-of-ownership (TCO) for deployment of both the current and future systems. A stakeholder analysis will clarify in the initial stage of the project the role and relevance of each group of stakeholders. The economic model would not be exhaustive in all the results since it would be difficult to have a clear and precise idea about the future deployment of energy systems at this initial stage of the project.

Concerning to the 'business cases' box, after building the economic model, if primary data will be available and sufficient, we would apply the economic models for different use cases in different EU countries and highlight the main differences.

Finally, a 'guide book' of the simulation tool and model will be realised for Partners to be used by Partners themselves to exploit the economic models in t+30 when more real data and information will be available.

To build our model, we use a bottom-up approach, where we started from primary and secondary data, get from Partners and other secondary sources (e.g. official reports, white paper, etc.) to draw, as much as possible, the contour of the theoretical virtual line. Consequently, we have selected some candidate technologies that could be used, alone or jointly, in the building of the route (Figure 2). In the following chapters, we will describe the selected EH technologies.

Figure 2. Methodological approach for Economic Modelling



(*) Source: ETALON Consortium elaboration

The figure shows the scenario 0, the counterfactual one, that will be compared with the future EH_i (where i=1,2,3,…,n) scenarios with different selected technologies with the scope to generate economic simulated insights at M8, that will be used also in the following period of the project

[6] Also welfare and environmental analysis will be considered but in a more qualitative way.

(t+30) when more data about trackside architecture and requirements for the feasibility will be available.

In the next sections, we are going to describe the process for building the virtual route with the identification of the main components and variables to be used for it.

2.1 Virtual Route Model

To properly assess the economic advantages or disadvantages of the energy supply for the trackside equipment in both AS-IS and TO-BE scenarios, it is not sufficient to analyse the unitary cost of an equipment due to the characteristics of the implementation in a railway line.

The unitary cost of energy supply for an object controller could vary depending on the following parameters: type of line (regional, high speed line, main line, etc.), the redundancy and reliability required for the installation. Nevertheless, the overall cost of the installation will be impacted by more parameters, such as: the length of the line and its sections, number of elements to control, complexity of the layout, climatic conditions, cost of connection to public network, topology of the line and availability of power connections (Table 1 and Table 2).

Table 1. Parameters affecting OCs unitary cost

Unitary Cost for energy supply of OCs depends on:	Explanation
Type of line (HSL, mainline, regional, etc.)	Usually for HSL and mainlines increased reliability, availability and performance of the equipment are required which impact on cost.
Redundancy factor	The duplication of critical components or functions of a system leads to increased total cost of equipment.
Reliability required for installation	Usually the reliability increase is archived implementing redundancy.
Traffic density	The higher is the traffic density the higher is the number of operating hours per year per device, and consequently the overall life cycle is shortened.

(*) Source: ETALON Consortium elaboration

Table 2. Parameters affecting OCs total cost for a route

Total cost of deployment OCs depends on:	Explanation
Length of the line and its section	The total amount of wires needed for the installation will depend on the length of each section to be covered.
Number of field elements controlled	More FEs means more boards to control them for each OC (OC is modular and it is possible to add or substitute boards very easily), as a consequence, higher costs for equipment and for energy power, even if the marginal cost of powering energy to additional new boards should be very low and, perhaps, it could be indifferent for an economic analysis.

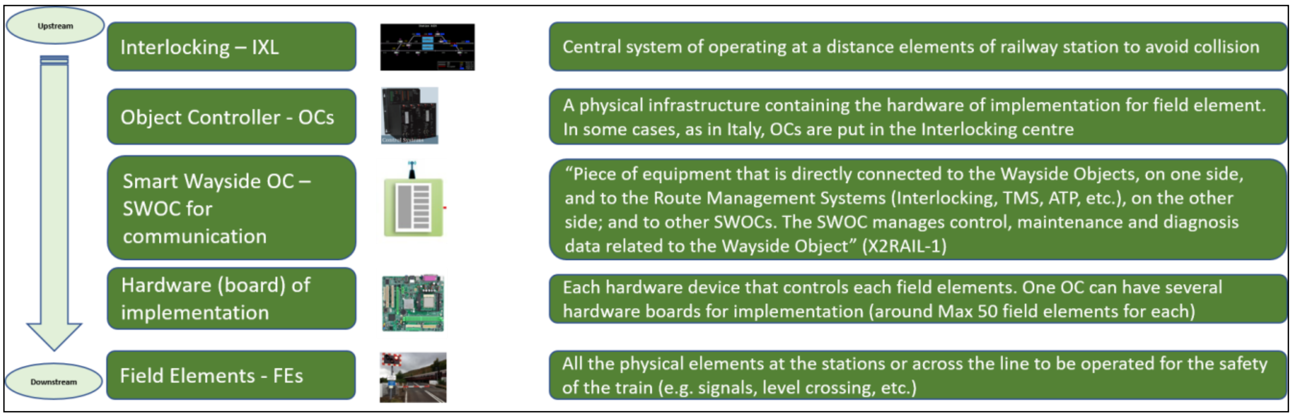
Complexity of layout	Related to the previous one, the complex layout will require more complex installation with higher number of field objects and/or the necessity to cover remote areas with difficult access.
Climatic conditions	Harsh climatic conditions require better protection systems for the equipment (shelters, cable duct, HVAC installation, etc.)
Cost of connection network	A fee for the connection to public network.
Topology of the line	Tunnels, mountains, remote areas, areas without electric network coverage, etc.
Availability of the power connections	When not available, the alternative power sources shall be implemented.

(*) Source: ETALON Consortium elaboration

To create an appropriate economic model, that will allow to take into account all the required parameters, the 'Virtual Route' methodology has been chosen. Virtual route represents a hypothetical railway line with several variables and parameters that can be entered by the user to define the main conditions of the calculation. After processing the introduced parameters model will export the output corresponding to the economic viability to switch from traditional approach for energy supply of the object controllers to energy harvesting solution. For this reason, CapEx and OpEx costs for the current scenario - traditional energy supply from electric network, and for the future scenario - energy harvesting solution, will be found.

Before describing the methodology more in deep, we would set up a common terminology to be used for the rest of the model (Figure 3).

Figure 3. Terminology for the Economic Modelling Approach



(*) Source: ETALON Consortium elaboration

The previous terminology highlights the main elements from upstream to downstream of the railway control system. The interlocking (IXL) represents the centralised systems that operates to control and manage the railway tracks to avoid collision and guarantee the safety of trains.

Object controllers (OCs) are the intermediate physical interface between interlocking and final object elements, called here field elements (FEs). OCs are deployed along the track of a route and they are modular elements with many hardware (boards) of implementation that control the final FEs. OCs are not standardised elements and every supplier can provide different type of these. In some countries and in some areas (as in Italy), we can have OCs together with the interlocking system.

SWOC concept is supposed to be the next evolution of OC performing the same main functions but moreover providing some advantages, for instance, wireless communications between trackside and control centre, reduced power consumption and possibility to be powered by an energy harvester, major independence from interlocking system, etc (X2Rail-1 D7.1).

SWOC can control just one or several FEs (as axle counters, track circuit, sensors, signals, etc.)[7]. SWOC can have also a predictive maintenance goal (e.g. providing the status of the elements) in order to "reduce the time dedicated to maintenance tasks, or allocate the maintenance task in the most adequate time slot, in order to affect the train operation the minimum possible time" (X2RAIL-1, 2017) allowing the track have more time available and, as consequence, the capability could be increased. Predictive maintenance model permits to have a more effectiveness management system and monitoring system in order to reduce the 'direct' (e.g. cost of substitute equipment, work) and 'indirect' (e.g. cost of interruption of a line, delays for trains, etc.) costs from maintenance preventing failures before they happen and avoiding critical interventions, mainly if compared with the current systems where in order to repair some infrastructure, the interruption of the lines or working at night are the common way to manage these criticalities.

Finally, the FEs are the final objects that should control the trains along the line that are managed and controlled by OCs and/or IXL.

Hereafter, we provide a list of the main FEs (X2RAIL-1, 2017):

- Audio Frequency track circuit
- Relay track circuit and detection systems
- LED Signal
- Incandescent lamp
- Halogen lamp
- Point Machine
- Heating for switching/points
- Axle counter
- Level crossing
- Motor for barrier
- Switch

Every element (i.e. IXL, OCs, SWOC or FEs) has own power consumption that can affect the final decision to implement new systems of EH or not, based on the economic viability point of view. For a well-defined architecture of the system, we remind to the next chapters.

We should keep in mind the power supply to provide local energy to SWOC needs to have energy storage with batteries and capacitors and environmental conditions.

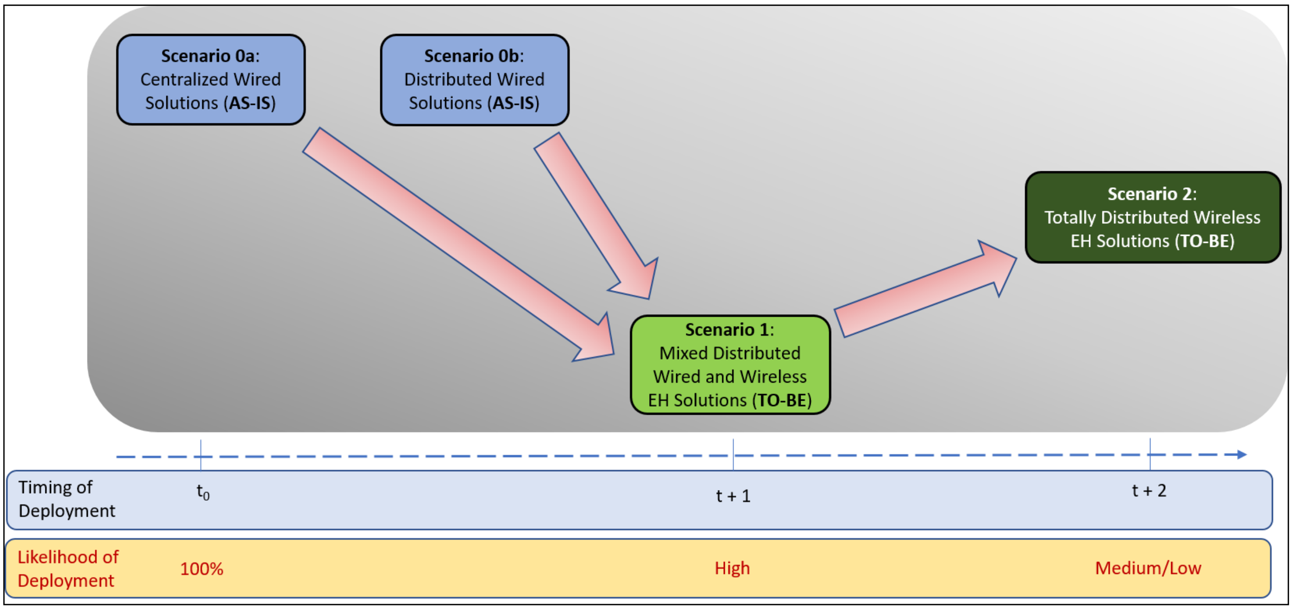
2.1.1 Definition of high level scenarios methodology

Starting from this terminology, the first step of our process is to identify the 'high level' main scenarios. The aim of WP6 is to provide economic modelling for energy solutions, as a consequence, we will consider all the objects affecting power consumption, in particular, we will

[7] SWOC will provide also wide information about the status of the elements, allowing to create predictive maintenance models, able to prevent failures before they happen, avoiding critical interventions and timely interventions (X2RAIL-1, 2017).

focus on EH systems for railway communication solution. First, we have outlined three macro-scenarios with a hypothetical timeline and with different likelihood to be really deployed (Figure 4). From these, we will consider different more detailed sub-scenarios that will be described in next chapters.

Figure 4. High level description of macro-scenarios for the Virtual Route approach

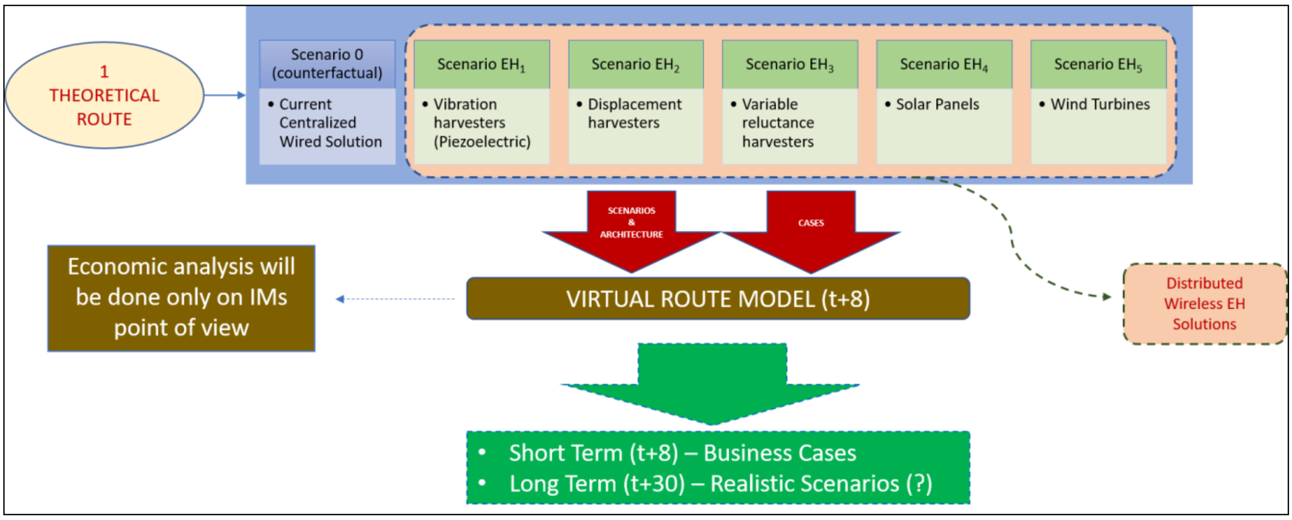


(*) Source: ETALON Consortium elaboration

Scenario 0 that corresponds to AS-IS family will be described better in the next chapters and is actually implemented. It can be characterised by two types of deployment. The first is when object controllers (OCs) are connected usually in a centralized way through cables with interlocking and field elements (i.e. scenario 0a) where OCs are usually form part of interlocking installation. The second is when, for some routes and/or in some areas (e.g. rural), we can have also a more decentralised solution where the OCs are installed in some distance from interlocking (station) and powered by local power supply systems, again with wired solution (i.e. scenario 0b). Both options can be implemented along the same railway route depending on its the topological characteristics, even if the scenario 0b can be more likelihood in rural area. Moving from this, the scenario 1 represents a hybrid scenario and also an 'incremental' change from the scenario 0, more likely to be deployed in the 'short-medium term'. Starting from the logic of 'distributed' wired solution we should consider a gradual migration towards a TEH solutions, where some locally power supply systems will be substituted by locally/distributed EH solutions. This could be the more viable scenarios, with the highest likelihood to be deployed. Finally, scenario 2 would be the most environmentally and economically viable but, in some cases, less feasible scenario. Indeed, it seems difficult to think about the possibility to have only wireless EH systems providing energy to OCs. Many strict requirements for safety are needed in case EH systems cannot provide more energy and they need to have a seamless power sources. Another reason is that, in some cases, EH systems cannot provide enough energy to OCs. This scenario can be seen as a 'disruptive' change, where only EH solutions are deployed in a specific route/routes by using one or more EH systems. This scenario could be more likely to be implemented in the 'long run' and it can be divided in a subset of two sub-scenarios: the first in which one EH provide energy to one OCs (scenario 2a) and, the second in which one EH can provide energy to more OCs (scenario 2b), similarly to the AS-IS scenario 0 architecture.

By considering these macro-scenarios, the main EH systems selected for our purpose are shown in the Figure 5 and they will be described better in next chapters according to their own technical characteristics. In particular, the EH technologies we will consider in our model are: vibration harvester, displacement harvester, variable reluctance harvester, solar panel, wind turbines. All these contribute to define scenarios and use cases, because in some cases, with geographical-topological-capacity conditions, we cannot have only one EH solution for the power generation, but more mixed technologies together. The economic analysis will be done only on the IM point of view. The following EH systems will be considered for different scenarios and use cases to build the virtual route model.

Figure 5. Type of TEH systems selected for economic model



(*) Source: ETALON Consortium elaboration

3 STATE-OF-THE-ART: AS-IS SCENARIO

One of the starting point for our economic analysis is to define the current architecture of the energy systems deployed in the main EU countries, that will be the reference for the final counterfactual analysis of economic modelling. The rationale of the migration towards new ways of supplying power to OCs and FEs are to decrease the km of cables, to improve the environmental quality and to decrease the total costs of ownership from deployment and maintenance energy supply system, that can be translated in a saving of money for IMs.

In this chapter, we analyse the technical overview of the current trackside energy system and some economic implication.

Today's field-element controllers, i.e. OCs, are designed and developed by each supplier in a different way, since there is no a standardised model for them. They are connected with copper – at least to be connected to the required power supply. The connection to Interlockings, Radio Block Centre, Automatic Blocks, Train Management Systems (TMS), etc. follows either rules or techniques of manufactures themselves or requirements given by railway authorities, not yet harmonised.

Currently trackside objects are interfaced to control systems in one of two ways:

a) Where trackside objects are fairly near signalling equipment, tail cables to individual objects are used;

b) Where trackside objects are geographically distributed, Object Controllers (OCs) are placed near the trackside objects, controlling a number of them, with a data link back to the signalling equipment [ref. S2R MAAP].

The current situation has several disadvantages that motivates the necessity to shift to different self-sufficient approach to energy supply (cost of cabling, especially in remote areas, cable theft, complex and costly changes associated to track layout changes, distance limitations, etc.)

The following chapters will describe the current infrastructures with their degree of relevance with a comprehensive evaluation of costs.

3.1 TECHNICAL AND ECONOMIC OVERVIEW OF THE CURRENT TRACKSIDE ENERGY SYSTEM

In order to develop a THE solution, consisting in a unit that can be installed in stations or along a railway line and able to feed object controllers, D2.1 established a list of theoretical assumption and technical requirements to be considered in our model. From these requirements,

3.1.1 Infrastructure and Equipment

The present infrastructure includes the following elements:

- Technical building (TB) close to the trackside (small TB, about 50-100m^2, in 20-40 m from track, feed from a currently deployed electrical network, and connected with optical fiber to interlocking and wayside objects).
- Inside this technical building there are rack with object controllers which represents interlocking modules. Each module is able to control up to 50 objects.

As depicted in deliverable D3.1, currently, all field elements including signals, track circuits, level crossings, switches, eurobalises are connected using a wired communication to the object controller, from there it goes to the interlocking which processes and forwards the received data to the control centre, and the other way around, the command generated in control centre or by the interlocking are transmitted downlink to the trackside objects (D3.1).

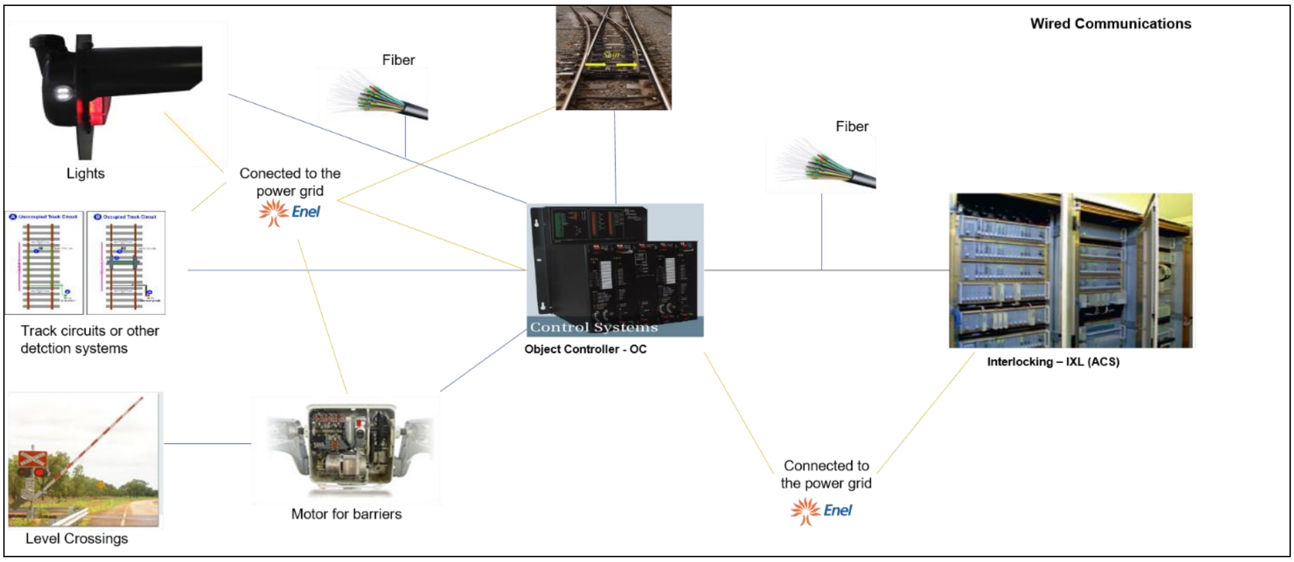
In particular, the current infrastructure for object controllers is characterised by the following main equipment:

• Object controllers, represent an interface between Interlocking and wayside objects. We consider both object controllers for energy suppling (wiring) and for communication (fiber optic wiring, from Interlocking to Object Controllers, Object controllers to wayside objects). Actually, objects controllers control also: lights, track circuits, axle counters, switches and level crossing barriers mainly. In ERTMS L3 track circuits, axle counters, lights will be removed, so future object controller will basically control switches and level crossings. They can:
    - Receive from objects: state of the object
    - Send to objects: commands (required position)
    - Send to interlocking: data about elements state

Interlocking knows all trains position and wayside objects position on the section. Interlocking communicates with others interlockings and with the command center

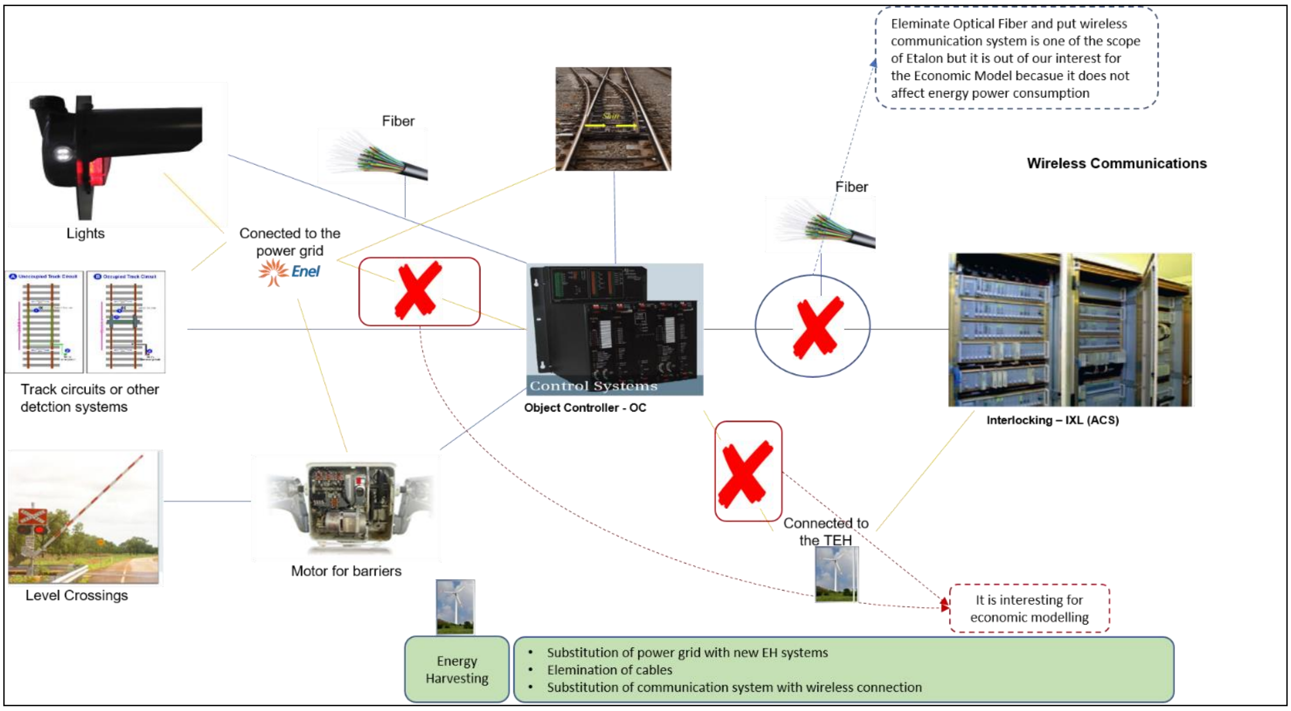
The following Figure 6 shows the architecture of a typical infrastructure for object controllers, while Figure 7 shows what is the aim of ETALON project and, in particular, focusing on some part of the architecture where cables can be eliminated (i.e. grid power and optic fiber cables).

Figure 6. AS-IS infrastructure: State-of-the-Art of the current architecture for trackside communication system



(*) Source: Ardanuy elaboration

Figure 7. Goal of ETALON project with respect to the AS-IS scenario



(*) Source: Ardanuy elaboration

In the Figure 6, two types of communications are depicted:

1 - communications between Interlocking (TMS, ATP, etc.) and object controllers realized by fibre optic and SDH protocol.

It is also should be mentioned that the interlockings are connected between each other through fibre optic cables as well.

2 - communications between object controllers and trackside objects using proprietary solutions not standardized generally with copper cables. Every supplier uses own bus and own protocol due to security and safety purpose (for example: duplicate transmission channels, security protocol, different protocol simultaneous transmission, etc).

The communication between control centre (Interlocking, TMS, ATP, etc.) and controlled devices on field shall ensure continuous transmission to provide high availability, detect failures and to supervise electric parameters (to forecast possible needs). ETALON will investigate on the possibility to provide the energy harvester able to feed the radio communication solution able to provide a carrier for these communications.

Most long-range connections of field elements to the central device like Object controller or IXL do not cross distance range of 10 km. Majority of connections for such applications are in the range of 100 – 3000 m. Even lower connection distances around 30 m are used for applications like Level-crossing warning board to controller or Level-crossing annulment circuit.

It is important a well appropriate description of a typical trackside architecture based on control centre and object controllers and the different types of equipment installed along the line. There could be some advantages from concentration of the electronic equipment in a control room (e.g. availability and reduced maintenance costs) and equipment should be installed along the line (e.g. mostly switches and level crossings in view of the future removal of the track side detection systems and signals). The connections between object controllers and control centre seems to be critical, because of costs of cabling, reduced reliability and costs for maintenance of electronic equipment along the line and substitution of cables in case of damages. But complete elimination of cabling seems impossible at the present stage: indeed, power required to operate switches. On the other hand, use of radio communication should eliminate cabling for communication and it seems also realistic to feed radio communication units through energy harvesting (D2.1).

Finally, we should say that wireless communication could be a very serious factor for power consumption, particularly when considering low power OCs with energy harvesters operating under SIL4 (Safety Integrity Level-safety standard 4) conditions.

3.1.2 Characteristics and power supply of SWOC

Power consumption is one of the most important consideration to be done for SWOC and, in general, for OCs and FEs, in order to make all these elements "self-sufficient" in energy, that is, when energy is produced locally and not distributed from a central power plant with cables. Indeed, the goal of ETALON project is to decrease the needs for power cabling. It is important to estimate the needed power for all these elements in order to draw the right architecture for future TEH systems, if we would consider a centralised, decentralised (integrated solution) or mixed model of power supply. This can depend on the demand of energy. High demand of energy could imply a centralised model with one harvester providing energy for several OCs and FEs. On the other side, low demand of energy could have a decentralised model with different EH systems for different OCs and FEs (X2RAIL-1, 2017).

From this point, we would synthetize our analysis on the power consumption for OCs and SWOCs. Power consumption for existing OCs is around 10-20 W and expectation for the future is that this value cannot increase, if anyone, it could and should decrease with improvement of technologies and research in this field. If we add a wireless communication (small radio transceiver with a range of 1-2 km) the power consumption increases around +10 and +50 mW, when idle or active, respectively and it depends also on the type of technology (e.g. GSM consumes 6W).

In our project we are not interested in the FEs, so the analysis of power consumption for FEs will be not considered.

As mentioned before, future improvement of technologies will permit to reduce power consumption (e.g. in the case of 5G) because of more efficient algorithms, etc.

Self-sufficient energy equipment is a goal that requires also to have a guarantee of uninterrupted power supply for OCs and FEs. So, redundant power is needed and solution can be to put different power-sources (e.g. solar-wind, solar-piezoelectric, etc. instead of solar-solar). The most feasible and simple way to have a redundant power is to have catenary together EH solution, since cables and power provided from national grid can guarantee the lowest risk of discontinuity of energy. However, also using energy storage through batteries can be another solution, but it depends also on the demand of energy, size and quality of battery, and cost of maintenance the batteries. Indeed, the cost for high battery could be very high. To store electrical energy there exists a two main solution: 'rechargeable batteries' (materials that via chemical reactions produce electricity during discharge/use. By applying an electrical current, the reaction is reversed, thus charging the battery. Because of self-discharge, batteries need periodic recharges) or 'capacitors/supercapacitators' (electrical component that is easy to charge, tolerates high electrical current, withstand many recharge cycles and there are essentially no maintenance needs, with a virtually unlimited cycle life but also much costly). Possible future improvement in the quality of batteries could affect considerably in the future the cost and the duration of these elements, becoming more advantageous for EH solutions (X2RAIL-1, 2017).

4 TO-BE SCENARIO FOR THE SYSTEMS

This chapter would be not a very exhaustive chapter about EH technologies and their technical characteristics, because we remind for more technical analysis in other deliverables as D3.1 and D2.1. This chapter would provide only a short list and description of the different energy systems developed in the market of energy both for generic application and for railway specific application (i.e. TEH) with a particular focus on some metrics of energy power and costs. From this high level analysis and from indication from Partners of the Consortium we will make a list of the most candidate technologies with their relevant variables and parameters to be used for the economic models.

The main input for this chapter will come from the contribution of WP4 where we remind for more detailed description.

4.1 EH SYSTEM AT A GLANCE

EH is a process of production of energy derived from external sources as solar power, thermal energy, wind energy, salinity gradients, kinetic energy, electromagnetic energy that is captured and stored in a capacitor or in a rechargeable battery to provide electrical energy for extensive applications including small autonomous electronic devices and wireless network sensors, as sensor networks, wearable electronics as clocks [31].

The EH generally refers to the capture and storage or direct use of ambient energy for several purposes. EH may or may not capture renewable energy. In the case of sunlight, the energy is renewable because it is sourced from the sun, a source of nearly infinite energy for the planet and the solar system. In the case of waste heat in an industrial facility may not be renewable since the processes generating the waste heat may not be renewable, however, waste heat may be a significant source of energy to be harvested.

Generally, the term “renewable” tends to be paired as “inexhaustible” in the context of energy, so the classification of harvested energy depends on this definition. In the sense that all processes are inherently inefficient (as stated in the second law of thermodynamics), there is theoretically an inexhaustible supply of waste energy and fractions of it may be harvested from inefficient processes [32].

Energy harvesting can be grouped in two different types according to the size of sources of energy:

- Macro EH, characterised by:
    - Solar
    - Wind
    - Hydro
    - Ocean energy (i.e. wave power)
- Micro EH (and that cannot be scaled up to industrial size), characterised by:
    - Radiation
        - Solar energy (Photovoltaics)
        - Electromagnetic radiation (RF source – rectifying antenna)
    - Thermal Energy (waste energy from heaters, friction sources, etc.)
        - Thermoelectric generators
    - Mechanical energy
        - Kinetic movement
            - On-board regenerative breaking

- Electromagnetic dampers
- Sag of rail or sleepers (electromagnetic, piezoelectric or magnetostriction physical principle)
- Mechanical shock of passing train – kinetic oscillator

▪ Variable reluctance harvester/wheels while passing over harvester (Magnetic induction)

▪ Vibrations – electromechanical resonators with a constant operation frequency

- Electromagnetics
- Piezoelectrics
- Electrostatics
- Magnetostriction

▪ Deformation, Pressure (mechanical stress and strain – piezoelectric effect)

▪ Human body motion

▪ Medium flow

- Micro wind turbine
- Ell generators (piezoelectric flags, strips, etc.)

o Acoustic

o Pyroelectric

o Biological and chemical sources

o etc.

This dichotomy and the 'discontinuous' nature of EH sources have some effects in the way the electric devices powered by energy harvesting are operated. Two can be the usual situations: the power consumption of the device is lower than the average harvested power, allowing the device to be operated in a continuous way; or the power consumption of the device is higher than the average harvested power and, as a consequence, operation is discontinuous and the time between operations is dependent on the stored energy of the device [30].

A further taxonomy of EH systems can be done by application point of view:

- Building & Home Automation
- Consumer Electronics
- Industrial
- Transportation
- Security

Hereafter, we make a brief indication of characteristics for main EH solutions taking in consideration also the information collected from X2RAIl-1 project.

SOLAR

- "Solar Energy Location, which determine the available light over time. Weather, e.g. amount of clouds and snow which reduce or cut off the light. Temperature, high temperature will reduce the produced power" (X2RAI-1, 2017)

WIND

- "Wind Energy Location, which determine the average wind speed. There is also a minimum wind speed for power production" (X2RAI-1, 2017)

- Fuel cells and combustion engine generators Fuel consumption, which depends on the size (in kW) of the generator/cell and the load" (X2RAI-1, 2017)

ELECTROMAGNETIC

Electromagnetic is one of the main physical principles for 'kinetic' Micro EH approaches, which generators operate based on electromagnetic induction, known as Faraday's law, that if an electric conductor is moved relative to a magnetic field, electric voltage will be induced in the conductor. For instance, Nagode et al. [33] proposed a vibration-based electromechanical system to scavenge mechanical energy wasted in dampers of railcars to provide electrical power for railroad. Also onboard applications such as smart devices that could be added to improve the efficiency of rail operation but which have been held back because of the lack of electrical power.

PIEZOELECTRIC

Piezoelectric is one of the main physical principles of Micro 'kinetic' EH approaches. The piezoelectric materials generate electricity when compressed. Piezoelectric materials generate electricity with the application of stress. Materials have the ability to generate electricity as a response to mechanical strain. Using piezoelectric to harvest vibration energy from humans walking, machinery vibrating, or cars moving on a roadway is an area of great interest, because this vibration energy is otherwise untapped (cleaner technology).

Several studies have been devoted to the field of piezoelectric power harvesting from human body motion for implanted devices and wearable electronics to regular or random displacements and vibrational energy. For instance, in 2008, Nelson et al. (2008) investigated the possibility of scavenging electrical power from railcar traffic by deploying piezoelectric and inductive voice-coil techniques. Nowadays the vibration generated by a train is seen as potential energy source to power wireless sensors for structural health monitoring or temperature monitoring purposes, for example. An investigation using a piezoelectric transducer attached to the bottom of the rail to scavenge energy from vibration induced by loaded and unloaded freight trains was presented in [12]. An energy harvesting device was designed and embedded into a sleeper to convert the vertical vibration induced by a passing train into a rotational motion and then into electrical energy in [13]. A numerical investigation about the potential to harvest energy from trackside vibration induced by high speed train in the UK was presented in [11, 14, 29]. Cleante et al. [29] develop also a model about how much mechanical energy can potentially be harvested from the vertical vibration of a sleeper induced by trains passing at different speeds. To achieve this, a model of a track structure was combined with a model of an energy harvester[8].

The report of Hil et al. [32] provides a description of the present state of the art in piezoelectric materials[9] and make also a techno-economic analysis of real data to assess the cost of energy for piezoelectric energy harvesters in roadways[10].

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[8] They find the total energy that could be potentially harvested is about 1.1 J/kg, at a frequency of 16.65 Hz, which correspond to a passing train at speed of 196 km/h, with a damping ratio of 0.007276.

[9] The majority of literature for piezoelectric materials is directed toward vibration, ultrasonic acoustic sensors, and transducers.

[10] They study the EH system from California roadways.

4.2 Some metrics of energy and cost for EH system

Hereafter, a selection of metrics has been done with the extent to catch some relevant information for the model.

Power and power density

This represents the maximum power output of module. Usually, power is defined with Watts (W) or Megaqatts (MW) or unit of energy per second[11]. Power density refers to an area or a volume. For instance, for the solar panels, power density might be in units of watts per square foot (or square meter)[12].

Energy and energy density

There are different ways to define energy. Usually, it is used Joules (J) for the energy while for the electricity is used watts per hour (Wh) to indicate how many watts are produced in one hour[13]. Also energy density refers to an area or a volume. In the report of Hil et al. [32] they provide an example of a different order to size of these metrics from piezoelectric roadway systems to power plant where vibration can generate 1 W, solar panel 100W and power plant 200,000,000 W.

Capacity factor

It represents the relationship of traffic volume to capacity factor is important for the consideration of power output for a roadway energy harvesting system. It is computed by the time between vehicle axle hits divided by the power pulse width. If the time between axle hits is less than the pulse duration, capacity factor is 100 percent.

Traffic volume

It seems to be much important to build an appropriate traffic model. For instance, can traffic volume (e.g. number of vehicles/trains passing in a route per hour, for instance) affect and generate benefits for EH systems? In some studies, it seems the EH system will benefit the most from roads with high traffic volumes in the same way that a piezoelectric floor will benefit from high foot traffic. It seems to be appropriate to define a theoretical simplified traffic model of rail (estimate a traffic flow rate).

- Number of vehicles
- Weight of vehicles
- Traffic wheelbase
- Average speed of traffic
- Traffic/vehicles speed (mph)

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[11] For instance, a natural gas power plant may produce as much as 200 million watts (megawatts, or MW) to power a city and its surrounding neighbourhoods, one million times more powerful than a single solar panel.

[12] Consider the solar panel example from above, producing 200 W or 200 Wh in an hour. A typical solar panel might measure 2 ft (feet) x 3 ft, or six square ft (6 ft). Its power density would then be 200 watts in six square feet, or 200/6=33W/ft.

[13] For instance, the solar panel would produce 200 Wh from noon to 1 PM. The natural gas power plant would produce 200 million watt-hours (200 megawatt-hours, or MWh) in the same hour.

COST METRICS

- Capital costs of technology and installation[14]
- Levelised Energy Cost (LEC) or Levelised Cost of Energy (LCOE)
- Overnight Capital Cost (OCC) is an estimate for the materials and installation for energy systems, and does not include the sometimes immeasurable costs of permitting, construction delays, and other delays which add to the cost of construction projects that are specific to the location, the contractors, and the technology. Overnight costs are a generally accepted comparison for energy systems and are often quoted in this fashion in DOE, EIA, and IEA documents.
- Cost of Energy (electricity sale price)
- Maintenance and other operational costs
- Lifetime of the system and its components
- Power output, the number of units, and the cost per km

Examples of cost metrics for a similar roadway traffic rate with very different power levels are given by the following tables taken from the literature. In some case, we have an average cost for a single EH solution is around $66 for low power generation system (150 kW per km) to $13,000 for high power generation system (13,600 kW per km). From the literature, installed cost is around from $108 to $200 per harvester (for 1 km of installation and around 6,000 harvesters and 0.06 kW per harvester, life cycle from 10 to 20 years) [32].

4.3 SELECTION OF THE CANDIDATE EH SYSTEMS FOR ETALON PROJECT

A review of EH devices suitable for railroad applications was completed in order to identify energy harvesting approaches that could potentially fulfil the requirements of the ETALON project. A list of found devices and their characteristics is provided in Table 3.

The ambient energy source differentiates between the vibrations, which is understood here as an excitation for a harvester with proof mass oscillating in relative motion with respect to its frame (housing); and displacement, which signifies a relative motion of two bodies that is directly exploited by a harvester to generate electricity.

In a similar manner, electromagnetic energy conversion principle is defined here as exploitation of Faraday's law in linear generators or other non-tradition designs, while "generator" stands for a traditional rotary generator, even though it operates on the very same physical principle.

Table 3. Energy Harvester technologies and related performances

Reference	Ambient energy source	Conversion principle	Date	Placement	Reported Average Performance
[1]	Displacement	Electromagnetic	2013	Suspension	0.6W
[2]	Displacement	Generator	2011	Sleeper	11.08W
[3]	Displacement	Generator	2012	2 sleepers	1.4W

[14] It would appear that the capital and installation costs of railway systems are less than the costs for roadway systems [32].

[1]	Displacement	Generator	2013	Suspension	„few watts“
[4]	Displacement	Generator	2016	Sleeper	-
[5]	Displacement	Magnetostrictive	2015	Rail car	77mW
[6]	Displacement	Piezoelectric	2014	?	?
[7]	Displacement	Piezoelectric	2014	Under sleeper	100mW
[8]	Displacement	Piezoelectric	2015	Rail	856μJ/train
[9]	Passing wheels	Electromagnetic (variable reluctance)	2013	Sleeper	5.9mW
[10]	Vibrations	Electromagnetic	2012	?	97μW
[11]	Vibrations	Electromagnetic	2013	Rail car	1.28mW
[12]	Vibrations	Electromagnetic	2017	Track	50mW
[13]	Vibrations	Magnetostrictive	2013	?	450mW @ 50Hz
[14]	Vibrations	Not defined (simulation only)	2013	Track?	150mJ/train
[15]	Vibrations	Not defined (simulation only)	2016	Sleeper	250mJ/train
[16]	Vibrations	Piezoelectric	2011	Sleeper	395μJ/train
[17]	Vibrations	Piezoelectric	2012	?	0.74mW
[18]	Vibrations	Piezoelectric	2014	?	21.4mW @ 150Hz
[19]	Vibrations	Piezoelectric	2014	Rail bridge	588μW
[20]	Vibrations	Piezoelectric	2016	Bridge	30μW
[21]	Vibrations	Piezoelectric	2016	Track	4.88mW
[22]	Vibrations	Triboelectric	2015	?	3.7W/m^2 @ 13.9Hz
[23]	Wind	Generator	2012	Trackside	2kW
[24]	Wind	Generator	2017	On-board	1kW
[25]	Wind	Generator	2017	Trackside	5W
[26]	Wind	Not defined (simulation only)	2013	Trackside-tunnel	Up to 132mJ/train
[27]	Wind	Piezoelectric	2017	Trackside	5mW/cm^3

Based on the already published information from different sources the potential candidates for suitable EH systems can be evaluated by comparing the reported performances and presumed environmental impact.

A list of the main candidate EH systems are piezoelectric (vibration), electromagnetic (vibration), variable reluctance harvester, solar panel and wind power.

4.3.1 Infrastructure and Equipment for selected EH systems

Vibration (both piezoelectric and electromagnetic) EH systems allow for black-box approach, and as such they can be easily installed to either tracks or sleepers of already existing railway corridors. Due to their nature, they do not require special equipment of additional infrastructure that is not already present. Furthermore they are virtually maintenance-less systems, which leads to additional savings in maintenance costs.

Vibration EH systems can also be embedded directly into the body of new generations of railways sleepers, making them even better protected from outer environment, while keeping their main advantages.

4.3.2 Definition of a cost function and threats for selected EH systems

Vibration harvesters costs

Materials (piezo elements[15], permanent magnets, other parts): ~500 EUR per prototype (serial production is expected to be considerably cheaper)

Installation: ~50 EUR (stand-alone system); 0 EUR (integrated inside the sleeper)

Maintenance: 0 EUR

Power output: ~5mW (piezoelectric); ~50mW (electromagnetic)

Number of units per km: ~140

Possible threats for vibration energy harvesters (both electromagnetic and piezoelectric) include sensitivity of the vibration type EH systems to the excitation variables linked to passing trains (passing speed, type of bogies, number of rail cars) and to the quality of track where the EH system is implemented. Due to this the power output can vary significantly both between harvesters in different locations, and for one harvester excited by different passing trains.

[15] www.mide.com

5 SCENARIO BUILDING

This chapter presents the selection of the main scenarios to be built for the migration from the current energy systems to the new one with energy harvesting solutions. For doing this, we consider the main plausible future use cases where the deployment of new technologies requires to have also a set of assumptions as initial steps of our methodology. The goal for the following period of time of the ETALON project will be to relax these assumptions and to consider more realistic use cases according to the prototype and new information get inside the Consortium after the end of the current WP6.

Our first aim has been to define the contour and boundaries of the possible future systems compared to the current one. In doing this, we consider also the input coming from WP4 and the shared activities with other Partner of WP2 and WP3.

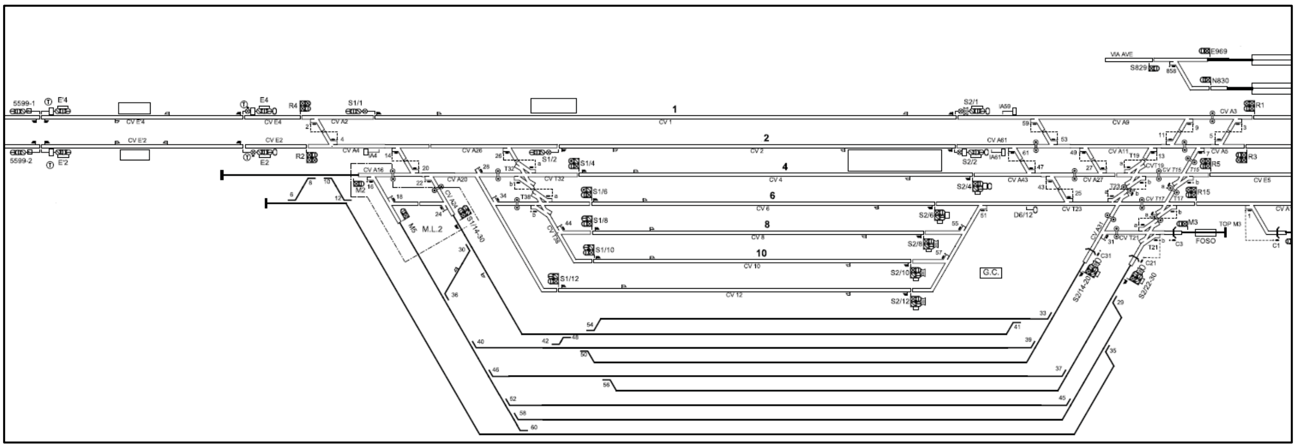
The validation of the following 'high level' scenarios from Partners of the Consortium has been a relevant step that confirmed our approach.

The following paragraphs will show the selection and description of each scenario, the identification of the main variables for each, and a synthesis of the values we collected for all of them. Our approach will consider a comparison among a subset of EU countries in order to catch the similarities and differences among their values in order to generalise as much as possible the techno-economic model.

5.1 ARCHITECTURE OF ENERGY SYSTEMS

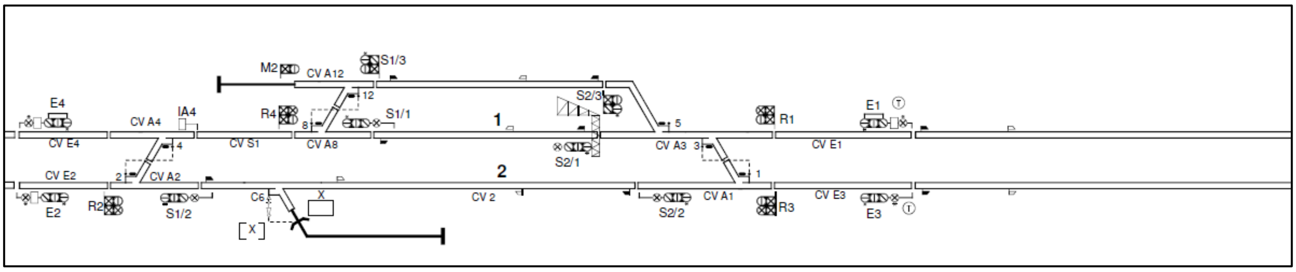
To be able to manage all the objects on trackside, i.e. FEs, data packets need to travel long distances because the depots and stations of a mainline transportation grid typically cover a wide physical area. The topology of each area (station, depots, marshalling yards, sections between stations, etc.) could vary drastically thus representing completely different scenarios for the trackside architecture. In the next picture the example of a layout of passenger station is depicted in Figure 8:

Figure 8. Example of layout of a main station on mixed conventional line



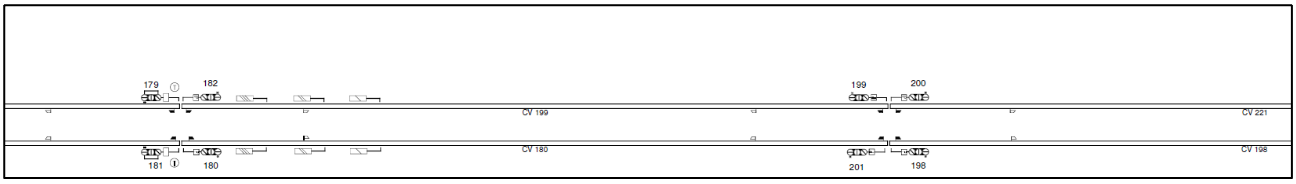
(*) Source: Real Track layout of a main station on conventional line (speed up to 160 km/h).

Figure 9. Example of layout of a secondary station on mixed conventional line



(*) Source: Real Track layout of a secondary station on conventional line (speed up to 160 km/h).

Figure 10. Example of layout of a section between stations on mixed conventional line



(*) Source: Real Track layout of a section between stations on conventional line (speed up to 160 km/h).

This layout corresponds to a mixed conventional line (both passenger and freight trains can circulate at the maximum speed of 160kmph), where the Main Technical Building is located on a main station (interlocking, OCs and remote OCs) and a Secondary Technical Building (interlocking and OC) is placed on a secondary station.

MTB provide a shelter for the trackside control equipment and the energy equipment. Characteristics of MTB control area:

- Number of level crossings: none[16]
- Number of switching points: 65
- Overall length of the area controlled from MTB: 7 km 119 m.

Remote OC installed on secondary station are controls the following equipment:

- Number of level crossings: none
- Number of switching points: 8
- Overall length of the area controlled from MTB: 5 km 615 m.

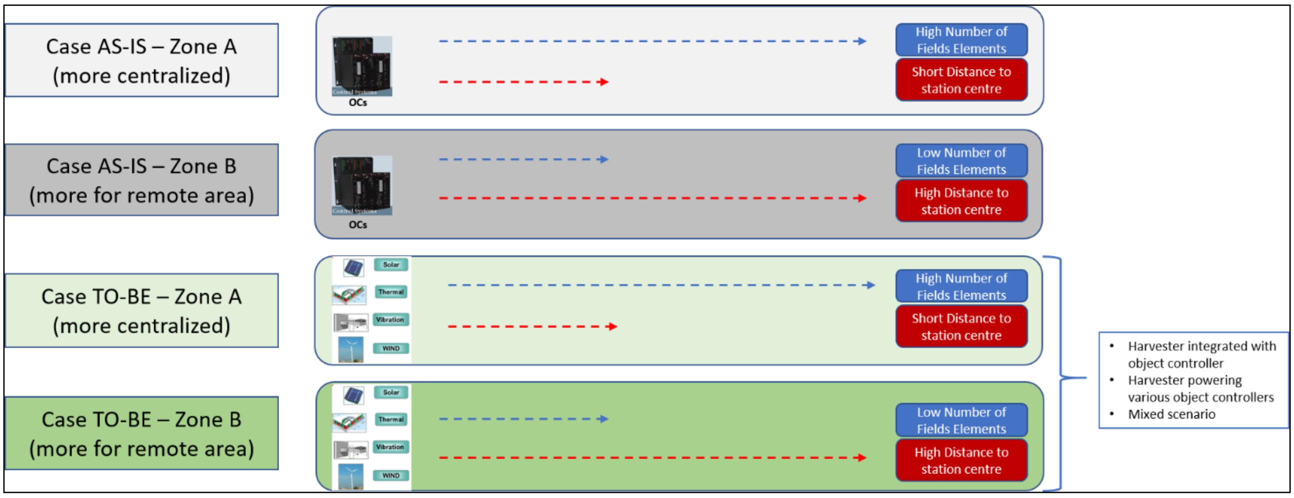
From Figure 8 to Figure 10 it can be seen that there are clearly different zones on a typical Railway line: station (and marshalling yard) that are characterized by a large number of field elements, and the section between station that has low number of field elements which in case of ERTMS L3 would be reduced to few level crossings and even more rarely switches in most of the cases.

These zones can be defined as Zone A and Zone B, being Zone A (station, marshalling yard) characterized by a high number of field elements and short distance to the station control centre (where interlocking or other equipment is located). Zone B is defined by low number of field elements and higher distance to control centre. In the Figure 11 we have a picture of the AS-IS and TO-BE according to the different zones described before. In particular, Zone A is a more

[16] This is a normal situation for instance in Spanish lines where the purpose is to reduce as much as possible the number of level crossings which are not so safe. But in other countries they are still in use, like for example in UK.

centralised area and Zone B is a decentralised one more typical for remote or rural areas. We would study the differences between the current energy systems and future TEH solutions.

Figure 11. Classification of different areas according to number of FEs and distance to station centre



(*) Source: ETALON Consortium elaboration

In terms of energy harvesting it is traduced into possible different architecture solution to provide energy to the equipment on the track.

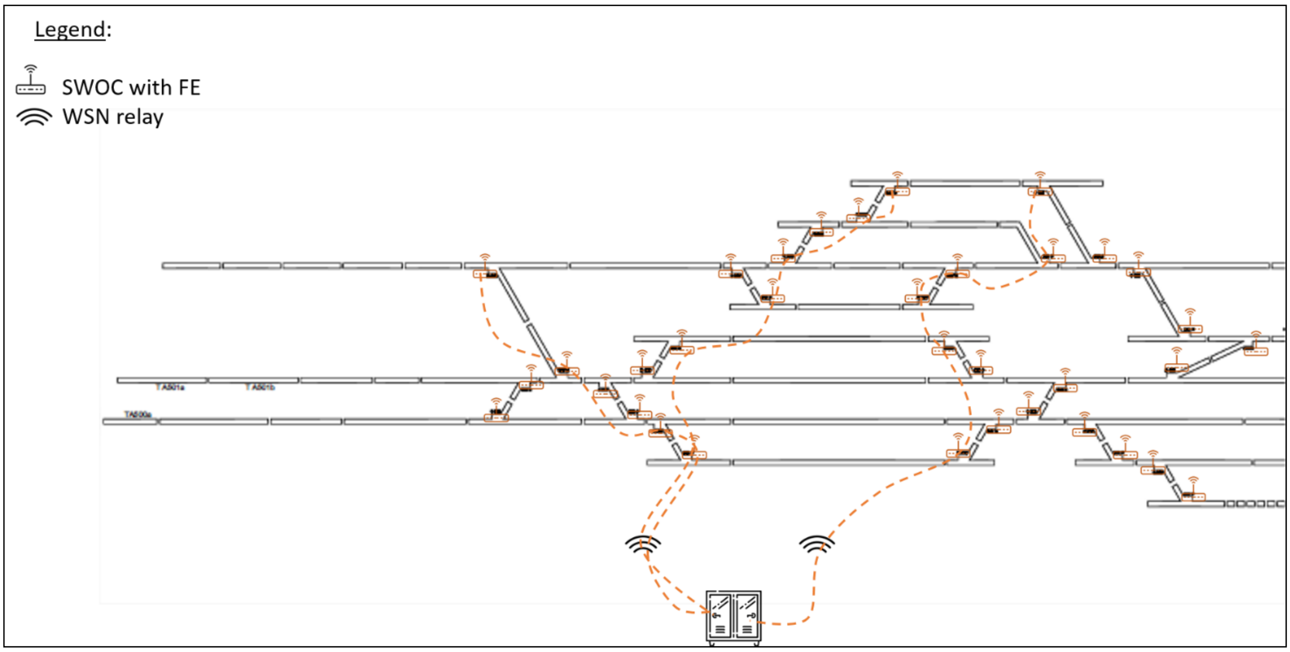
In the X2Rail-1 deliverable D7.1 three different scenarios of the energy harvester integration are depicted:

1) Object Controller and power source are integrated in the field elements. The initial assumption is that this solution is possible in case of low consumption, so the energy component can be small in size.
2) In case that the energy component requires bigger size solutions it could result in local but centralized energy supply for one OC o several OC controlling a group of field elements.
3) The middle way scenario could represent a mix of the first two scenarios, in which the common power source can be used for high-energy users and integrated power source for the rest of field elements.

Economic analysis of these scenarios implemented in the Virtual Route will provide the base for the decision and choice, and better analyse the parameters related to each of them. Examples of architecture by considering the previous zone A and B, configuration of SWOC (integrated or not integrated with FEs) and two possible radio technologies (independent Wireless Sensor Network and LTE dedicated network replacing current GSM-R network[17]) are shown in the following graphs (Figure 12, Figure 13, Figure 14 and Figure 15).

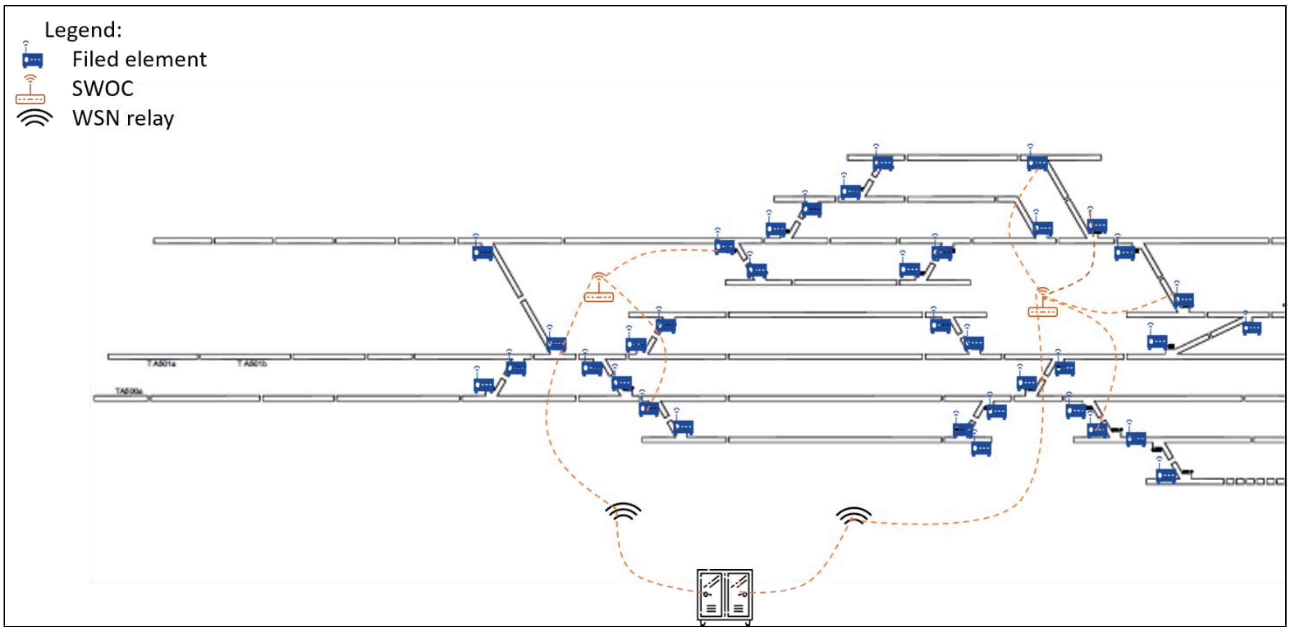
[17] The detailed description of analysed technologies and technical scenarios for communication solution can be found in the ETALON deliverable *D3.5 Communication Systems and RF Components for Trackside and Power Requirements*.

Figure 12. Zone A (stabling areas), SWOC integrated with FE: WSN Architecture



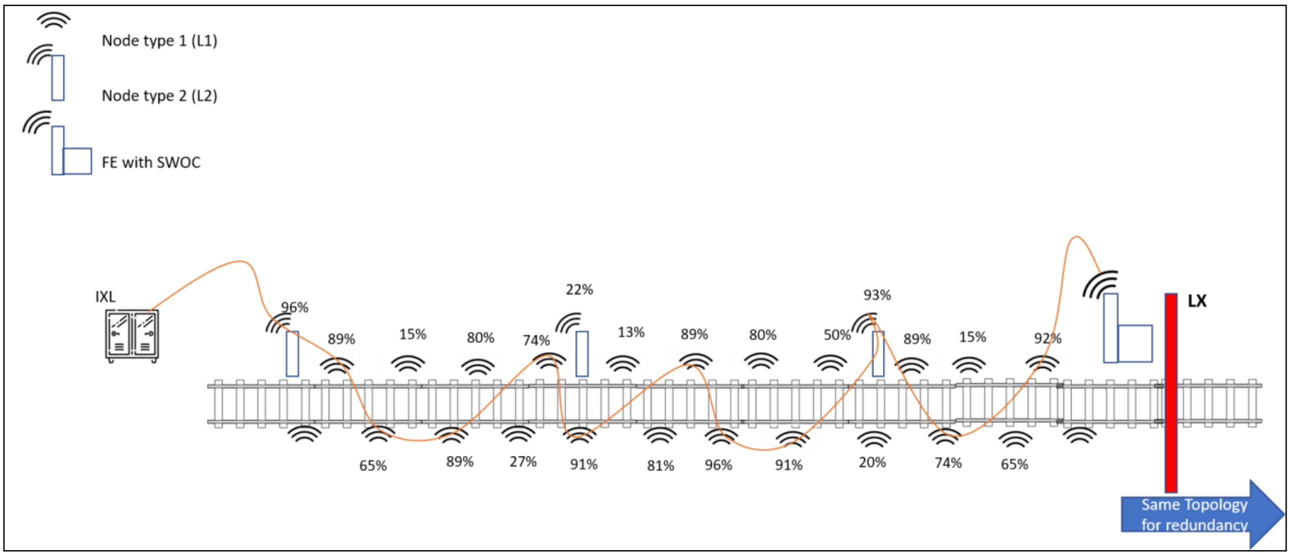
(*) Source: ETALON elaboration

Figure 13. Zone A (stabling areas), SWOC not integrated with FEs: WSN Architecture



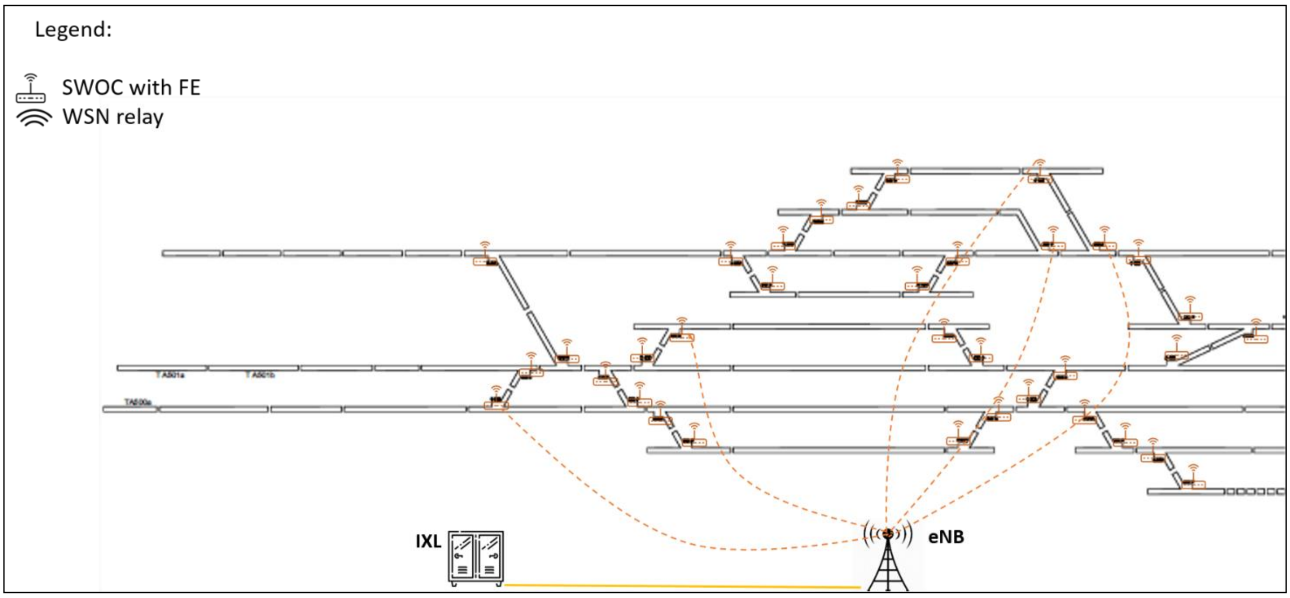
(*) Source: ETALON elaboration

Figure 14. Zone B (remote areas), SWOC integrated with FE : LWSN Architecture



(*) Source: ETALON elaboration

Figure 15. Zone A (stabling areas), SWOC integrated with FE : LTE network



(*) Source: ETALON elaboration

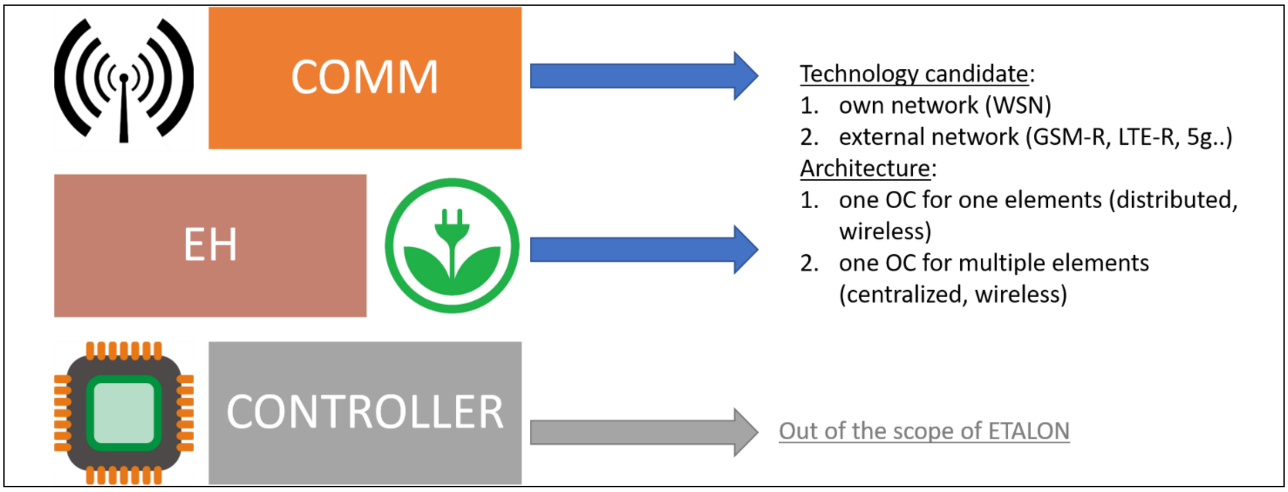
5.2 Scenarios and technologies for communication

In this paragraph, we identify the possible technologies candidate for future EH systems and give a brief introduction regarding SWOC communication system to be powered with these EH. Since the FEs are not in the scope of our project, the focus is placed on the specific part of the SWOCs for communication, in particular, focusing on two possible cases to implement it (Figure 16):

- Own network based on Wireless Sensor Network (WSN)
- External network based on train-to-wayside communication network.

In the first case the network shall be entirely deployed for the SWOC communications and in the second case only end equipment is needed to be installed on field, this end equipment will use the coverage provided by railway communication network.

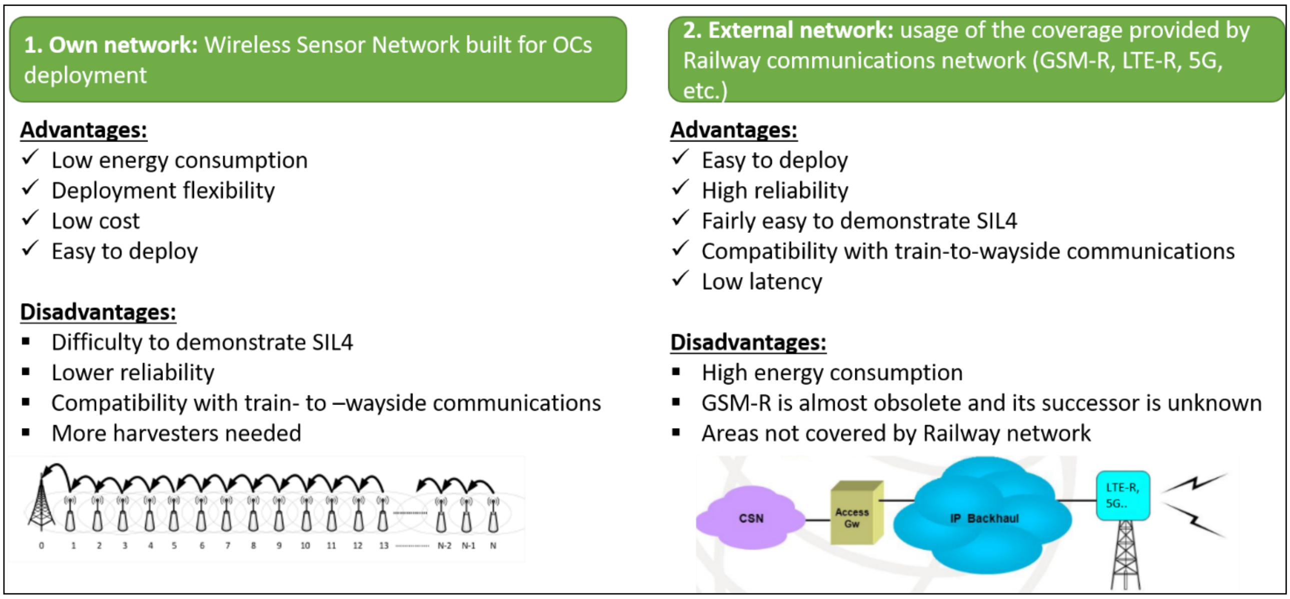
Figure 16. Technologies for communication network OCs



(*) Source: ETALON elaboration

We remind to deliverable D3.1 for a more detailed description of the WSN technology (Figure 17). Concerning to GSM-R technology, it refers to the current network communication system for railway sector for all the EU countries. These systems will be probably replaced by new wireless technologies (e.g. 4G or 5G) because of the increasing rate of obsolescence of GSM-R after 2030 , as it has been described in some official reports of ERA [34] and in deliverable D3.1 of MISTRAL project (2018).

Figure 17. Technologies for wireless communication



(*) Source: Ardanuy elaboration

Both chosen candidates for communication part of SWOC will be simulated by ETALON according the scenarios described below to find the energy consumption rate in each configuration. This consumption should at least be lower than in the case of OCs for FEs that normally can be around 10-20 W.

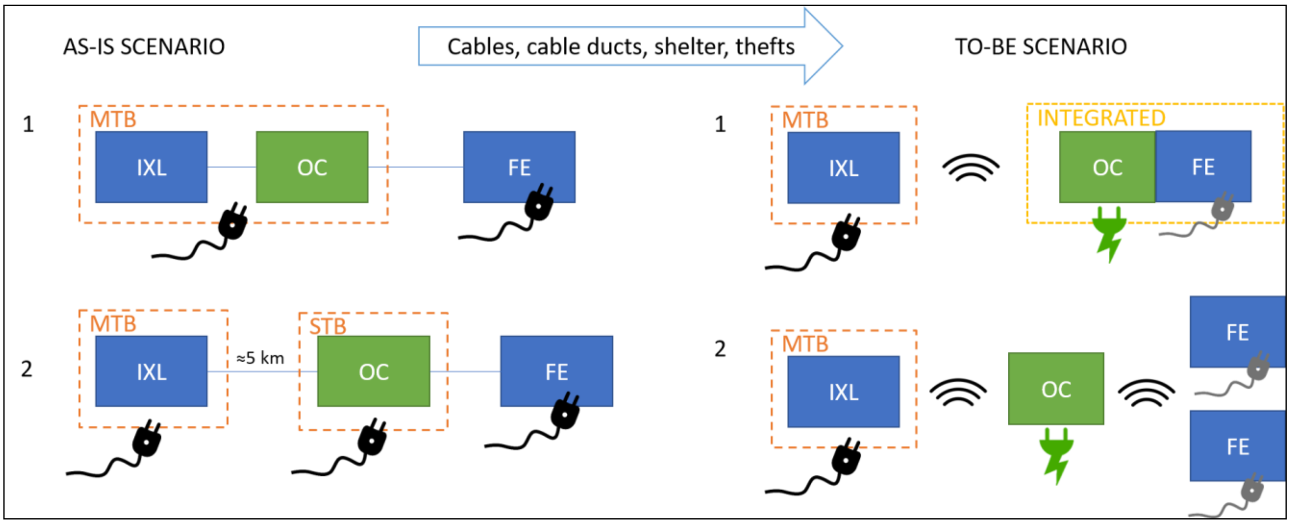
This model would help to understand which and how many EH technologies can be used for powering the two selected communication technologies. In the following paragraph 4.3 we have a description of the main EH systems and their technical characteristics in terms of power generation.

The following configuration scenarios are considered in ETALON (Figure 18 and Figure 19).

1. AS-IS (mains powered devices) scenario 1 is when the IXL is quite close (or, in some cases, integrated) to the OCs and the FEs are far away from OCs. This is the case where power connection can come from two separated systems, the first for IXL and OCs, the second for final FEs. All, IXL, OCs and FEs are interconnected by cables of data communication (e.g. optic fiber cables or Ethernet cables). Cables for data transmission are not considered in our model because this is not the scope of our project, also this type of cables are not usually stolen.
2. AS-IS (mains powered devices) scenario 2 is when IXL and OCs are in a certain distance and they can have separated power cables for powering them (e.g. 5 km of distance). Also in this case, FEs are mains powered and IXL, OCs and FEs are interconnected by cables of data communication.
3. TO-BE (EH) scenario 1 is when we can substitute the OCs for communication and integrate them in each FE, but where OCs will be powered by power wireless solution (i.e. TEH), while FEs and IXL are connected with power cables. In this case, IXL is connected with OCs with data wireless solution, while OCs and FEs are integrated.
4. TO-BE (EH) scenario 2 is when both IXL and OCs are connected by communication wireless solution. In this case, IXL are connected with power cables, as also FEs, while OCs are connected to EH systems for powering energy.

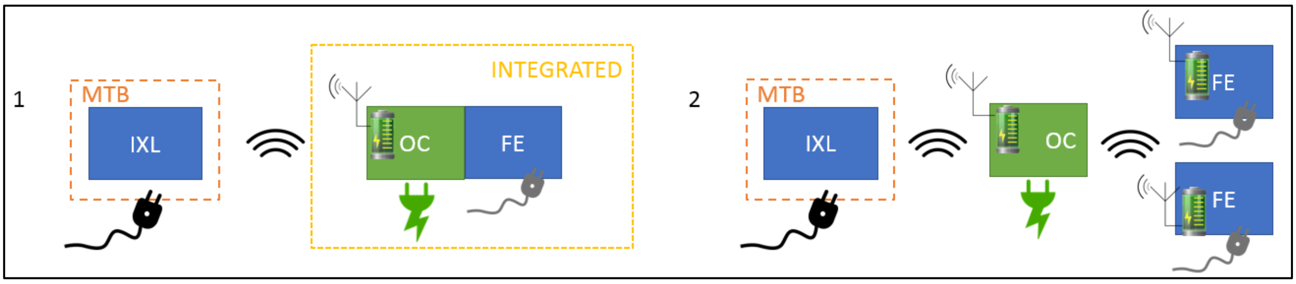
In this set of scenarios, the distance and the topological characteristics can be much important for the feasibility of the solutions. Indeed, distance is relevant for the wireless communication part, that can be not possible to be deployed in a feasible way if the distances are too extensive. Also the topological, geographical (e.g. mountain, hill, urban centres, etc.), environmental (sun, wind, etc.) and traffic characteristics (e.g. frequency of trains) can affect the decision if doing EH systems in a route. In our model, we will consider these issues in order to define the thresholds of feasibility of EH solution with respect to the current AS-IS solution.

Figure 18. Configuration OC- FE scenarios description



(*) Source: ETALON elaboration

Figure 19. Configuration OC- EH Main scenarios description



(*) Source: ETALON elaboration

We have also to fix a set of assumptions coming from the technical requirements described in deliverable D2.1 from which we define our boundaries.

1. TD2.10: Within the Smart radio-connected all-in-all wayside objects concept it is assumed that all trackside elements including object controllers and field elements (signals, points, level-crossing barriers, track circuits, axle counters, etc.) are self-sufficient and powered by energy harvesting systems. In the ETALON project we will only focus on the harvester for the object controller. The configuration can be either “one controller for one object” or “one controller for several objects”. At this stage we assume that in the future field elements will also have an energy harvester.
2. TD2.10: Smart Wayside Object Controllers will replace the object controllers that are now in use and will be able to communicate to Route Management System (interlocking), to other SWOCs and, including, to the train by means of wireless transmission. SWOC will have the intelligence sufficient to control field elements (CPU) and a radio communication part (i/o) powered by energy harvester In the ETALON project, we will focus on radio communication solution to assure the connection between Route Management system and the Controller (CPU part is out of scope). The power requirements for this radio communication solution will be estimated.
3. TD2.10: Smart Wayside Object Controllers will be suitable for all type of signalling systems including those with fixed block, which mean the existence of trackside detection (track circuits, axle counters) and signals. In the ETALON project we focus on ERTMS L3 system (as stated in GA), where the trackside detection and signals are removed, which means

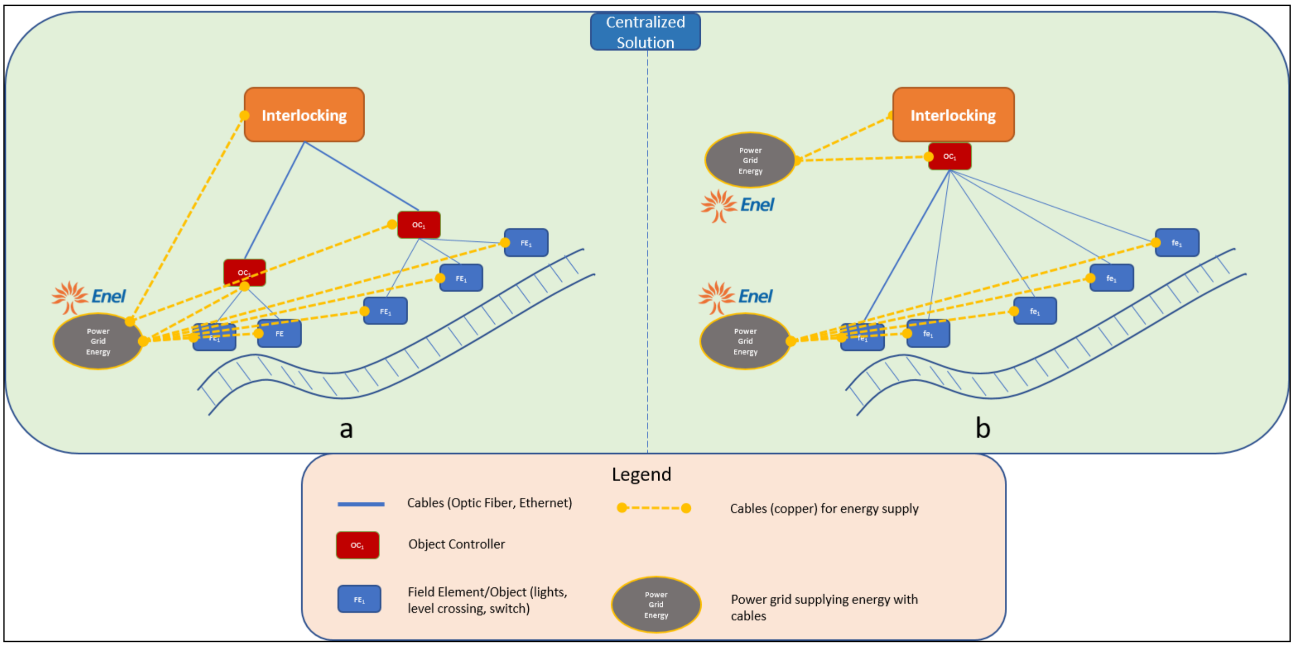
that the object controllers are needed for point machines (switches) and level crossing barriers. It is meaningful for Data bandwidth/throughput and timing latency requirements.

As a wrap-up, the graphical description of the possible scenarios has been realised with more details in the following figures. Hence, we divided centralised and decentralised solutions by considering that in a route we can have a mix of all the possibilities, depending also on the geographical area.

In Figure 20 we describe the AS-IS cases, mostly developed in urban areas, where an IXL can control several OCs and FEs and all of them are powered by the same grid power, with longer length of cables. Figure 20a is the case in which IXL is separated by OC while in Figure 20b we can have IXL integrated with the OC, as in the Italian case for instance.

On the other side, Figure 21a shows two types of decentralised solutions where, especially in more rural areas, grid power can arrive in a more difficult way and requires higher costs of deployment both for building the OCs and for the deployment of cables. In Figure 21b is the situation in which different IXLs, integrated with OCs, can have separated grid power for energy for FEs and OCs.

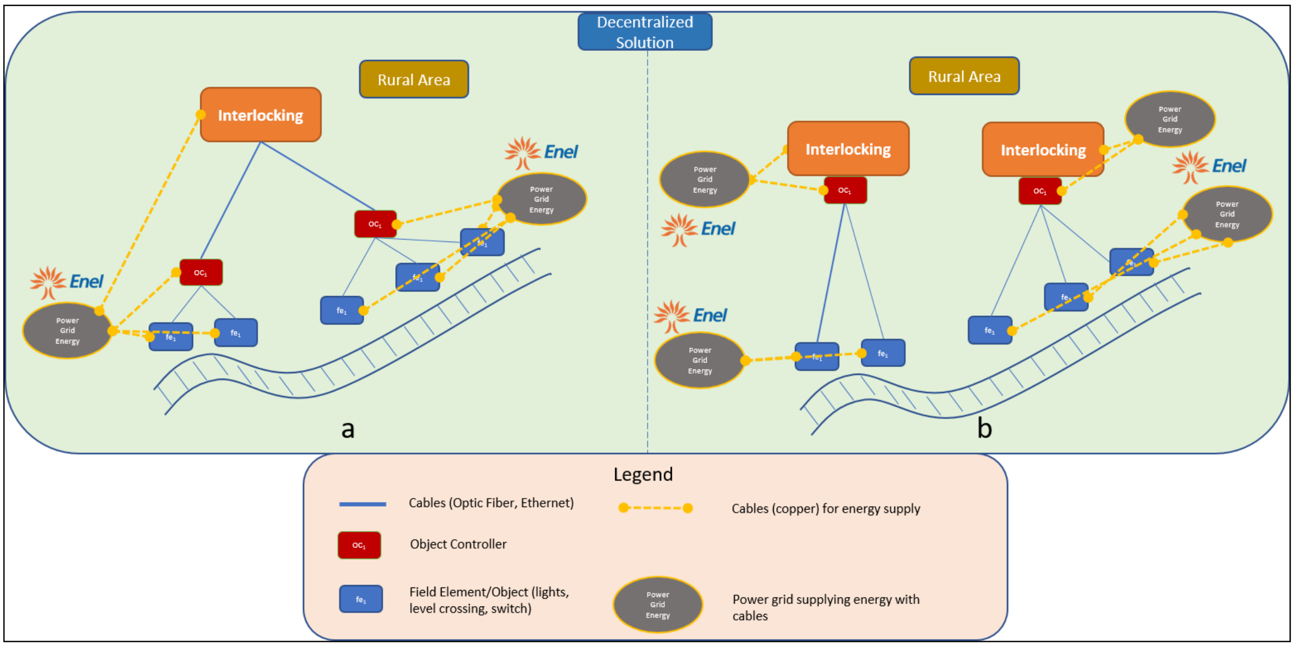
Figure 20. AS-IS scenarios: Centralised solutions



(*) Source: ETALON Consortium elaboration

In Figure 21a and Figure 21b, a decentralised solution has been presented where, mainly in the main rural areas, we have separated power grid energy because of few elements and long distance to the railway line. The cost of deployment for energy power will be higher and less profitable.

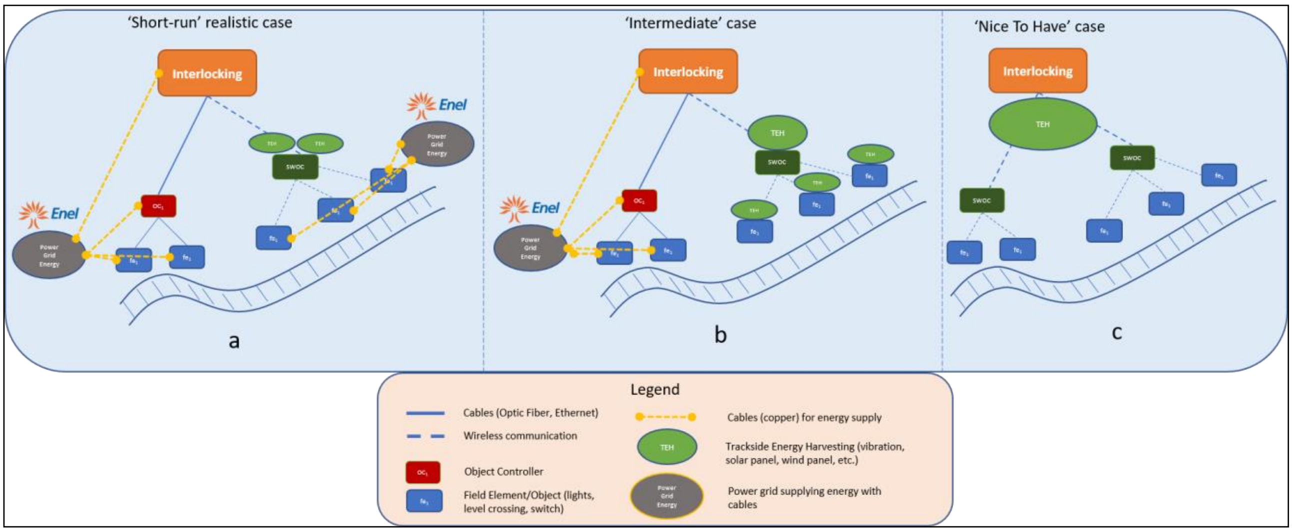
Figure 21. AS-IS scenarios: Decentralised solutions



(*) Source: ETALON Consortium elaboration

As a consequence, we consider AS-IS scenarios as a basis also for the TO-BE scenarios where equipment should be substituted both by considering centralised and decentralised cases. Figure 22a highlights the case of building SWOC equipment for communication systems and to substitute the power grid for OCs with TEH. This can be seen as an intermediate situation, more likelihood in the short run, where still the power grid provides energy to the final FEs but one or, most likelihood, more EH systems (e.g. solar, piezoelectric, etc.) can be deployed for each SWOC. In this case, we are in a situation where communication is wireless and we can consider eliminate all the cable for Ethernet or optical fiber. Figure 22b is a similar case in which we can have one EH for the SWOC and one EH for each final FEs (i.e. for communication in the case of WSN). In this case, we can suppose it is a medium run solution where technologies will be more developed and TEH can provide a sustainable energy for the objects, without to be supported by power grid. Finally, Figure 22c is the situation in which all the route can use TEH systems for SWOC and final FEs in a sustainable way. This is a long-run scenario that we can called the ‘nice to have’ scenario where all the cables can be substituted and the most environmental friendly case.

Figure 22. Possible TO-BE scenarios



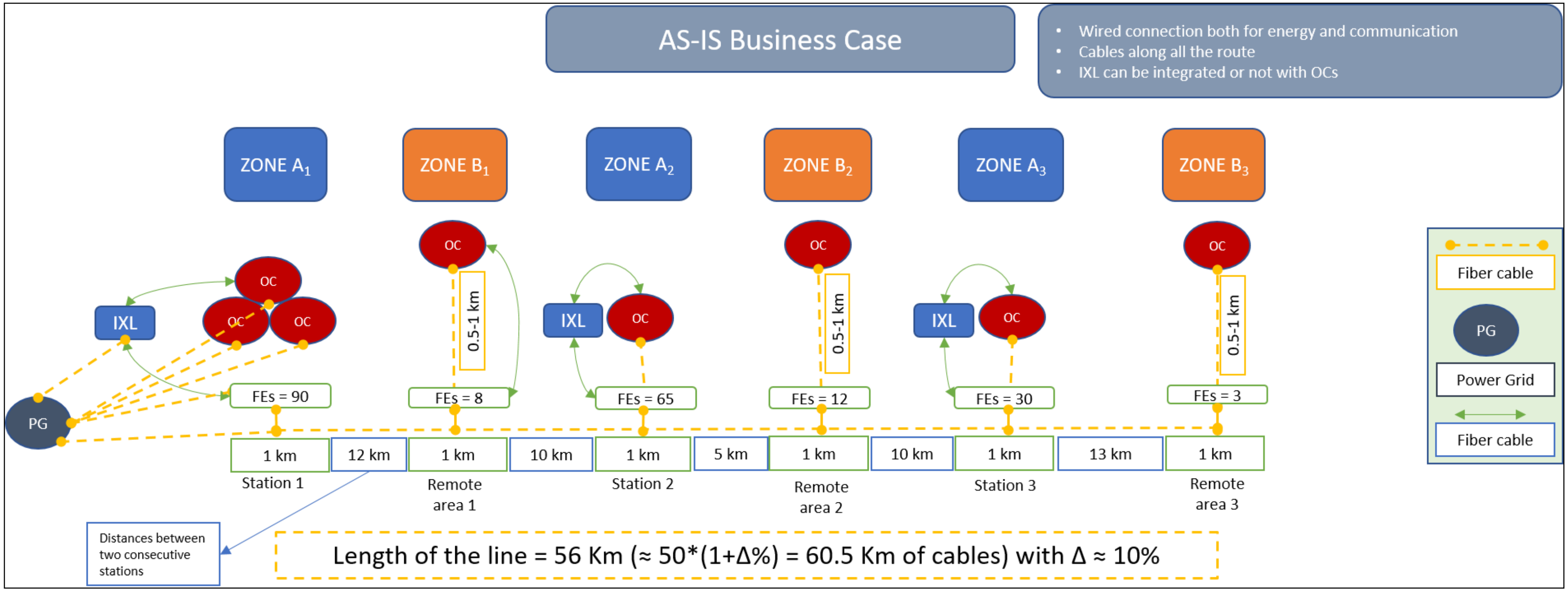
(*) Source: ETALON Consortium elaboration

From the high level description of these types of scenarios, now we built and selected a set of 4 main business cases that will be the basis for our computation in the virtual route model: AS-IS Business Case 1, TO-BE Business Case 1a, TO-BE Business Case 1b and TO-BE Business Case 1c.

The AS-IS Business Case 1 (Figure 23) is referred to the *status quo*, the current status of deployment of energy power to the IXLs, OCs and FEs. As described in the previous part of this chapter, we divided zones in Zone A and Zone B and we make a simulation with a typical distribution of km and objects for each area. We assume length of Zone A is around 1 km and that the distance between Zone A and B changes according to the geographical area. In this scenario, all the elements are powered by cables (wired energy supply) through power grid and that the average distance between the FEs and OC can arrive until 1 km in Zone B, while in Zone A is much shorter. Also in the communication part, we have wired connection between OC, IXL and FEs (fiber cables). Cables are deployed along all the route.

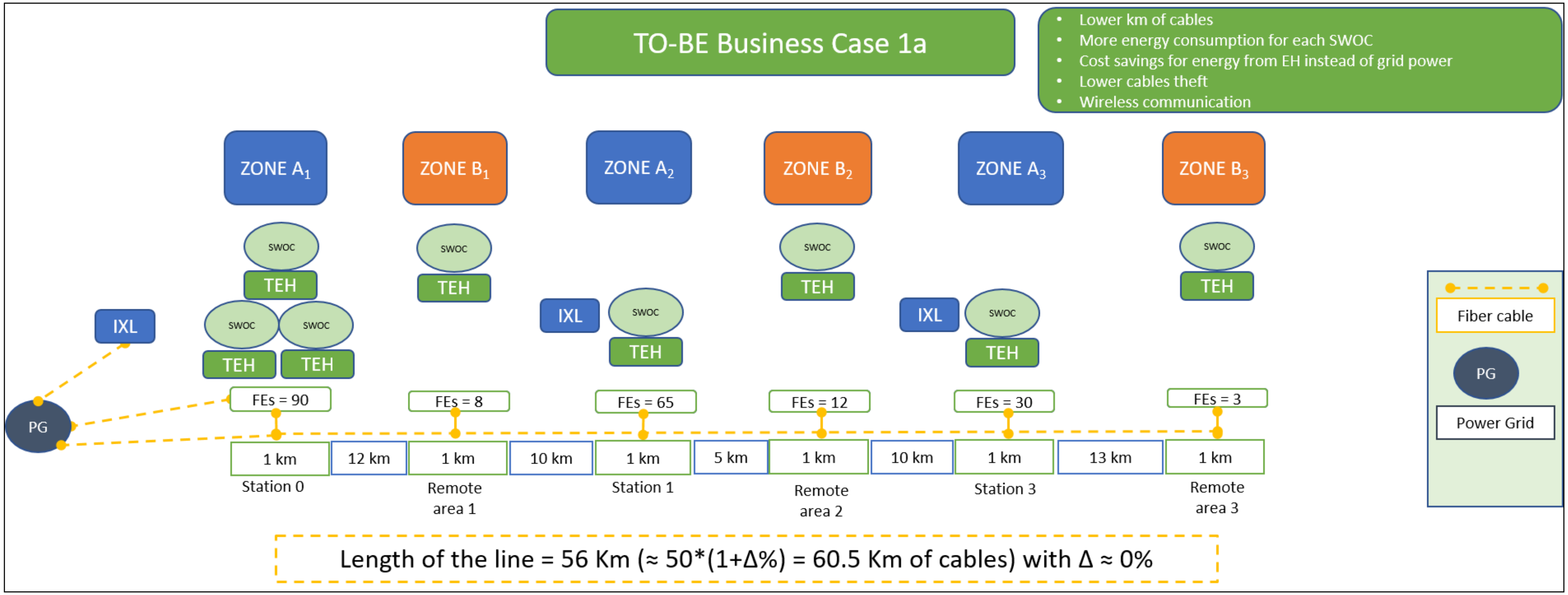
The TO-BE scenarios are depicted in the Figure 24, Figure 25 and Figure 26. Figure 24 shows the TO-BE Business Case 1a, an intermediate case of where the FEs still are powered by cables while OCs, that now we can call as SWOC, are powered by TEH systems, one for each SWOC object. In some cases, we have more than one SWOC. In this case, savings come from dismantling cables and from decreasing the cost for energy from power grid and lower rate of cable thefts. Figure 25, scenario TO-BE Business Case 1b, is and improving of the previous scenario 1a but with the case of on TEH for different SWOC that controls several elements. Finally, TO-BE Business Case 1c is the 'nice to have' scenario where all the cables are dismantled and only few elements, as IXL, can be still powered by the power grid.

Figure 23. AS-IS BUSINESS CASE



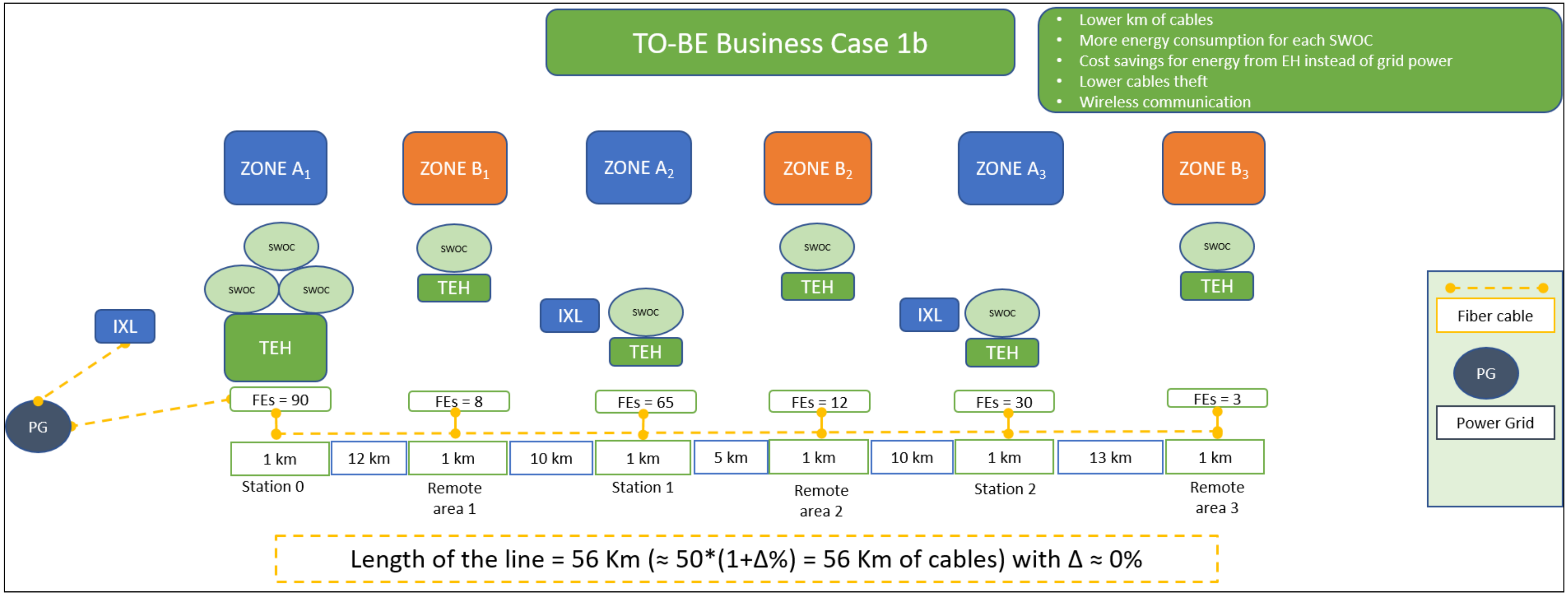
(*) Source: ETALON Consortium elaboration

Figure 24. TO-BE BUSINESS CASE 1a



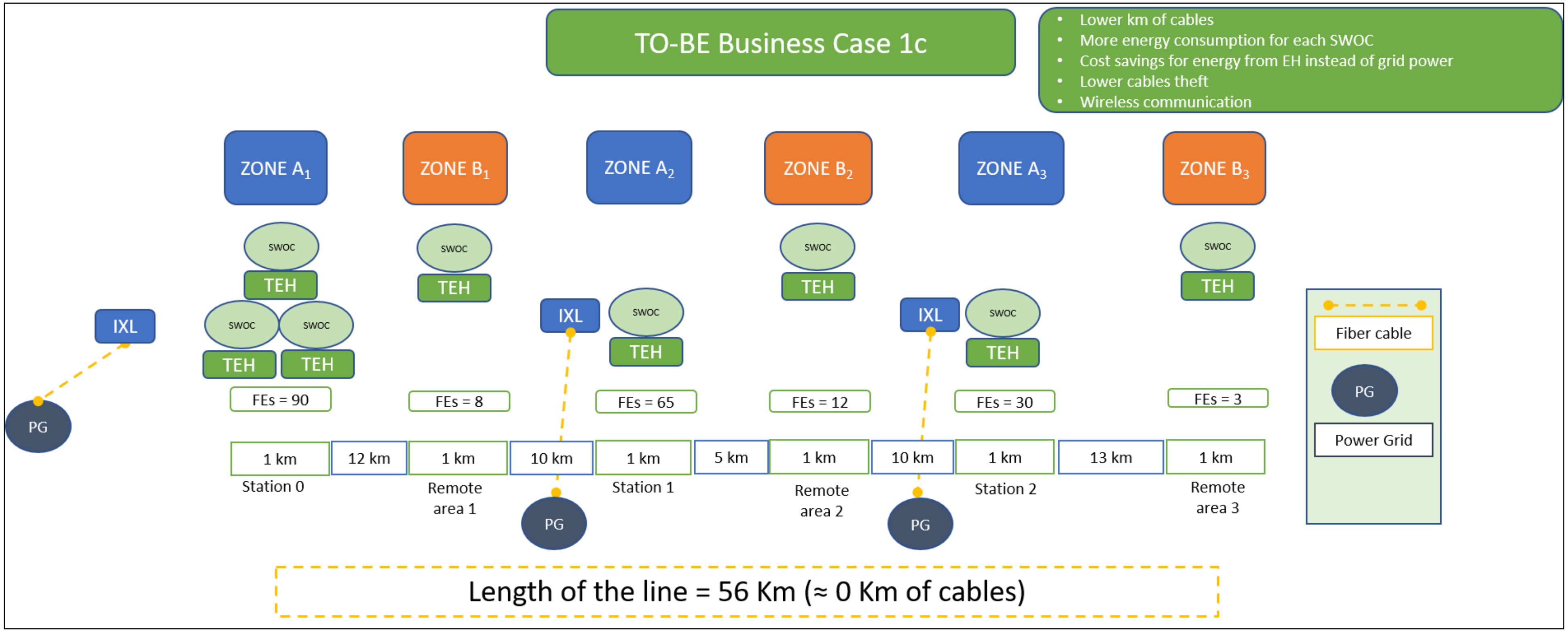
(*) Source: ETALON Consortium elaboration

Figure 25. TO-BE BUSINESS CASE 1b



(*) Source: ETALON Consortium elaboration

Figure 26. TO-BE BUSINESS CASE 1c

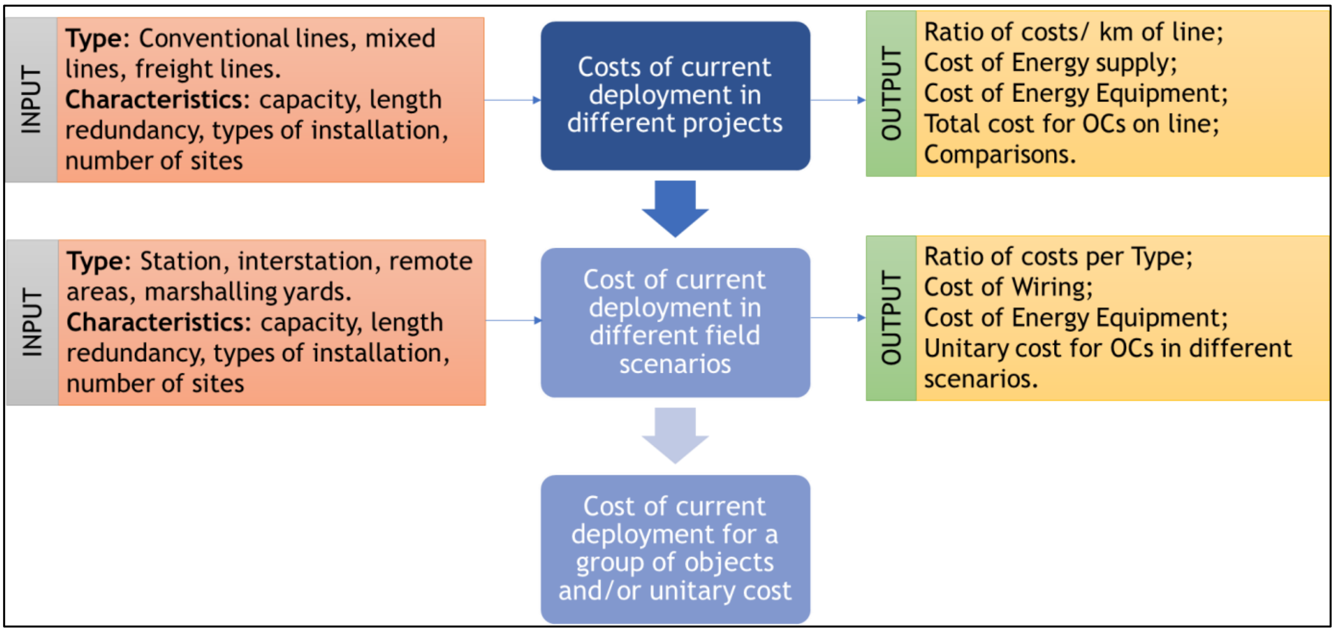


(*) Source: ETALON Consortium elaboration

5.3 LIST OF SELECTED INPUT AND PARAMETERS

This paragraph describes the set of input and parameters needed for the economic modelling approach. For most of them we have already collected some values from different countries while for other we will use or generic values coming from reports or white papers or values coming from experience of Partners or expert in the sector. The following diagram (Figure 27) shows the logical flows that put in relationship inputs and final output of the model concerning to the current AS-IS deployment of energy systems by considering some items of costs, mainly CapEx and OpEx.

Figure 27. Diagram of logical flows of cost analysis for AS-IS scenario



(*) Source: ETALON elaboration

From this, we have selected a set of variables or parameters to be included in the model and for which we tried to give a set of cross-countries figures in order to generalise as much as possible the model. As shown in the Table 4, Table 5 and Table 6, we have collected from Partners of the Consortium some values in order have at least one value for each variable. In particular, for some inputs, we have values for all countries for other no, but all the variables have at least one value. Table 4 shows the inputs for the AS-IS model that will be the counterfactual scenario, Table 5 shows inputs that should be inserted transversally both in AS-IS and TO-BE formula, and Table 6 highlights the main parameters to be included for the TO-BE analysis.

Table 4. List of variables for AS-IS analysis collected by countries

ID	ITEMS - State of the Art (AS-IS - scenario 0)	Description	ES	IT	GR
A.1	Type of line	HSL, mainline, regional line, freight line, traffic density, ridership, length	V	V	V
A.2	Object controller equipment	List, number (for a route), description, (cost of deployment), no. of controlled field element	V	V	V
A.3	Interlocking	Number, cost	V	V	V
A.4	Energy Equipment	Type, cost, metrics	V		V
A.5	Energy Budget Supply	Type, cost, metrics	V		V

A.6	Cables (cost of deployment)	Length (number of km - country side), Cost of deployment		V	
A.7	Cost of restore the line after cable theft	We can have additional cost w.r.t cost of deployment of cables and we have also more “indirect costs” for railway operators, RUs, damage for equipment, additional test on-site (e.g. deployment in the night, etc.)		V	
A.8	Operational (ordinary) maintenance (preventive and consecutive)	Costs and/or frequency of maintenance	V		V
A.9	Power consumption or Energy Efficiency issue	Some metrics, costs, some metrics to measure energy efficiency to be compared with the TEH)	V	V	
A.10	Price of Energy	Cost of energy for railway sector (per KW)	V	V	V
A.11	Suppliers of trackside technology for object controllers	Names, size of enterprises	V	V	V
A.12	Labour Cost	Number of employee involved in the deployment and maintenance of future and current system, respectively	V	V	V
A.13	Theft of cables	Economic value	V		
A.14	Life Cycle for current equipment	LIFE CYCLE for current equipment (cables and OCs)	V	V	V

(*) Source: ETALON Consortium elaboration

Table 5. List of generic variables for the Economic Model (AS-IS and To-BE)

ID	OTHER ITEMS	Description	ES	IT	GR
B.1	Residual Value (salvage value)	The value of the fixed investments must be included within the investment costs account for the end-year. The residual value reflects the capacity of the remaining service potential of fixed assets whose economic life is not yet completely exhausted. The latter will be zero or negligible if a time horizon equal to the economic lifetime of the asset has been selected. in the case of non-revenue generating projects, by computing the value of all assets and liabilities based on a standard accounting depreciation formula or considering the residual market value of the fixed asset as if it were to be sold at the end of the time horizon. Also, the depreciation formula should be used in the special case of projects with very long design lifetimes, (usually in the transport sector), whose residual value will be so large as to distort the analysis if calculated with the net present value method	We assume similar values for all the countries		
B.2	Taxes, VAT	Taxes or VAT on capital/income and other direct taxes	V	V	
B.3	Subsidies, economic incentives for green economy and renewable sources	If any, for environmental friendly technologies. In Italy and in Spain there are not anymore fiscal incentives for green energy for private investors, but only for public companies (e.g. IMs?)		V	

B.4	Source of Financing	To be considered together interest rate: loans, debt, equity, public contribution, EU grant, PPP	We assume similar values for all the countries		
B.5	Mark-up for suppliers	We can compute as a sort of shadow price	We assume similar values for all the countries		
B.6	Environment externalities (spillover effect)	GHG emission, CO_2 equivalent	We assume similar values for all countries		
B.7	Replacement cost for TEH objects (lif-cycle for EH object)	includes costs occurring during the reference period to replace short-life machinery and/or equipment, e.g. engineering plants, filters and instruments, vehicles, furniture, office and IT equipment, etc.	We assume similar values for all the countries		
B.8	Geography	Urban, remote area (rural, regional area) and 'difficult to access' (mountain, tunnels) area where independent equipment could be needed. It is important to say that environment is much important also for EH solution (e.g. in a sunny area it is more likelihood to have solar panel)	V	V	V
B.9	Timing	Length of the investment (15-20 years)	We assume similar values for all the countries		
B.10	Capacity of a route	Number of train in a route, traffic density, ridership (PPHPD)	We consider this not relevant for the model		

(*) Source: ETALON Consortium elaboration

Table 6. List of variables for TO-BE analysis

ID	ITEMS - State of the Art (AS-IS - scenario 0)	Description
C.1	SWOC equipment	List, number (for a route), description, (cost of deployment), no. of controlled field element
C.2	Power Energy Generation for each TEH solution	List of Power energy (W)
C.3	Energy Budget Supply	Type, cost, metrics
C.4	Cost of deployment for TEH	Equipment and Deployment, materials, number per km, energy storage (cost of batteries, lifetime, etc.)
C.5	Operational (ordinary) maintenance cost (preventive and consecutive)	Costs and/or frequency of maintenance, energy storage (cost of recharge batteries, life-cycle, replacement, etc.). It includes costs occurring during the reference period to replace short-life machinery and/or equipment, e.g. engineering plants, filters

		and instruments, vehicles, furniture, office and IT equipment, etc.
C.6	Labour Cost for deployment of EH systems	Number of employee involved in the deployment and maintenance of future EH system, respectively (number of hours and cost per hour for installing, maintenance EH system)
C.7	Cables (cost of dismantling)	in case of substitution with new EH systems
C.8	Suppliers of SWOC and EH technologies for object controllers	Names, size of enterprises

(*) Source: ETALON Consortium elaboration

5.4 Definition of a set of values for parameters and variables

The second stage of the WP6 is to define an initial cost structure for the infrastructure from IM point of view. As we will depict better in chapter 0, the main drivers for investing in new energy systems could come from IMs that are the owner of the network. For this reason, a set of variables, parameters and other information will be collected by Partners of the Consortium to be validated and used for the economic analysis. The following Table 7, Table 8 and Table 9 show the list of information we are going to analyse with some average values.

Table 7. Values for the selected variables and parameters for AS-IS scenario

ID CODE	CapEx/OpEx	NAME of the INPUT	Description	TYPE OF VALUES	SPAIN	ITALY	GREECE
A.1	CapEx/OpEx	Type of line	HSL, mainline, regional line, freight line, traffic density, ridership, length	¤ Regional Lines - RL (Km) ¤ Mainline - ML (Km) ¤ High Speed Line - HSL (Km)	¤ 2 (35-65) ¤ 2 (70-114) ¤ 3 (88-107-125)	¤ 2 (35-42)	¤ 1 HSL (73 km)
A.2	CapEx	Object controller (OC) equipment	List, number (for a route), description, (cost of deployment), no. of controlled field element	¤ Number of OCs per route ¤ Cost of installation	¤ See Table 9 ¤ Missing	¤ See Table 9 ¤ From 140,000€ to 200,000€	¤ See Table 9 ¤ Missing
A.3	CapEx	Interlocking (IXL)	Number of IXL per route, distance between IXLs (to the most remote FEs)		OK	OK	OK
A.4	CapEx	Energy Equipment	Type, cost, metrics	1. Type of Equipment (€): ¤ Cabinet to host electric equipment (€) ¤ Transformer (€) ¤ UPS for 1 hour reserve (€) ¤ Medium voltage connection from ENC (€) ¤ PLC control (€) ¤ Mono-Phase voltage stabilizer (€) 2. Average Cost of Equipment per type of line (€): ¤ For RL (€) ¤ For ML (€) ¤ For HSL (€)	¤ From 6,500€ to 15,000€ ¤ From 1,400€ to 7,000€ ¤ From 8,000€ to 52,000€ ¤ From 25,000€ to 70,000 ¤ From 2,800€ to 52,000€ ¤ From 13,000 to 19,000€ ¤ From 297,000€ to 3,043,125€ ¤ From 48,785€ to 54,438€ ¤ From 56,376€ to 139,440€	n/a	¤ Power cabinet ¤ Stabilizer ¤ Main power distribution panel ¤ UPS for 3 hours reserve (?)

A.5	OpEx	Energy Budget Supply (per route)	Type, cost, metrics	1. Energy Budget supply of OC per type of line: ◘ For RL (€) ◘ For ML (€) ◘ For HSL (€)	◘ ◘ From 570,263€ to 5,083,123€ ◘ From 7,222,979€ to 10,906,943€ ◘ From 10,155,185€ to 20,898,850€	n/a	◘ HSL: 753,000€ ◘ IXL cost: for Main IXL 121,000€ ◘ 65,000€ for peripherical IXL
A.6	CapEx/OpEx	Cables (cost of deployment)	Length (number of km - country side), Type of cable (aluminium, copper), Size of cable (section, diameter, no. of conductors). OK, our assumptions are: 1. the number of km of cable is equal to the km of the route 2. in every cable we have 2 conductors (2x25mm2)	Cost: ◘ € per route (generic cable) ◘ € per mt (aluminium) ◘ € per mt (copper)		Cost: ◘ From 80,000€ to 120,000€ ◘ 4.32-5.42€/mt ◘ 5.75€/mt (computed from data of copper quotation)	
A.7	OpEx	Cost of restore the line after cable theft	We can have additional cost w.r.t cost of deployment of cables and we have also more "indirect costs" for railway operators, RUs, damage for equipment, additional test on-site (e.g. deployment in the night, etc.)		We can make assumption by considering an yearly rate of theft and put the cost of installation of cables plus cost of work at nigh (substituting the cables without interrupting the traffic). We can suppose extra cost could be around +15% per night, for 1/2 night(s), and for around 1 km of copper cable theft (for 4/5 hours of work, standard team work is of 3 people). Time of installation for OC is around 2 workers per 3 days. (usually 2 weeks for restore cables for all the FEs). Around 3 persons for cables and around 6 hours for 1 km of cables.		
A.8	OpEx	(Ordinary) Operational maintenance costs	These are preventive and consecutive costs and/or frequency of maintenance. (per year and per OC)		See Labour cost variables	See Labour cost variable	See Labour cost variable

A.9	OpEx	Power consumption or Energy Efficiency issue	Some metrics, costs, some metrics to measure energy efficiency to be compared with the TEH)	¤ Average consumption for OC (only for communication): 45 mW (see also the table of simulation)SWOC = 1-3 W ¤ Average consumption for OC (comunicazione e passaggio dati) = 10-20W o 200W?	¤ Average consumption for OC (only for communication): 45 mW (see also the table of simulation), SWOC = 1-3 W ¤ Average consumption for OC (comunicazione e passaggio dati) = 10-20W o 200W?	¤ 60 KW for 800 FEs ¤ Consumption for OC is around 10-20 W (X2RAIL-1 Report, 2017)	(Thales)
A.10	OpEx	Price of Energy	Cost of energy for railway sector (per KW)	¤ Price of Energy per kW	¤ Around 0.111€ per kWh	¤ Around 0.10-0.20€ per kW	¤ Around 0.085€ per kW
A.11	CapEx/OpEx	Suppliers of trackside technology for object controllers	Names, size of enterprises		Oligopoly market – few suppliers, big companies usually with direct negotiated procurement tendering process. Main suppliers are: ¤ THALES is the main actor, dominant position with respect to the other players) ¤ Ansaldo ¤ Alstom ¤ BBRAIl ¤ Bombardier		
A.12	CapEx/OpEx	Labour Cost	Number of employee involved in the deployment and maintenance of future and current system, respectively	¤ Number of hours for OC installation per year ¤ Cost of Installation team ¤ Number of hours per year for maintenance ¤ Repair cost ¤ Maintenance (team) cost ¤ Software engineering ¤ Field engineering ¤ Site engineering	¤ Around 86.55 ¤ Around 92.38€ ¤ 20 ¤ 0.3€ ¤ 48.46€ per hour ¤ ¤ ¤	¤ 70€ per hour ¤ 60€ per hour ¤ 55€ per hour	¤ 67.67€ per hour ¤ 45.11€ per hour ¤ 67.67€ per hour

				¤ Craftsman ¤ Assistant	¤ ¤	¤ 42€ per hour ¤ 36€ per hour	¤ 19.86€ per hour ¤ 16.84€ per hour
A.13	OpEx	Theft of cables	Value for Direct and Indirect Costs, Time (hours and minutes) of delay (country side) in different years	¤ Ton of copper theft (year) ¤ Ton of copper theft (year) ¤ Days of delay of train (year) ¤ Minutes of delay of train every 10 kilos of stolen copper (year) ¤ Minutes of delay of train every day (year) in UK ¤ Cost of 1 kilos of stolen copper (year) ¤ Direct cost of delay in train (year) ¤ Direct+Indirect cost of delay in train (year) ¤ Direct+Indirect cost of cables theft (year) in UK	n/a	¤ 1,000 (in 2011) ¤ 134 (in 2015) ¤ 20.2 (in 2015) ¤ 2 (in 2014) ¤ 1,000 (in 2010) ¤ 10.95€ (in 2014) ¤ 1.3 million€ (in 2015) ¤ 20 million€ (in 2011) ¤ 770 million€ (in 2010)	n/a
A.14	OpEx	Life Cycle for current equipment	LIFE CYCLE for current equipment (cables and OCs)	¤ Number of years	20	20	20

(*) Source: ETALON Consortium elaboration

Table 8. List of generic variables for the Economic Model (AS-IS and To-BE)

ID	OTHER ITEMS	Description	ES	IT	GR	Note
B.1	Residual Value (salvage value) for cables	The value of the fixed investments must be included within the investment costs account for the end-year. The residual value reflects the capacity of the remaining service potential of fixed assets whose economic life is not yet completely exhausted. The latter will be zero or negligible if a time horizon equal to the economic lifetime of the asset has been selected. in the case of non-revenue generating projects, by computing the value of all assets and liabilities based on a standard accounting depreciation formula or considering the residual market value of the fixed asset as if it were to be sold at the end of the time horizon. Also, the depreciation formula should be used in the special case of projects with very long design lifetimes, (usually in the transport sector), whose residual value will be so large as to distort the analysis if calculated with the net present value method	We assume similar values for all the countries (e.g. for communication is copper, for energy is aluminium)			OK
B.2	Taxes, VAT	Taxes or VAT on capital/income and other direct taxes	0.21	0.22	n/a	
B.3	Subsidies, economic incentives for green economy and renewable sources	If any, for environmental friendly technologies. In Italy and in Spain there are not anymore fiscal incentives for green energy for private investors, but only for public companies (e.g. IMs?)	Similar Some subsidies from EU are possible. For Spain the incentive is: 40% of the approved eligible cost (VAT excluded), with a limit of 60,000 euros, per beneficiary	Only for green energy and for public sector	n/a	n/a
B.4	Source of Financing	To be considered together interest rate: loans, debt, equity, public contribution, EU grant, PPP	We assume similar values for all the countries (Debt)			OK

B.5	Mark-up for suppliers	We can compute as a sort of shadow price	We assume similar values for all the countries (μ)	OK
B.6	Environment externalities (spillover effect)	GHG emission, CO_2 equivalent	We assume similar values for all countries (CO_2 equivalent)	OK
B.7	Geography	Urban, remote area (rural, regional area) and 'difficult to access' (mountain, tunnels) area where independent equipment could be needed. It is important to say that environment is much important also for EH solution (e.g. in a sunny area it is more likelihood to have solar panel). "How much electrical energy that is possible to produce from solar and wind depends on geographical characteristics, especially the solar irradiation, temperature levels and average wind speed at the specific site" (X2RAIl-1, 2017)	• Regional: • Mainline: • HSL: • Regional: sub-urban-rural area • HSL: Sub-urban-rural area	OK
B.8	Timing	Length of the investment (15-20 years)	15-20 years	
B.9	Capacity of a route	Number of train in a route, traffic density, ridership (PPHPD)	It is not relevant for our analysis	

(*) Source: ETALON Consortium elaboration

Table 9. List of variables for TO-BE analysis (future TEH energy systems for OCs and SWOCs)

ID CODE		NAME of the INPUT	DESCRIPTION	SUB-ITEMS of the INPUT	
C.1		SWOC equipment	List, number of SWOC (for a route), description, cost of deployment and energy consumption		
C.2	OpEx	Power Energy Generation for each TEH solution	List of Power energy (W)	See Table 14 of D6.1	See Table 14 of D6.1. we have a list of power energy per EH system provided by BUT
C.3	OpEx	Energy Budget Supply	Metrics		
C.4	CapEx	Cost of deployment for TEH	Equipment and Deployment, materials, number per km, energy storage (cost of batteries, lifetime, etc.)	1. Vibration harvester:	
				· Materials Cost per each EH	500€ (prototype), 300€ (manufactured at large scale)
				· Installation Cost (specify if labout cost is included) per one EH. If the cost cannot be provided it could be fine to provide hours of work needed.	50€ / potential fully integrated inside sleeper
				· Number of units per km	140? (number of sleepers)
				· Power output	5 - 50 mW (simulation) - it depends on type of train and type of track
				· Life-cycle (years and/or hours)	TEH (20 years) + direct operation without battery - 10 years - capacitors. battery operation - 4000 rechargeable cycles of batteries
				· Batteries Cost (specify if the EH solution is a stand alone or requires batteries)	10 - 30 € - depends on capacity
				2. Displacement harvester:	
				· Materials Cost per each EH	**€500 (estimated price on the market, if manufactured at medium-large scale) [however, the prototype cost is much higher ~€1500]**

				• Installation Cost (specify if labour cost is included) per one EH. If the cost cannot be provided it could be fine to provide hours of work needed.	€100 (inc labour as in C.6) (Estimated for UK market, may be lower in other countries)
				• Number of units per km (if available)	Up to 1000 units vould be installed per 1km (on both sides of the track) - this is much more than the actual energy needs for object controllers
				• Power output	300 W (from computational simulation)
				• Life-cycle (years and/or hours)	20 years (Estimated)
				• Batteries Cost (specify if the EH solution is a stand alone or requires batteries)	€150 for battery; €200 for converter.
				3. Variable reluctance harvester:	
				• Materials Cost per each EH	850€ prototype
				• Installation Cost (specify if labout cost is included) per one EH. If the cost cannot be provided it could be fine to provide hours of work needed.	60
				• Number of units per km (if available)	local source of energy ~ 40 cm lenght of rail
				• Power output	2.5 W per 90km/h in train passing time (simulation)
				• Life-cycle (years and/or hours)	10 years estimated
				• Batteries Cost (specify if the EH solution is a stand alone or requires batteries)	140
				4. Solar panel:	
				• Materials Cost per each EH	**€300/per unit (60 W)**
				• Installation Cost (specify if labout cost is included) per one EH. If the cost cannot be provided it could be fine to provide hours of work needed.	€250 (inc labour as in C.6)
				• Number of units per km (if available)	500 (maximum)
				• Power output	60 W / per unit
				• Life-cycle (years and/or hours)	20 year

				· Batteries Cost (specify if the EH solution is a stand alone or requires batteries)	€150 for battery; €200 for converter.
				5. Wind turbines:	
				· Materials Cost per each EH	€350/per unit
				· Installation Cost (specify if labout cost is included) per one EH. If the cost cannot be provided it could be fine to provide hours of work needed.	€300/per unit (inc labour as in C.6)
				· Number of units per km (if available)	100 (maximum)
				· Power output	300 W / per unit
				· Life-cycle (years and/or hours)	20 years
				· Batteries Cost (specify if the EH solution is a stand alone or requires batteries)	€150 for battery; €200 for converter.
C.5	OpEx	Operational (ordinary) maintenance cost (preventive and consecutive)	Costs and/or frequency of maintenance, energy storage (cost of recharge batteries, life-cycle, replacement, etc.). It includes costs occurring during the reference period to replace short-life machinery and/or equipment, e.g. engineering plants, filters and instruments, vehicles, furniture, office and IT equipment, etc.	1. Vibration harvester:	
				· OpEx (specify if labour cost is included) per one EH per period of time (1 year, 5 years, etc.). If the cost cannot be provided it could be fine to provide hours of work needed.)	0
				· Batteries maintenance (and time of recharge)	1 times per year
				· Cost and time of replacement EH objects	30 minut - 20 EUR
				2. Displacement harvester:	
				· OpEx (specify if labour cost is included) per one EH per period of time (1 year, 5 years, etc.). If the cost cannot be provided it could be fine to provide hours of work needed.)	~10% CapEx per 1 year
				· Batteries maintenance (and time of recharge)	~€20 / recharged unit (period for recharge: 6 - 48 months, depending on the battery type)
				· Cost and time of replacement EH objects	€150 / per unit; 2 hours.
				3. Variable reluctance harvester:	
				· OpEx (specify if labour cost is included) per one EH per period of time (1 year, 5 years, etc.). If the cost cannot be provided it could be fine to provide hours of work needed.)	4 x 1 hour per year
				· Batteries maintenance (and time of recharge)	2 times per year

				· Cost and time of replacement EH objects	3 hours - 80 EUR
				4. Solar panel:	
				· OpEx (specify if labour cost is included) per one EH per period of time (1 year, 5 years, etc.). If the cost cannot be provided it could be fine to provide hours of work needed.)	~10% CapEx per 1 year
				· Batteries maintenance (and time of recharge)	~€20 / recharged unit (period for recharge: 6 - 48 months, depending on the battery type)
				· Cost and time of replacement EH objects	€60 / per unit; 2 hours.
				5. Wind turbine:	
				· OpEx (specify if labour cost is included) per one EH per period of time (1 year, 5 years, etc.). If the cost cannot be provided it could be fine to provide hours of work needed.)	2 - 5 years
				· Batteries maintenance (and time of recharge)	6 months to 48 months
				· Cost and time of replacement EH objects	€150 / per unit; 2 hours.
C.6	CapEx and OpEx	Labour Cost for deployment of EH systems	Number of employee involved in the deployment and maintenance of future EH system, respectively (number of hours and cost per hour for installing, maintenance EH system)	1. Vibration harvester:	
				· Number of hours for installing EH system	1 hour or integrated solution inside sleeper
				· Cost per hour of workers for installing EH system	
				· Cost per hour of workers for maintenance EH system	
				2. Displacement harvester:	
				· Number of hours for installing EH system	3 hours
				· Cost per hour of workers for installing EH system	**€20/per hour**
				· Cost per hour of workers for maintenance EH system	**€20/per hour**
				3. Variable reluctance harvester:	
				· Number of hours for installing EH system	4 hours
				· Cost per hour of workers for installing EH system	
				· Cost per hour of workers for maintenance EH system	
				4. Solar panel:	

				· Number of hours for installing EH system	8 hours
				· Cost per hour of workers for installing EH system	**€20/per hour**
				· Cost per hour of workers for maintenance EH system	**€20/per hour**
				5. Wind turbine:	
				· Number of hours for installing EH system	10 hours
				· Cost per hour of workers for installing EH system	**€20/per hour**
				· Cost per hour of workers for maintenance EH system	**€20/per hour**

(*) Source: ETALON Consortium elaboration

6 MARKET ANALYSIS

The EH market is expected to increase, in particular, to grow from 311.2 Million of USD in 2016 to 645.8 Million by 2030, at a CAGR of 10.2% between 2017 and 2023[18]. A FMI research show that the global EH market will grow more than 10% of CAGR by the end of 2020 with a set of innovative applications. The main drivers of this growth can be the increasing of demand for safe, power-efficient, and durable systems that require minimum or no maintenance, extensive implementation of IoT devices in automation and energy harvesting technology in building and home automation, and increasing trend for green energy and favorable initiatives by the governments[19]. The light energy harvesting technology is likely to propel the energy harvesting system market growth but also transducers and secondary batteries are expected to contribute significantly in energy harvesting system market owing to the increasing adoption of transducer devices such as photovoltaic cells and piezoelectric devices to generate energy for low-power devices.

6.1 Stakeholders involved in the AS-IS and TO-BE scenarios

Stakeholder analysis is an another step of the economic model building since it helps to understand main stakeholder interests, influences, expectations and attitudes related to a project. Its purpose is to define the political and people-oriented aspects of the project environment, and the processes and functions that impact (or are impacted by) the project. The result is a better understanding of the stakeholders (e.g. interests, relationships), better decision making process and greater project acceptance by stakeholders.

According to the methodological approach adopted by ISMB analysts, the stakeholders' analysis represents the first step as it allows to gain a deep understanding of the main actors involved in the transition, of the interests they bring, and of the attention they deserve. To this end, we highlight a list of stakeholders, their description, their degree of involvement in the migration, and costs and benefits potentially yielded by the advent of a new network technology. These characterization of stakeholders involved in the AS-IS landscape acts as input for the analysis of TO-BE stakeholders.

The objective to strategically profile the key players and competitive landscape for market players and provide information on product launches, acquisitions, partnerships, agreements, contracts, and collaborations in the energy harvesting system market are important for the market analysis[20]. The vendor offerings should also been taken into consideration to determine the market segmentation and the prices.

Main stakeholders are: railway undertakings (RUs), that is the rail freight operators who provide the service of transporting goods, since 2007 competing on an open market in the EU), infrastructure managers; IMs, that is who own the infrastructure and are in charge, among other tasks, of allocating capacity on the infrastructure to railway undertakings, national regulatory bodies (in charge of ensuring fair and non-discriminatory access to the rail network to all railway undertakings); national safety authorities (responsible for issuing safety certificates for railway undertakings and for the delivery of authorisation of rail vehicles in cooperation with the European Railway Agency); government and EU community, as the main regulatory body for pushing the systems to invest and give subsidies in new green energy systems and provide incentives the openness of the markets; and manufacturers (i.e. suppliers of technologies who produce, deploy, install and, sometimes, maintain the infrastructure) as depicted in Table 10.

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[18] https://www.marketsandmarkets.com/Market-Reports/energy-harvesting-market-734.html

[19] The light energy harvesting technology has been extensively adopted because of the wide availability of solar energy source and availability of advanced research on the technology

[20] https://www.marketsandmarkets.com/Market-Reports/energy-harvesting-market-734.html

Table 10. Stakeholders involved in the migrationto EH systems

Stakeholders	Description	Degree of participation in the migration towards TEH	Costs	Benefits[21]
IMs	Infrastructure managers own the main infrastructure of cabling. They are the major investors for a new technology in the TEH	High	WP6 insights	High
RUs	Railway undertakings (rail freight operators) that manage the railway services. They have the ownership of rolling stocks and they also are relevant investor for on-board technology in TEH	Low	Low	High
Manufacturers (Suppliers of technology)	They are the key actors about providing new technologies and sustainability of the supply	High	High	High
Governments (EU)	It is a key driver for the innovation and to put the condition to make available a shift of paradigm towards new environmental friendly technologies. They can be the main actors to push a sustainable and credible migration of IMs into energy harvesting system	Medium	Medium-high	High, in terms of welfare analysis, in terms of socio-environmental and economic effects
Railway Authorities (i.e. UIC, etc.)	They should make interest of IMs and RUs. They have a central role in collecting intention and possibilities from IMs and RUs to implement new technologies	Medium	High	High

(*) Source: ETALON Consortium elaboration

The goal of the ETALON project is to aim at significantly reducing the life cycle cost of future railway project through elimination of cabling, which is expensive, subject to theft and difficult to maintain, especially in case of changes in the trackside layout.

While, for an IM, the advantages are clear (e.g. the installation of radio communication and energy harvesting for object controllers is more than compensated through elimination of cables and related one-time and recurrent costs), for RUs the conditions might appear controversial, because on-board train integrity is for them a new installation. However, the project believes that once there is an on-board power supply and communication system, significant cost savings can be achieved with both on-board maintenance and improved logistics for freight companies. It could be argued that a RU would significantly benefit of the reduced requirements for compatibility of vehicles with track circuits and/or axle counters (that are in fact an important cost factor in vehicle development and authorization, and a serious obstacle for interoperability). Unfortunately, these advantages would only appear in the medium or long term, once all EU

[21] t.b.e. = to be elaborated, means that costs/benefits for stakeholders as IMs, RUs and other actors will be evaluated during the project life (Task T3.2, T3.3 and T3.4) according to the selected scenarios.

railway infrastructure are migrated to operate with train detection systems. It is therefore very important, for the success of this project and the achievement of S2R goals, that the costs of on-board train integrity remain relatively low, both in terms of equipment cost and of operational cost.

Train detection systems and communication links between control centers and objects controllers represent a significant cost for Infrastructure Managers. ERTMS level 3, allows further reduction of costs by moving more ATP functions on-board. As of today, the applications without secondary train detection (e.g. track circuits, axle counters, a device on a railway that detects the passing of a train between two points on a track etc.) are practically possible only for fixed train compositions, where the integrity of the train is technically ensured by construction and the risk of “lost” vehicles along the line is negligible. The installation of electronic equipment for rail signaling will be enabled also in areas where it was not previously available due to the lack of energy supply. Solutions for train integrity at reasonable costs will make it possible for Railway Undertaking to exploit the advantages originated by increased performance of rail systems, without expensive new on-board installations, that could be very challenging, especially for small freight operators.

On the side of manufacturers, data on key vendor revenues through primary or secondary research is important. The bottom-up procedure has been employed to arrive at the overall market size for energy harvesting system from the revenue of the key players. Some reports also profile the most promising players in this market. The competitive landscape of the market presents an interesting picture where a large number of players have become a force to reckon with.

The key players in this market are EnOcean GmbH (Germany), Mide Technology Corporation (US), Lord Microstrain (US); secondary battery and capacitor providers such as Cymbet Corporation (US), Linear Technologies (US), Murata Manufacturing Co. Ltd., (Japan), and Infinite Power Solution Inc. (US); power management IC manufacturers such as Linear Technologies (US), Cypress Semiconductor Corp. (US), STMicroelectronics (Switzerland), Texas Instruments (US), and Fujitsu (Japan). Other prominent players competing in the industry include ABB Limited, Arveni, Enocean, Fujitsu, Cypress Semiconductor Corp., Green Peak Technologies, Honeywell International, Inc., Levant Power Corporation, Marlow Industries, Inc., Microchip Technology, Inc., MicroGen Systems, Maxim Integrated, G24 Innovations Limited, Texas Instruments Inc., and STMicroelectronics. Other notable players include Silicon Laboratories, Inc., Siemens AG, Murata Manufacturing Co., Ltd., Mide Technology Corporation, Laird Plc., Lord Microstrain, EnOcean GmbH, Cymbet Corporation, POWERleap, Inc., Schneider Electric, Linear Technology, Microstrain, and Micropelt.

The ecosystem for energy harvesting system comprises manufacturers such as EnOcean GmbH (Germany), Mide Technology Corporation (US), Lord Microstrain (US); secondary battery and capacitor providers such as Cymbat Corporation (US), Linear Technologies (US), Murata Manufacturing Co. Ltd., (Japan), and Infinite Power Solution Inc. (US); power management IC manufacturers such as Linear Technologies (US), Cypress Semiconductor Corp. (US), STMicroelectronics (Switzerland), Texas Instruments (US), and Fujitsu (Japan).

On the supply side we have a sort of oligopoly market with very few suppliers that dominates the market. Usually they are big companies that get contract for energy equipment with direct negotiated procurement tendering process. The main actors are Ansaldo, Alstom, BBRAIL, Bombardier.

CURRENT DEPLOYMENT: POWER SUPPLY EQUIPMENT ON FIELD

There are several main big suppliers of the installation of object controllers in European Railways: Thales, Siemens, Alstom, Bombardier, Ansaldo.

Each supplier can include a particular solution to the architecture of the system, but the similar principles are used for energy supply of this equipment.

For example, the Thales equipment has the energy distribution usually done through the connection to two different networks as follows:

• Primary network: 2200V network, from the Substation owned by Infrastructure Manager.

The principal components of the Primary network are:

- Line 2200V
- Power Transformer Reducer 2200/220V
- Isolation transformer
- UPS
- Power Cabinet
- Object Controller

• Secondary network: local (public) network connection in Low Voltage Board (LVB):

The principal components of the Secondary network are:

- Connection to LVB
- Electrical Panel Technical Building
- Power Cabinet
- Object Controller

The switching is done in the energy cabinet and the protections for the lighting, object controllers and power cabinet are installed in the Electrical Panel Technical Building.

The object controllers are normally fed from the Secondary network (to not overload the primary network, but if the secondary network fails, they are switched to the Power cabinet (2200V or UPS).

For other technologies, the operation is similar although it does not have an independent power cabinet like Thales (for instance, Siemens counts with auxiliary cabinet where the power supply for the signalling equipment is installed).

There is also may be another type of power network supply (local and generator, catenary, etc.), it could foresee redundancy or not, depending on the type of line and the reliability required by the customer.

Power consumption for an existing object controller is in the range of 10 - 20 Watts when controls up to 50 elements in field.

SWOT ANALYSIS

Hereafter, a brief SWOT analysis[22] (i.e. Strength-Weakness-Opportunities-Threats) has been done from a more qualitative point of view (Table 11 provides a description of what is the meaning of the SWOT, while Table 12 shows the results).

[22] SWOT is a qualitative methodology to elaborated by Albert S. Humphrey in the 1960s.

Table 11. SWOT: meaning and explanation

	Internal to the organisation (in the present)	External to the organisation (in the future)
Helpful to achieving the goal	**Strengths** • What does your organisation do better than others? • What are your unique selling points? • What do your competitors and customers in the market perceive as your strengths? • What is your organisation competitive edge?	**Opportunities** • What political, economic, social, cultural or technology (PEST) changes are taking place that could be favour to you? • Where are there currently gaps in the market or unfulfilled demand? • What new innovation could your organisation bring to the market?
Harmful to achieving the goal	**Weakness** • What do other companies do better than you? • What elements of your business add little or no value? • What do competitors and customers in your market perceive your weakness?	**Threats** • What political, economic, social, cultural or technology (PEST) changes are taking place that could be unfavourable to you? • What restraints to you face? • What is your competition doing that could negatively impact you?

Table 12. SWOT for migration towards a new energy harvesting systems

SWOT	Internal to the organisation	External to the organisation
Helpful to achieving the goal	**Strengths** • Cables reduction and decreasing of maintenance costs • Decreasing of costs from the cable theft • Decreasing costs for the energy power supply mainly in rural areas • Spillover effect on RUs costs decreasing (indeed, usually IMs recharge the energy power costs to the RUs) • Decreasing costs from the dismantling of optical fibers for communication systems (wireless communication solutions) • More feasibility/ease to substitute new EH materials with respect to cables substitution (indeed, for substituting cables it could be required to interrupt railway traffic and/or working in the night	**Opportunities** • Environmental improvement (spillover environmental effect) • Improvement of railway QoS in more remote areas • Public incentive (e.g. subsidies) for the deployment of LTE and WSN technologies in a more easy way (ERTMS L3 systems)

	with consequent higher labour costs)	
Harmful to achieving the goal	**Weaknesses** • Difficulties to implement the EH systems in the short run (Long run deployment due to the feasibility of the Eh technologies) • Not clear feasibility of TEH systems • Difficult to estimate, now, the real costs for EH materials for railway application • Impossibility to substitute all cables both for OCs and for FEs, at the same time. Indeed, it is difficult that in the short run the EH systems can generate sufficient power for both OCs and FEs. As a consequence, cables could remain also with the introduction of EH systems for SWOC	**Threats** • Not sustainable EH systems in the short run • A better Life Cycle Assessment (LCA) analysis needed to be implemented for each EH system

(*) Source: ETALON Consortium elaboration

7 ECONOMIC MODELLING

The current chapter represents the description of the model and the main insights. The model is based on the scenarios described in chapter 5.2 and on the variables described in chapters 5.3.

7.1 TECHNO-ECONOMIC PROPOSITION

We started from a model that can be adapted to several scenarios according to the different parameters and values. First, we defined CapEx and OpEx functions for the AS-IS scenario. Before explaining the CapEx and OpEx functions, we set the parameters and related acronyms for each in the following Table 13 and Table 14:

Table 13. Parameters for AS-IS: acronym and description

Name	Description
P(ESC)	Unitary price for energy supply only for connection of power network per OC
cextra	Extra cost for Zone B
αcab	Minutes of work for 1 mt of cable
β	Unit Labour Cost for cable Installation Team per 1 hour of work
γ	Unit cost of installation for 1 mt of cable
δ	Hours of work for connection for OC in urban area
ε	Cost of installation team
η	Hours of work (every year)
θ	Repair (every 1 year)
λ	Cost of maintenance team (per year) of OCs energy power
μ	Minutes for substitution of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)
ν	Meter of substitution in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)
β	Labour cost per hour
γ	Unit cost of installation for 1 mt of cable
ρ	Percentage of theft per year
σ	Additional cost for work in the night
αcab	Minutes of work for 1 mt of cable
γ	Material cost
pEN	Price of Energy per kWh
ConsOC	Consumption of energy per each OC (kWh)

(*) Source: ETALON Consortium elaboration

Table 14. Parameters for TO-BE: acronym and description

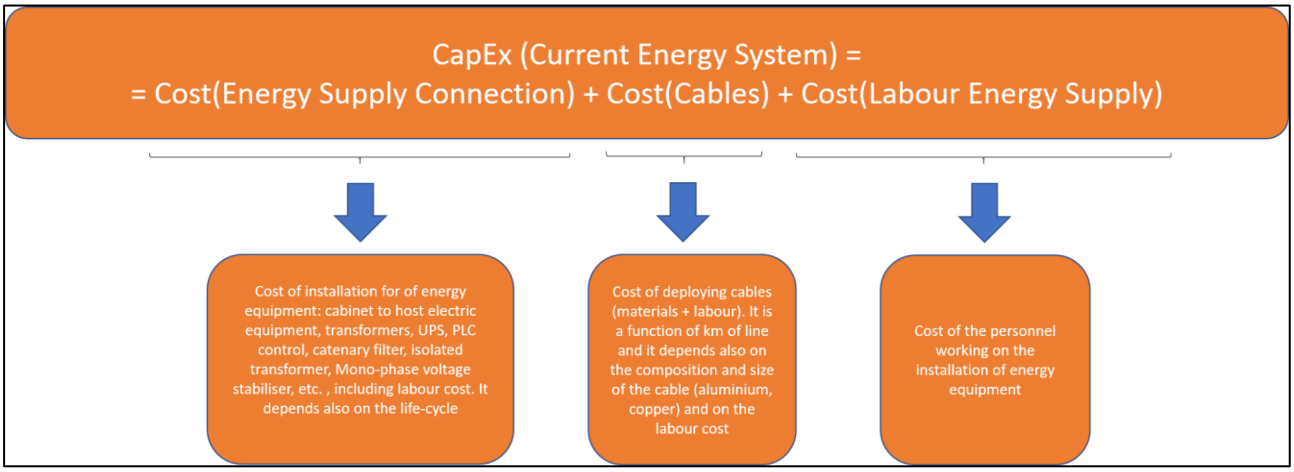
EH Type	Name	Description
VH	pTEH	Total price for Vibration harvesters

DH	pTEH	Total price for Displacement harvesters
RH	pTEH	Total price for Variable reluctance harvesters
SP	pTEH	Total price for Solar Panels
WT	pTEH	Total price for Wind turbines
VH	Lab(TEH)j	Labour cost per unit Vibration harvester
DH	Lab(TEH)j	Labour cost per unit Displacement harvester
RH	Lab(TEH)j	Labour cost per unit Variable reluctance harvester
SP	Lab(TEH)j	Labour cost per unit Solar Panel
WT	Lab(TEH)j	Labour cost per unit Wind turbine
VH	OpEx(%)j,TEH	% of CapEx per year
	C(Bat)j,TEH	Battery maintenance
DH	OpEx(%)j,TEH	% of CapEx per year
	C(Bat)j,TEH	Battery maintenance, mean
RH	OpEx(%)j,TEH	% of CapEx per year
	C(Bat)j,TEH	Battery maintenance
SP	OpEx(%)j,TEH	% of CapEx per year
	C(Bat)j,TEH	Battery maintenance
WT	OpEx(%)j,TEH	Maintenance 2 h every 2 - 5 years, mean
	C(Bat)j,TEH	Battery maintenance
	cteam	Cost of maintenance team
	Geo1	Geographical parameter (Remote area + 10%), areas with difficult access + 20%)
	Geo2	Geographical parameter (Area with difficult access + 20%)
	OverCost	Overhead costs
	μ	Minutes for dismantling of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)
	ν	Meter of dismantling in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)
	β	Labour cost per hour
	γ	Unit cost of installation for 1 mt of cable
	p(cab-cop)	Price of cables (copper) per kg
	w(cab-cop)	Weight of cable per mt
	%(cop)	Percentage of copper in 1 mt of cable

(*) Source: ETALON Consortium elaboration

CapEx has been defined as the sum of cost of energy equipment, cost of cables deployment and labour cost for energy supply (as depicted in Figure 28).

Figure 28. AS-IS CapEx: definition of function



(*) Source: ETALON Consortium elaboration

The cost of energy supply connection is the cost for connection of power network per OC installation, depending to the life cycle costs. The equipment is given by several items, as cabinet to host electric equipment, transformer (e.g. 2x2000 V), isolation transformer, UPS for 1 hour reserve, high voltage connection from electricity company, catenary filter (50 KVA), mono-phase voltage stabilizer (50 KVA), PLC control, energy distribution rack and protection box. It is difficult to find a common type of energy equipment for all the EU countries, hence, we use this a reference by considering the possible value as average values. Hereafter, in the Table 15, Table 16 and Table 17 and Table 18, we have some examples of costs for energy equipment for generic object controllers in a mainline, a regional and a HSL routes, respectively. From our empirical analysis we can find some generic statistic insights. The average value of OC per km is around 6 OC/km for regional line, 10 for HSL and mainline (with low discrepancy in terms of standard deviation) and 1 IXL every 20-30 km. The number is around 30-35 elements per OC in regional lines. In terms of expenses for energy supply, the mean is around 670,000€/OC (equivalently 44,000€/km) for regional line, 900,000€/OC (equivalently 77,500€/km) for HSL, 1,800,000€/OC (equivalently 200,000€/km) for mainline.

Table 15. Example of cost for energy equipment for OCs in a mainline route

Mainline (114 km, 12 OCs, 6 IXLs)	
CABINET TO HOST ELECTRIC EQUIPMENT	7,358 €
PLC CONTROL	3,000 €
MONO-PHASE VOLTAGE STABILIZER 50 KVA	13,816 €
CATENARY FILTER OF 50 KVA	5,882 €
UPS 40 KVA WITH 1 HOUR RESERVE	30,000 €
ISOLATED TRANSFORMER 20 KVA	4,500 €
HIGH VOLTAGE CONNECTION FROM ELECTRIC NETWORK COMPANY	70,000 €
TOTAL	**134,556 €**
Total x 15 OC	2,018,347 €

(*) Source: ETALON Consortium

Table 16. Example of cost for energy equipment for OCs in a regional route

REGIONAL (65 km, 4 OCs, 2 IXLs)	
CABINET TO HOST ELECTRIC EQUIPMENT	6,746 €

PLC CONTROL	2,859 €
ENERGY DISTRIBUTION RACK	6,000 €
PROTECTION BOX OF OCL	5,300 €
TRANSFORMER OF 10 KVA	1,800 €
MONO-PHASE VOLTAGE STABILIZER 50 KVA	13,816 €
CATENARY FILTER OF 50 KVA	5,882 €
UPS 40 KVA WITH 1 HOUR RESERVE	30,000 €
ISOLATED TRANSFORMER 20 KVA	4,500 €
HIGH VOLTAGE CONNECTION FROM ELECTRIC NETWORK COMPANY	70,000 €
TOTAL	**146,903 €**
Total x 4 OC	587,610 €

(*) Source: ETALON Consortium

Table 17. Example of cost for energy equipment for OCs in a HSL route

HSL (107 km, 7 OCs, 5 IXLs)	
CABINET TO HOST ELECTRIC EQUIPMENT FOR TRACKSIDE	7,941 €
PLC CONTROL	3,000 €
MONO-PHASE VOLTAGE STABILIZER 50 KVA	19,954 €
CATENARY FILTER OF 50 KVA	6,471 €
UPS 40 KVA WITH 1 HOUR RESERVE	35,580 €
ISOLATED TRANSFORMER 20 KVA	4,721 €
HIGH VOLTAGE CONNECTION FROM ELECTRIC NETWORK COMPANY	70,000 €
TOTAL	**147,667 €**
Total x 12 OC	1,772,000 €

(*) Source: ETALON Consortium

Table 18. Summarise of Lines and Energy Supply costs

Country	Name of the Line	TYPE	LENGTH (km)	OC	IXL	FEs	TOTAL ENERGY SUPPLY BUDGET	OC and FE ENERGY EQUIPMENT Cost	Power cables Installation Cost	Cable Maintenance Cost	Energy Power
Spain	**TORRELAVEGA - SANTANDER**	REGIONAL	35	12	6	n/a	570,263 €	297,000 €	232,968 €	n/a	n/a
Spain	ANTEQUERA - GRANADA	MAIN LINE	114	12	4	n/a	10,906,943 €	2,018,347 €	1,954,315 €	n/a	n/a
Spain	MONFORTE - MURCIA	MAIN LINE	70	6	3	n/a	7,222,979 €	1,034,004 €	1,001,988 €		
Spain	OLMEDO - ZAMORA	HIGH SPEED	107	7	5	n/a	10,155,711 €	1,772,000 €	1,734,648 €	n/a	n/a
Spain	ORENSE - SANTIAGO	HIGH SPEED	88	11	3	n/a	20,502,185 €	1,527,738 €	1,469,042 €	n/a	n/a
Spain	PEDRALBA - ORENSE	HIGH SPEED	125	11	3	n/a	20,898,850 €	1,527,738 €	1,469,042 €	n/a	n/a
Spain	**VANDELLOS - TARRAGONA**	REGIONAL	65	4	2	n/a	5,083,123 €	587,610 €	566,266 €	n/a	n/a
Greece	**KIATO - RODODAFNI**	HIGH SPEED	72.5	13	3	n/a	n/a	753,000 €	n/a	n/a	n/a
Italy	ASTI-TROFARELLO	REGIONAL	42	12	1	346	n/a	n/a	120,000 €	100,000 €	60KW
Italy	ASTI-ALESSANDRIA	REGIONAL	35	12	1	346	n/a	n/a	80,000 €	100,000 €	40KW

(*) Source: ETALON Consortium

From our empirical analysis we can find some generic statistic insights. The average value of OC per km is around 0.3 OC/km for regional line, and 0.1 for HSL and mainline (with low discrepancy in terms of standard deviation) and 1 IXL every 20-30 km. The number of field elements is around 30-35 elements per OC. In terms of expenses for energy supply, the mean is around 85,800€/OC (equivalently 8,700€/km) for regional line, 155,000€/OC (equivalently 77,500€/km) for HSL, 1,800,000€/OC (equivalently 14,800€/km) for mainline.

In the following Table 19, we compute as average values for energy equipment costs, the number of km for each OCs from our real data of 11 routes in different EU countries.

Table 19. Average values for energy equipment and different type of lines.

TYPE	LENGTH (km)	OBJECT CONTROLLER/km	INTERLOCKING/km	ENERGY SUPPLY BUDGET/OC	ratio (€/km)
HIGH SPEED	107	15	21	1,450,816 €	94,913 €
HIGH SPEED	88	8	29	1,863,835 €	232,979 €
HIGH SPEED	125	11	42	1,899,895 €	167,191 €
HIGH SPEED	72.5	6	24	57,923 €	10,386 €
MAIN LINE	114	10	29	908,912 €	95,675 €
MAIN LINE	70	12	23	1,203,830 €	103,185 €
REGIONAL	35	3	6	47,522 €	16,293 €
REGIONAL	65	16	33	1,270,781 €	78,202 €
REGIONAL	42	4	21	n/a	n/a
REGIONAL	35	3	35	n/a	n/a
REGIONAL	35	3	35	n/a	n/a
Average	-	8	27	1,087,939	99,853
Std Dev	-	5	9	672,243	68,707
Mean	LENGTH (km)	OBJECT CONTR./km	INTERLOCKING/km	ENERGY SUPPLY BUDGET/OC	ratio (€/km)
HSL	98	10	29	1,318,117	126,367
MAIN LINE	92	11	26	1,056,371	99,430
REGIONAL	42	6	26	659,151	47,248

(*) Source: ETALON Consortium elaboration

In our model, we consider, as input, the price of energy supply for connection of power network per OC and the extra cost for the zone B.

The cost for OC is a cost can be relevant of compared with a SWOC, in case of TEH, but we assume to be not relevant for the investment, hence, we exclude from our model, since it is difficult to collect data and to estimate the future cost for SWOC.

The cost of cables is relevant and it depends on the number of km of deployment and on the number of OCs are deployed along the route. We should consider both the cost of the raw material for cables (e.g. aluminium, copper) and the workforce (i.e. labour cost). From the data of Table 7 we have an average cost for workforce. The computation takes into account the minutes of work for 1 meter of cables, the unit cost of installation for 1 meter of cable (for the material) and the unit labour cost for cable installation team for 1 hour of work. From these main information we built the total cost for material and the labour cost in all the theoretical route.

Finally, the cost for personnel for installation of energy supply considers the hours of work for connection OCs and the cost of installation team, with an extra cost for connection power network in rural area.

In the Figure 29 we show the analytical functional form of the CapEx for AS-IS scenario.

Figure 29. AS-IS CapEx: analytical cost function

CapEx (Current Energy System) =
= $[CapEx(ESC)]_j$ + CapEx(Cab) + CapEx(LabEnSup)

$$CapEx(ESC) = \sum_{j=1}^{n} n(OC)_j \times \left[\overline{CapEx}(ESC)_{A_j} + c_{extra} \times \overline{CapEx}(ESC)_{B_j}\right]$$

$$CapEx(Cab) = \left(\alpha_{cab} \times L \times \frac{1{,}000\ km}{60\ h} \times \beta\right) + (\gamma \times L \times 1{,}000\ km)$$

$$CapEx(LabEnSup) = \sum_{j=1}^{n} \left(n(OC)_j \times \delta\right)_{A_j} + \sum_{j=1}^{n} (\varepsilon \times \xi)_{B_j}$$

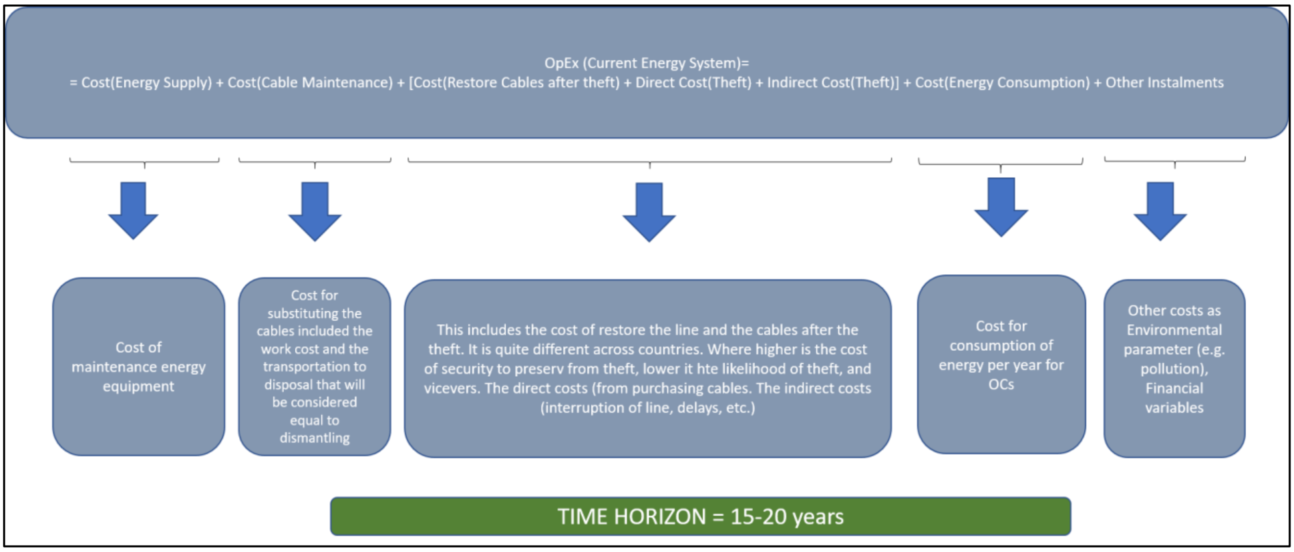
$$j = \{1, \dots, n\}$$

- A.1
- A.2
- A.4
- A.6
- A.12

(*) Source: ETALON Consortium elaboration

On the other side, the OpEx is a function of inputs, computed on yearly basis, along a period of time of 15 and/or 20 years, since there usual maintenance for OCs, cables and other equipment have this common time horizon. OpEx is the sum of energy supply for maintenance energy equipment (maintenance costs), cost for cable maintenance, cost of theft, cost of energy consumption and cost coming from other types of financial instalments (e.g. debt, taxes, etc.). The OpEx is depicted in Figure 30.

Figure 30. AS-IS OpEx: definition of cost function



(*) Source: ETALON Consortium elaboration

The cost of maintenance of energy supply, energy equipment, is represented by the number of hours of work per year, the cost of repair material and the labour cost of the maintenance team per hour.

The cost of maintenance of cables refer to the cost substitution cables including the transportation to the disposal. It has been computed by the minutes of work for 1 meter of cables, the average number of meters of cables to be substituted every year, the labour cost per hour of a typical team. From these values, we will compute a discounted cash flow for all the flows with defined interest rates and obsolescence rates.

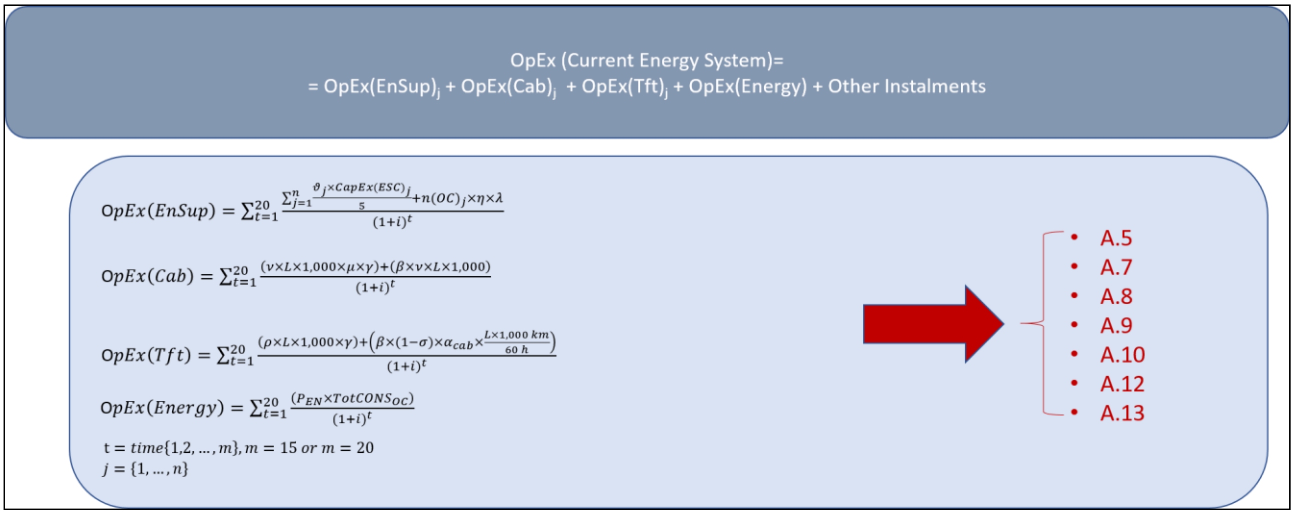
The cost of cable theft is characterised by three items: the cost of restore cables after theft, a direct costs from the cost of lost materials and to repurchase new ones, and indirect costs coming from the interruption of the line and delays caused to the trains. Every year we can compute several values from 134 to 1,000 of ton of theft of copper for an equivalent indirect costs of 20 days of delays of train per year and an average of 1,000 minutes of delay of train every day. The sum of direct and indirect cost of delay in train per year is around 20 millions and the total cost of cable theft is around 770 millions per year in some countries. In our model, we will compute a theoretical average value for this, since it is difficult to get precise estimation of cable theft per countries. In our model, since it is difficult to estimate the indirect costs, we will focus only on the direct costs for substituting cables after theft.

The cost of energy coming from the centralised power grid can be relevant even if, in some cases, IMs charge this cost on the railway undertakings (RU) in terms of euro per train per km for passage of trains along the line. However, we assume this cost for now is in charge on IMs. Today in Italy for instance the price of energy is around 0.10-0.20€ per kW.

Other costs and instalments can come from rent some fields where the OCs or cables are deployed, other financial costs of loans and interests and other variables linked to environmental issues (greenhouse emissions from power generation) that can represent a cost in terms of welfare analysis.

A more detailed description of the analytical function of AS-IS OpEx is depicted in the Figure 31.

Figure 31. AS-IS OpEx: analytical cost function



(*) Source: ETALON Consortium elaboration

Considering to the TO-BE scenarios, we consider the two main business cases: one for LTE deployment and the other for WSN deployment. The CapEx for the future EH systems is built by considering a route both with decentralised and centralised systems for both the two scenarios. The decentralised case in which we can have a every EH system for each FE (i.e. SWOC) and the centralised one where we can have on OC for many FEs, and where also the distance between the SWOCs should be affect the number of TEH systems to be deployed.

We consider also that there can be more than one EH system to provide energy to the same SWOC. Indeed, many systems cannot support alone the sufficient energy for SWOCs and they require to be enforced with other types of EH system together. Also the environmental conditions and the traffic in the line can affect the choice of one type of EH rather another one.

In the TO-BE scenarios, we consider a similar cost function for LTE and WSN according to the inputs described in the Table 9 for the deployment of new equipment and for dismantling to the old infrastructure. Cables are an important element since dismantling can generate a direct and indirect effect in terms of costs, possible revenues and welfare. On the one side, dismantling cables can generate direct effect to recover some raw material from them (e.g. aluminium and copper) and resell part of them to the market. On the other side, indirect effect is that no more cables means zero likelihood of theft and minus direct for IMs[23]. Moreover, another indirect effect is the reducing of pollution from decreasing the usage of traditional energy providing. Savings come also from the reducing need of energy from the power grid energy. On the part of the new TEH systems to be deployed, the costs will be more related to the capacity of these new systems to provide energy, cost of raw materials, installation and maintenance.

The CapEx for TO-BE scenarios (Figure 32 and Figure 33) is a function of material energy for equipment, labour cost for installing energy equipment and the cost of dismantling cables.

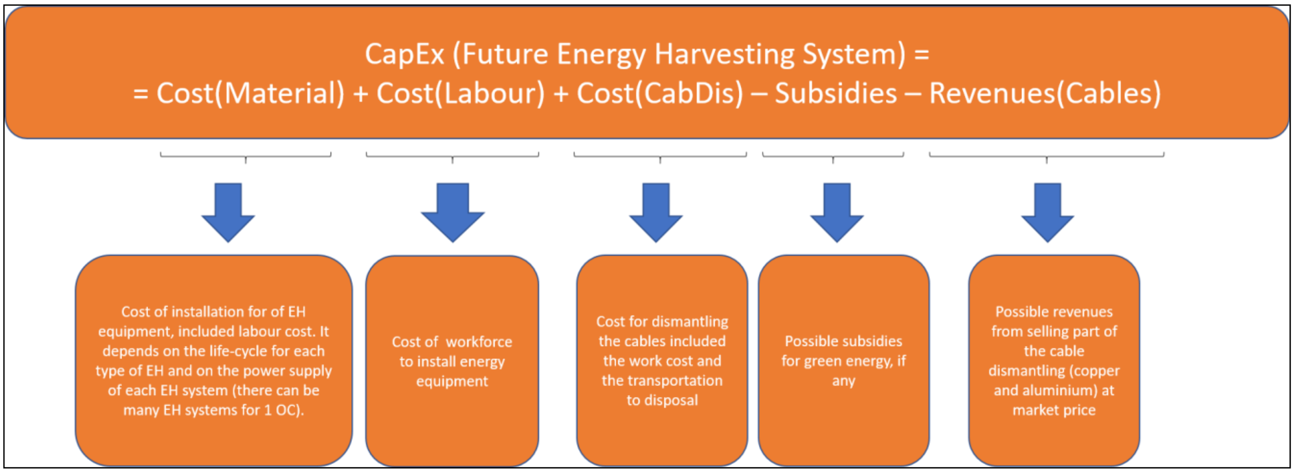
In the CapEx cost function, we consider also the possibility to have some subsidies from central authorities, government bodies, that can push and stimulate the change of the paradigm in a new more environmental friendly scenario and substitute green energy with the traditional fossil energy generation currently used to power OCs. This case is not unrealistic if we think about the past government incentives for green energy in many EU countries to stimulate public and private entities to invest in this. Actually, in many countries there are not incentives for private enterprises, but only for state-owned ones. IMs are private enterprise from a legal point of view

[23] Let consider also that the likelihood for EH systems to be stolen is lower than for the cables. Mainly in the case of solar panel, we can consider a percentage of20% of material thefts.

(*de iure*), even if, *de facto*, they are owned by the government. We should consider that in the future possible changes in EU regulations can permit do simplify the migration towards TEH systems, when and if it becomes technically feasible and economically viable. Indeed, the open issue coming from the current work, is that ETALON project should verify if the current TEH systems are feasible to be used for powering not only OCs for the part of the communication network for railway, but also all the FEs.

Finally, also the revenues from cables has been considered as a sort of salvage value. This value comes from the dismantling of cables and recover the value of the aluminium and, mainly, the copper inside cables. Part of the cable can be sold to the market and get revenues. Cables usually can be of two types: copper and aluminium. The first are more attractive for thief and more costly. The quotation of copper, indeed, today is quite high and it is also one of the reasons of theft in many routes. Today, the price of copper is quoted around euro 5,750 per ton, while for the aluminium is around euro 2,400 per ton. For the price of copper we make also an average estimation by considering that only part of the cable is of copper or aluminium and the rest is of other materials. So we consider only a share of the total diameter of cables by multiplying this for the price of raw materials[24]. A salvage values can arise also from recovering part of the material (e.g. cables) for other scopes.

Figure 32. TO-BE CapEx: definition of cost function



(*) Source: ETALON Consortium elaboration

[24] http://aice.anie.it/quotazione-lme-rame/#.Wsd0lUxuI-1

Figure 33. TO-BE CapEx: analytical cost function for LTE and WSN scenarios

CapEx (TEH) =
= Cost(Mat) + Cost(Lab) + CapEx (CabDis) – Sub – Rev(cab)

$$CapEx(Mat) = \sum_{j=1}^{n} p_{TEH} \times n(TEH)_j$$

$$CapEx(Lab) = \sum_{j=1}^{n} Lab(TEH)_j \times c(Team) \times n(TEH)_j$$

$$CapEx(CabDis) = \left(\frac{v \times L \times 1{,}000 \times \mu \times \pi}{60} + (\gamma \times v \times L \times 1{,}000)\right)$$

$$\mathrm{Rev}(Cab) = w(cab - cop) \times L \times 1{,}000 \times cop(\%) \times p(cab - cop)$$

$$\mathrm{Sub}(country) = yearly\ subsidies\ or\ incentives\ for\ green\ energy$$

(*) Source: ETALON Consortium elaboration

On the side of OpEx for TO-BE (Figure 34 and Figure 35), we consider the sum of maintenance cost, the cost of batteries, the replacement of EH systems after their own life cycle, the theft of TEH systems, the salvage value of EH objects after their dismantling and other financial instalments discounted today. The life cycle of EH system should be lower than 20 years and some of them cannot be reused after their life cycle.

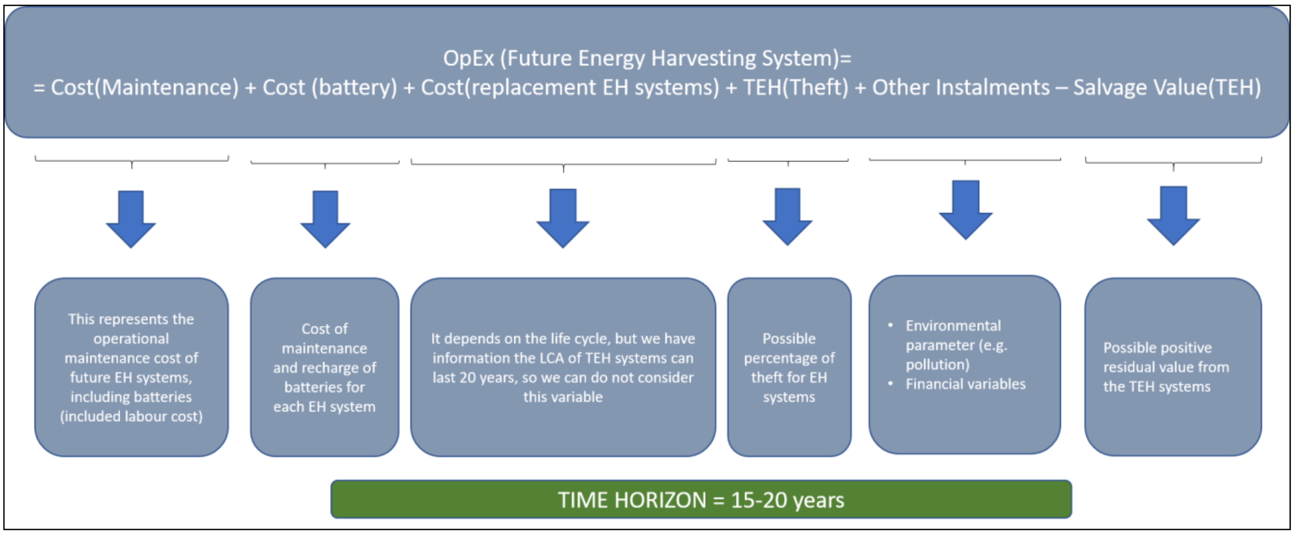
The cost of maintenance has been computed as a percentage of CapEx and the cost of battery maintenance: both of them change according to the type of EH. Moreover, in some cases, the cost of maintenance of some EH systems can be zero because they cannot be re-used but only totally substituted. We remind to the table for a detailed description of all the EH systems we consider for the model.

The cost of replacement EH systems also should be considered depending on the type of EH. In our model, we consider that all the EH systems can lasts around 20 years, hence, we cannot include in the computation.

The likelihood of theft for many of EH systems is very low and, in some cases, null. We consider in our model that only the solar panels can have a market value, hence, also can be subjected to thefts.

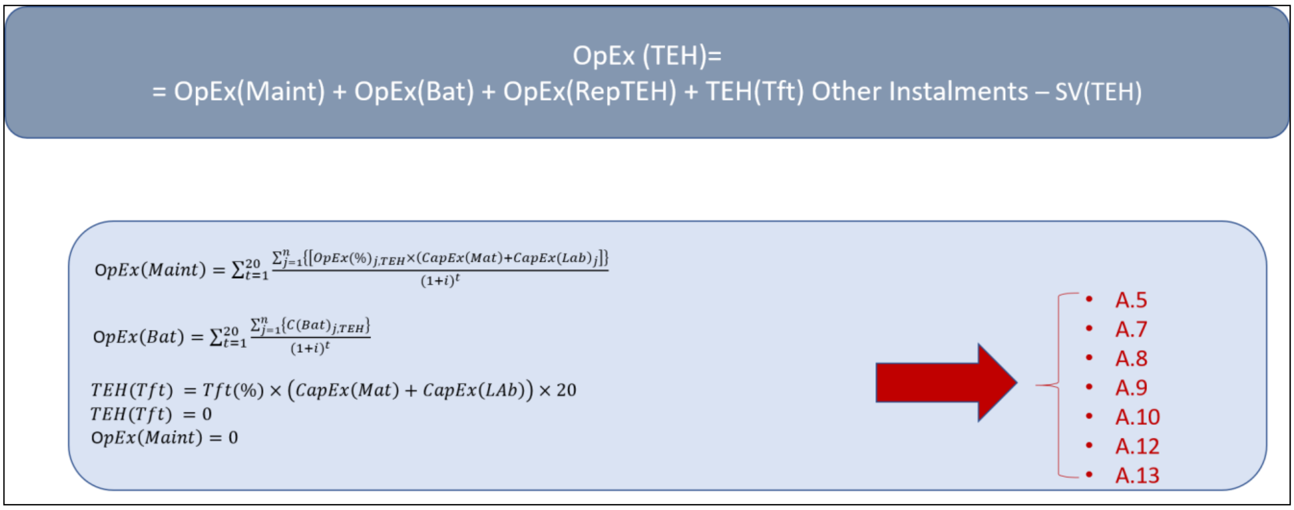
All the values of the OpEx have been discounted according to the discounted cash flow theory.

Figure 34. TO-BE OpEx: definition of cost function



(*) Source: ETALON Consortium elaboration

Figure 35. TO-BE OpEx: analytical cost function for LTE and WSN scenarios



(*) Source: ETALON Consortium elaboration

In the next chapters, we will provide the main assumptions, values of parameters and insights of the model.

7.2 CAPITAL BUDGETING MODELS RESULTS

This paragraph provides some insights of the model according to different assumption. The first tables (Table 20, Table 21 and Table 22) shows the selected values for the variables. Then, we show the results of the model by using these values (Table 23) and after we will highlight different results by changing some selected main variables.

Table 20. AS-IS selected values for inputs

Name	Description	Values	Unit
P(ESC)	Unitary price for energy supply only for connection of power network per OC	5,336	EUR
cextra	Extra cost for Zone B	0.8	EUR
αcab	Minutes of work for 1 mt of cable	1	minutes/mt
β	Unit Labour Cost for cable Installation Team per 1 hour of work	65.55	eur/h
γ	Unit cost of installation for 1 mt of cable	16	eur/mt
δ	Hours of work for connection for OC in urban area	86.55	h/OC
ε	Cost of installation team	92.38	eur/h
η	Hours of work (every year)	20	h/OC
θ	Repair (every 1 year)	0,3	n/a
λ	Cost of maintenance team (per year) of OCs energy power	48.46	eur/h
μ	Minutes for substitution of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)	1.5	minute/mt
ν	Meter of substitution in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	0.1	5-10%
β	Labour cost per hour	65.55	eur/mt
γ	Unit cost of installation for 1 mt of cable	16	eur/mt
ρ	Percentage of theft per year	0.2	%
σ	Additional cost for work in the night	0.15	%
αcab	Minutes of work for 1 mt of cable	1	minutes/mt
γ	Material cost	16	eur/mt
pEN	Price of Energy per kWh	0.111	EUR/kWh
ConsOC	Consumption of energy per each OC (kWh)	45	kWh

(*) Source: ETALON Consortium elaboration

Table 21. TO-BE (LTE) selected values for inputs

EH Type	Name	Description	Values	Unit
VH	pTEH	Total price for Vibration harvesters	500	EUR
DH	pTEH	Total price for Displacement harvesters	700	EUR
RH	pTEH	Total price for Variable reluctance harvesters	N/A	EUR
SP	pTEH	Total price for Solar Panels	650	EUR
WT	pTEH	Total price for Wind turbines	700	EUR
VH	Lab(TEH)j	Labour cost per unit Vibration harvester	0.54	Eur/TEH
DH	Lab(TEH)j	Labour cost per unit Displacement harvester	3	Eur/TEH
RH	Lab(TEH)j	Labour cost per unit Variable reluctance harvester	0	Eur/TEH
SP	Lab(TEH)j	Labour cost per unit Solar Panel	8	Eur/TEH
WT	Lab(TEH)j	Labour cost per unit Wind turbine	10	Eur/TEH
VH	OpEx(%)j,TEH	% of CapEx per year	0	%
	C(Bat)j,TEH	Battery maintenance	10	Eur/year
DH	OpEx(%)j,TEH	% of CapEx per year	0.1	%
	C(Bat)j,TEH	Battery maintenance, mean	20	Eur/year
RH	OpEx(%)j,TEH	% of CapEx per year	N/A	%
	C(Bat)j,TEH	Battery maintenance	N/A	Eur/year
SP	OpEx(%)j,TEH	% of CapEx per year	0.1	%
	C(Bat)j,TEH	Battery maintenance	20	Eur/year
WT	OpEx(%)j,TEH	Maintenance 2 h every 2 - 5 years, mean	0.67	Eur/year
	C(Bat)j,TEH	Battery maintenance	20	Eur/year
	cteam	Cost of maintenance team	48.46	eur/h
	Geo1	Geographical parameter (Remote area + 10%), areas with difficult access + 20%)	0.1	%
	Geo2	Geographical parameter (Area with difficult access + 20%)	0.2	%
	OverCost	Overhead costs	0.08	%
	μ	Minutes for dismantling of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)	0.035	minute/mt
	ν	Meter of dismantling in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	0.8	5-10%
	ß	Labour cost per hour	65.55	eur/mt
	γ	Unit cost of installation for 1 mt of cable	16	eur/mt
		Price of cables (copper) per ton	5,750	eur/ton
	p(cab-cop)	Price of cables (copper) per kg	5.75	eur/kg
	w(cab-cop)	Weight of cable per mt	0.317	Kg/mt
	%(cop)	Percentage of copper in 1 mt of cable	0.1	%

(*) Source: ETALON Consortium elaboration

Table 22. TO-BE (WSN) selected values for inputs

EH Type	Name	Description	Values	Unit
VH	pTEH	Total price for Vibration harvesters	500	EUR
DH	pTEH	Total price for Displacement harvesters	700	EUR
RH	pTEH	Total price for Variable reluctance harvesters	N/A	EUR
SP	pTEH	Total price for Solar Panels	650	EUR
WT	pTEH	Total price for Wind turbines	700	EUR
VH	Lab(TEH)j	Labour cost of Vibration harvester	0.54	Eur/TEH
DH	Lab(TEH)j	Labour cost of harvester	3	Eur/TEH
RH	Lab(TEH)j	Labour cost of Variable reluctance harvester	0	Eur/TEH
SP	Lab(TEH)j	Labour cost of Solar Panel	8	Eur/TEH
WT	Lab(TEH)j	Labour cost of Wind turbine	10	Eur/TEH
VH	OpEx(%)j, TEH	% of CapEx	0	%
	C(Bat)j,TEH	Battery maintenance	10	Eur/year
DH	OpEx(%)j, TEH	% of CapEx	0.1	%
	C(Bat)j,TEH	Battery maintenance, mean	20	Eur/year
RH	OpEx(%)j, TEH	% of CapEx	N/A	%
	C(Bat)j,TEH	Battery maintenance	N/A	Eur/year
SP	OpEx(%)j, TEH	% of CapEx	0.1	%
	C(Bat)j,TEH	Battery maintenance	20	Eur/year

WT	OpEx(%)j, TEH	Maintenance 2 h every 2 - 5 years, mean	0.67	Eur/year
	C(Bat)j,TEH	Battery maintenance	20	Eur/year
	cteam	Cost of maintenance team	48.46	eur/h
	Geo1	Geographical parameter (Remote area + 10%), areas with difficult access + 20%)	0.1	%
	Geo2	Geographical parameter (Area with difficult access + 20%)	0.2	%
	μ	Minutes for dismantling of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)	0.035	minute /mt
	ν	Meter of dismantling in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	0.8	5-10%
	β	Labour cost per hour	65.55	eur/mt
	γ	Unit cost of installation for 1 mt of cable	16	eur/mt
	p(cab-cop)	Price of cables (copper) per kg	5.75	eur/kg
	w(cab-cop)	Weight of cable per mt	0.317	Kg/mt
	%(cop)	Percentage of copper in 1 mt of cable	0.1	%

(*) Source: ETALON Consortium elaboration

Table 23. ECONOMIC RESULTS for AS-IS, TO-BE (LTE) and TO-BE (WSN) models

AS-IS	Values	TO-BE (LTE)	Values	TO-BE (WSN)	Values
TCO	12,185,586	TCO	2,767,456	TCO	1,309,747
TCO (net of revenues)	-	TCO (net of revenues)	2,708,763	TCO (net of revenues)	1,251,055
TCO per km	217,600	TCO per km	48,371	TCO per km	22,340
Total Cost for energy supply connection	90,712	Cost of material per zone and Total Cost	109,450	Cost of material per zone and Total Cost	371,500
Total cost or installation for all the route (CapEx)	957,180	Cost of Labour per zone and Total Cost	53,488	Cost of Labour per zone and Total Cost	37,065
Total Cost of personnel for installation of energy supply (CapEx)	134,724	Total Cost for dismantling cables	718,513	Total Cost for dismantling cables	718,513
Total CapEx	1,400,216	Total CapEx	956,582	Total CapEx	1,149,418
OpEx(Energy Supply)	218,621	OpEx for Maintenance and Battery (NPV)	1,467,419	OpEx for Maintenance and Battery (NPV)	128,921
OpEx(Cables Maintenance)	1,713,923				
OpEx (Cables Theft)	4,330,172	Thefts (for Solar panels only) per year	58,457	Thefts (for Solar panels only) per year	-
OpEx (Energy)	4,740,255		-		-
Total OpEx	11,002,970	Total OpEx	1,525,876	Total OpEx	128,921
Geographical parameter (Remote area + 10%), areas with difficult access + 20%)	-	Geographical parameter (Remote area + 10%), areas with difficult access + 20%)	10%	Geographical parameter (Remote area + 10%), areas with difficult access + 20%)	10%
Overhead costs		Overhead costs	8%	Overhead costs	-

		Revenues from selling cables (copper) per ton	58,693	Revenues from selling cables (copper) per ton	58,693
Interest Rate	2.00%	Interest Rate	2.00%	Interest Rate	2.00%
Time	20	Time	20	Time	20
		Meter of dismantling in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	0.8	Meter of dismantling in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	0.8
		Percentage of copper in 1 mt of cable	10%	Percentage of copper in 1 mt of cable	10%
		Total weight of cables to be dismantling	102,074	Total weight of cables to be dismantling	102,074
Length of the line	56				
Number of field objects in Zone A	197				
Number of field objects in Zone B	46				

(*) Source: ETALON Consortium elaboration

7.3 Guide Book

The Excel file attached to this document presents different sheets. The first, 'INSTRUCTION', describes the main steps of computation and the instruction to use the file to simulate the results.

The excel file has been built in order to have the possibility to change values according to the country specifics or more knowledge about inputs and variables of the model. The grey part represents the cells that can be filled in or where it is possible to change values. The orange cells shows the intermediate results of the model, while the red cells highlight the final results of TCO for each scenario.

Inputs to be inserted by each partner
Intermediate Results
Final Results

In the second sheet, '1.INPUTS' , there is the possibility to insert the information about the route with number of km, FEs and OCs for each zone, A and B, in all the grey fields.

Figure 36. INPUT for spreadsheet

1. INPUT DATA Zones (A_j) and (B_j) with j = (1,…,n)				ZONE A1	ZONE B1	ZONE A2	ZONE B2	ZONE A3	ZONE B3	ZONE A4	ZONE B4	ZONE A5	ZONE B5	ZONE A6
Main parameters			***Unit***											
L	Length of the line	56	*km*	1	12	1	10	1	5	1	10	1	13	1
d	Distance between Zones A		*km*		12		10		5		10		13	
f_j	Number of field objects in Zone A	197	*un*	90		65		30		12		0		0
f_j	Number of field objects in Zone B	46	*un*		8		12		3		10		13	
SWOC integration type														
ISWOC	i. SWOC and TEH integrated with FE	*0-1*	*%*	0,6	0	0,4	0	0,8	0	0	0	0	0	0
SSWOC	ii. SWOC controlling various FEs (enter maximum number n of FEs controlled by one SWOC)	*1-n*	*un*	15	1	15	1	10	1	10	1	1	1	1
ISWOC+SSWOC	iii. Total number of SWOC	*Sum*	*n/a*	40	8	41	12	9	3	12	10	0	13	0
Geographical/ environmental parameters														
	Remote area	*1*	*n/a*	0	1	0	0	0	0	0	0	0	0	0
	Defficult access (mountains, galleries, tunnels, etc.)	*1*	*n/a*	0	0	0	1	0	1	0	0	0	0	0

(*) Source: ETALON Consortium elaboration

The other sheets are the file of the model. Also there it is possible to insert value of inputs in the grey cells for all the scenarios, 2.AS-IS, 3.TO-BE(LTE) and 4.TO-BE(WSN). At the end of each sheet, there is the results of the TCO, results that can be found also in the sheet '5.COMPARISON'. For each scenario, the is also a sheet 'AS-IS NPV' where there is the computation of the Discounted Cash Flow for the OpEx items. It is important to say that some computation for Zone A and B have been computed in a different way by taking into account that some calculation can in Zone B have higher costs due to the difficult access areas. Hereafter, examples of computation are provided (Figure 37, Figure 38 and Figure 39).

Figure 37. Spreadsheet for AS-IS computation

	1. AS-IS ZONE A Zones (A_j) and (B_j) with j = (1,…,n)				ZONE A1	ZONE B1	ZONE A2	ZONE B2	ZONE A3	ZONE B3	ZONE A4	ZONE B4	ZONE A5	ZONE B5	ZONE A6	TOTAL
Quantity				***Unit***												
	f_j	Field objects	*From INPUT*	*Un*	90	8	65	12	30	3	12	10	0	13	0	***243,00***
	$n(OC)_j$	Object controllers	*1 OC/30 FEs*	*Un*	3	1	3	1	1	1	1	1	0	1	0	***13,00***
	L_j	Length	*From INPUT*	*km*	1	12	1	10	1	5	1	10	1	13	1	***56,00***
A. Material price of energy supply connection (CapEx)				***Unit***												
	P(ESC)	Unitary price for energy supply only for connection of power network per OC	*5336,01*	*EUR*												
	c_{extra}	Extra cost for Zone B	*0,8*	*EUR*												
		Cost per Zone		*EUR*	16008,03	9604,818	16008,03	9604,818	5336,01	9604,818	5336,01	9604,818	0	9604,818	0	***90712,17***
		Cost per km		*EUR*	16008,03	800,40	16008,03	960,48	5336,01	1920,96	5336,01	960,48	0,00	738,83	0,00	
A.	**CapEx (ESC)**	**Total Cost for energy supply connection**	***90.712***	***EUR***												
B. Cables (CapEx)				***Unit***												
	α_{cab}	Minutes of work for 1 mt of cable	*1*	*minutes/mt*												
		Total Time (minutes) of work for installation of cables in all the route	*56000,00*	*minutes*												
		Total Time (hours) of work for installation of cables in all the route	*933,33*	*h*												
		Labour cost per mt	*1,13*	*eur/mt*												
	β	Unit Labour Cost for cable Installation Team per 1 hour of work	*65,55*	*eur/h*												
		Total labour cost for all the hours of work to install cables in all the route	***61180***	***EUR***												
	γ	Unit cost of installation for 1 mt of cable	*16*	*eur/mt*												
		Total Material cost for all the route	***896000***	***EUR***												
B.	**CapEx (Cab)**	**Total cost or installation for all the route (CapEx)**	***957.180***	***EUR***												
C.	**CapEx (LabEnSup)**	**Total Cost of personnel for installation of energy supply (CapEx)**	***134.724***	***EUR***												
D. Maintenance Energy Supply (OpEx EnSup)				***Unit***												
	η	Hours of work (every year)	*20*	*h/OC*	60	20	60	20	20	20	20	20	0	20	0	***260,00***
	θ	Repair (every 1 year)	*0,3*	*n/a*	960,4818	576,28908	960,4818	576,28908	320,1606	576,28908	320,1606	576,28908	0	576,28908	0	***5442,73***
	λ	Cost of maintenance team (per year) of OCs energy power	*48,46*	*eur/h*	2907,6	969,2	2907,6	969,2	969,2	969,2	969,2	969,2	0	969,2	0	***12599,60***
		Cost of Energy Supply per year	***18042,33***	***EUR***	3868,0818	1545,48908	3868,0818	1545,48908	1289,3606	1545,48908	1289,3606	1545,4891	0	1545,4891	0	***18042,33***
D.	**OpEx(EnSup)**	**NPV (En Sup)**	***218.621***	***EUR***												
		Cost per km per year (price/km)	***322,18***	***eur/km***	3868,0818	128,790757	3868,0818	154,548908	1289,3606	309,097816	1289,3606	154,54891	0	118,88378	0	***322,18***
		Total Cost per km per 20 years (price/km * 20 years)	***3903,948564***	***eur/km***												
E. Maintenance (substitution) Cables (OpEx)				**Unit**												
	μ	Minutes for substitution of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)	*1,5*	*minute/mt*												
	ν	Meter of substitution in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	*10%*	*5-10%*												
		Total mt of cables to be substituted in all the route, per year	***5600***	*mt*												
		Total minutes for sustituting cables in all the route, per year	*8400*	*minutes*												
		Total hours for sustituting cables in all the route, per year	*140*	*hours*												
	β	Labour cost per hour	*65,55*	*eur/mt*												
		Total Labour Cost for substituting cables per year in all the route per year	***9177***	***EUR***												
	γ	Unit cost of installation for 1 mt of cable	*16*	*eur/mt*												
		Total cost for to substitute material in all the route per year	*89600*	*EUR*												
		Total Cost for to maintenance of cables in all the route per year	***98777***													
E.	**OpEx(Cab)**	**NPV (Cables)**	***1.713.923***													
E.	**OpEx(Cab)**	**NPV (Cables)**	***1.713.923***													
F. Theft cables (OpEx) Direct Cost for substituting cables theft				***Unit***												
	ρ	Percentage of theft per year	*0,2*	*%*												
		Total mt of cables to be substituted after theft in all the route, per year	*11200*	*mt*												
	σ	Additional cost for work in the night	*15%*	*%*												
		Unit Labour Cost for cable Installation Team per 1 hour of work	*75,3825*	*eur/h*												
	α_{cab}	Minutes of work for 1 mt of cable	*1*	*minutes/mt*												
		Total Labour Cost for substituting cables after theft per year in all the route per year	*70357*	*EUR*												
	γ	Material cost	*16*	*eur/mt*												
		Total Material cost after theft for all the route	*179200*	*EUR*												
		Total Cost for Theft per year	***249557***	***EUR***												
F.	**OpEx (Tft)**	**NPV (Theft)**	***4.330.172***	***EUR***												
G. Energy consumption (OpEx)				***Unit***												
	p_{EN}	**Price of Energy per kWh**	***0,111***	*EUR/kWh*												
	$Cons_{OC}$	**Consumption of energy per each OC (kWh)**	***45***	*EUR*												
	$TotCons_{OC}$	**Total consumption of energy per OC per year (Total kWh)**	***164.250***	*kWh*												
G.	**OpEx (Energy)**	**Total Cost for Energy for zone (20years)**	***4.740.255***	***EUR***	54695,25	18231,75	54695,25	18231,75	18231,75	18231,75	18231,75	18231,75	0	18231,75	0	237012,75
TOTAL COST OF OWNERHSIP					12.185.586											
TOTAL KILOMETRIC COST					217.599,76											

Figure 38. Spreadsheet for TO-BE (LTE) computation

1.TO-BE, energy harvesters deployment, LTE technology
Zones (A_j) and (B_j) with j = (1,...,n)

Matteo Ferraris:
For This scenario, we consider only the deployment of DH, SP and WT, not VH and RH

				Unit	ZONE A1	ZONE B1	ZONE A2	ZONE B2
Quantity				**Unit**				
Portion of harvesters								
VH	$n(TEH)_j$	i. Vibration harvesters		Unit	0	0	0	0
DH	$n(TEH)_j$	ii. Displacement harvesters		Unit	37	8	38	12
RH	$n(TEH)_j$	iii. Variable reluctance harvesters		Unit	0	0	0	0
SP	$n(TEH)_j$	iv. Solar Panels		Unit	3	0	3	0
WT	$n(TEH)_j$	v. Wind turbines (as a back up to Solar panels)		Unit	3	0	3	0
		Total			43	8	44	12
A. Material price (CapEx)			**Unit price**	**Unit**				
VH	p_{TEH}	Total price for Vibration harvesters	500	EUR	0	0	0	0
DH	p_{TEH}	Total price for Displacement harvesters	700	EUR	25900	5600	26600	8400
RH	p_{TEH}	Total price for Variable reluctance harvesters	N/A	EUR				
SP	p_{TEH}	Total price for Solar Panels	650	EUR	1950	0	1950	0
WT	p_{TEH}	Total price for Wind turbines	700	EUR	2100	0	2100	0
A.	**CapEx (Mat)**	**Cost of material per zone and Total Cost**	**109.450**	EUR	29950	5600	30650	8400
		Cost per km		EUR				
B. Labour cost (CapEx)			**Hours**	**Unit**				
VH	$Lab(TEH)_j$	Labour cost per unit Vibration harvester	0,54	Eur/TEH	0	0	0	0
DH	$Lab(TEH)j$	Labour cost per unit Displacement harvester	3	Eur/TEH	10254,18	2217,12	10531,32	3325,68
RH	$Lab(TEH)j$	Labour cost per unit Variable reluctance harvester		Eur/TEH	0	0	0	0
SP	$Lab(TEH)j$	Labour cost per unit Solar Panel	8	Eur/TEH	2217,12	0	2217,12	0
WT	$Lab(TEH)j$	Labour cost per unit Wind turbine	10	Eur/TEH	2771,4	0	2771,4	0
	C(Team)	Cost of installation team	92,38	Eur/h				
B.	**CapEx (Lab)**	**Cost of Labour per zone and Total Cost**	**53.488**	EUR	15242,7	2217,12	15519,84	3325,68
C. Total CapEx, life cycle 20 years for all TEH				**Unit**				
VH		Vibration harvesters		EUR	0	0	0	0
DH		Displacement harvesters		EUR	36154,18	7817,12	37131,32	11725,68
RH		Variable reluctance harvesters		EUR	0	0	0	0
SP		Solar Panels		EUR	4167,12	0	4167,12	0
WT		Wind turbines		EUR	4871,4	0	4871,4	0
C. = A + B	**CapEx (Labour+Mat)**	**Cost per zone and Total Cost**	**162.938**	EUR	45192,7	7817,12	46169,84	11725,68
		Cost per km		EUR				

D. OpEx, 20 years			**per TEH**	**Unit**			
VH	$OpEx(\%)_{j,TEH}$	% of CapEx per year	0%	%	0,00	0,00	0,00
	$C(Bat)_{j,TEH}$	Battery maintenance	10	Eur/year	0,00	0,00	0,00
DH	$OpEx(\%)_{j,TEH}$	% of CapEx per year	10%	%	3615,42	781,71	3713,13
	$C(Bat)_{j,TEH}$	Battery maintenance, mean	20	Eur/year	14800,00	3200,00	15200,00
RH	$OpEx(\%)_{j,TEH}$	% of CapEx per year	N/A	%			
	$C(Bat)_{j,TEH}$	Battery maintenance	N/A	Eur/year			
SP	$OpEx(\%)_{j,TEH}$	% of CapEx per year	10%	%	416,71	0,00	416,71
	$C(Bat)_{j,TEH}$	Battery maintenance	20	Eur/year	1200,00	0,00	1200,00
WT	$OpEx(\%)_{j,TEH}$	Maintenance 2 h every 2 - 5 years, mean	0,67	Eur/year	1948,09	0,00	1948,09
	$C(Bat)_{j,TEH}$	Battery maintenance	20	Eur/year	1200,00	0,00	1200,00
	c_{team}	Cost of maintenance team	48,46	eur/h	48,46	48,46	48,46
D.	**OpEx(Maint+Bat)**	**OpEx for Maintenance and Battery (NPV)**	**1.467.419**	EUR	**408536,45**	**69088,41**	**417172,50**
		Cost per km/1 year	Price/km/YEAR	eur/km			
		Cost per km/20 years	Price/km*20 YEARS	eur/km			
TOTAL CAPEX + OPEX					453.729	76.906	463.342
E. Additional costs							
	Geo_1	**Geographical parameter (Remote area + 10%), areas with difficult access + 20%)**	10%	%	453729,1489	84596,0834	463342,3402
	Geo_2	**Geographical parameter (Area with difficult access + 20%)**	20%	%	453729,1489	84596,0834	463342,3402
	OverCost	**Overhead costs**	8%	%	490027,4808	91363,77007	500409,7274
F. THEFTS							
F.	**$OpEx(tft)_{TEH}$**	**Thefts (for Solar panels only) per year**	20%	**58.457**	19485,6	0	19485,6

G. Dismantling Cables (CapEx)				Unit		
	μ	Minutes for dismantling of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)	0,035	minute/mt		
	ν	Meter of dismantling in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	80%	5-10%		
		Total mt of cables to be dismantled in all the route, per year	44.800	mt		
		Total minutes for dismantling cables in all the route, per year	1568	minutes		
		Total hours for dismantling cables in all the route, per year	26,13333333	hours		
	β	Labour cost per hour	65,55	eur/mt		
		Total Labour Cost for substituting cables per year in all the route per year	**1713,04**	**EUR**		
	γ	Unit cost of installation for 1 mt of cable	16	eur/mt		
		Total cost for to substitute material in all the route per year	716800	EUR		
		Total Cost for to maintenance of cables in all the route per year	**718513,04**			
G.	**CapEx(CabDis)**	**Total Cost for dismantling cables**	**718.513**	**EUR**		
TOTAL COST OF OWNERHSIP					**2.767.456**	EUR
TOTAL KILOMETRIC COST					**49.418,85**	eur/km
H. Revenues from cables						
		Price of cables (copper) per ton	**5.750**	**eur/ton**		
	p(cab-cop)	**Price of cables (copper) per kg**	**5,75**	**eur/kg**		
	w(cab-cop)	**Weight of cable per mt**	**0,317**	**Kg/mt**		
	%(cop)	**Percentage of copper in 1 mt of cable**	**10%**	**%**		
		Total weight of cables to be dismantling	**102.074**	**Kg**		
H.	**Rev(cab)**	**Revenues from selling cables (copper) per ton**	**58.693**	**EUR**		
TOTAL COST OF OWNERHSIP at the net to the revenues from cables					**2.708.763**	EUR
TOTAL KILOMETRIC COST					**48.370,77**	eur/km

Figure 39. Spreadsheet for TO-BE (WSN) computation

1.TO-BE, energy harvesters deployment, WSN technology **Zones (A_j) and (B_j) with j = (1,...,n)**					ZONE A1	ZONE B1	ZONE A2	ZONE B2	ZONE A3	ZONE B3	ZONE A4	ZONE B4	ZONE A5	ZONE B5	ZONE A6	TOTAL
Quantity				**Unit**												
Portion of harvesters																
VH	**n(TEH)ⱼ**	i. Vibration harvesters		n/a	90	128	65	112	30	53	12	110	0	143	0	743,00
DH	n(TEH)ⱼ	ii. Displacement harvesters		n/a												0,00
RH	n(TEH)ⱼ	iii. Variable reluctance harvesters		n/a												0,00
SP	n(TEH)ⱼ	iv. Solar Panels		n/a												0,00
WT	n(TEH)ⱼ	v. Wind turbines (as a back up to Solar panels)		n/a												0,00
		Total		n/a	90	128	65	112	30	53	12	110	0	143	0	743,00
A. Material price			**Unit price**	**Unit**												
VH	p_{TEH}	Total price for Vibration harvesters	500	EUR	45000	64000	32500	56000	15000	26500	6000	55000	0	71500	0	371500,00
DH	p_{TEH}	Total price for Displacement harvesters	700	EUR	0	0	0	0	0	0	0	0	0	0		0,00
RH	p_{TEH}	Total price for Variable reluctance harvesters	N/A	EUR												
SP	p_{TEH}	Total price for Solar Panels	650	EUR	0	0	0	0	0	0	0	0	0	0	0	0,00
WT	p_{TEH}	Total price for Wind turbines	700	EUR	0	0	0	0	0	0	0	0	0	0	0	0,00
A.		**CapEx (Material)**	**371.500**	**EUR**	45000	64000	32500	56000	15000	26500	6000	55000	0	71500	0	371500,00
		Price per km	6.634	EUR												6633,93
B. Labour cost			**Hours**	**Unit**												
VH	**Lab(TEH)ⱼ**	Labour cost of Vibration harvester	0,54	Eur/TEH	4489,668	6385,3056	3242,538	5587,1424	1496,556	2643,9156	598,6224	5487,372	0	7133,5836	0	37064,70
DH	**Lab(TEH)ⱼ**	Labour cost of harvester	3	Eur/TEH	0	0	0	0	0	0	0	0	0	0	0	
RH	**Lab(TEH)ⱼ**	Labour cost of Variable reluctance harvester		Eur/TEH	0	0	0	0	0	0	0	0	0	0	0	
SP	**Lab(TEH)ⱼ**	Labour cost of Solar Panel	8	Eur/TEH	0	0	0	0	0	0	0	0	0	0	0	
WT	**Lab(TEH)ⱼ**	Labour cost of Wind turbine	10	Eur/TEH	0	0	0	0	0	0	0	0	0	0	0	
	c_{team}	Cost of installation team	92,38	Eur/h												
B.		**CapEx (Labour)**	**37.065**	**EUR**	4489,668	6385,3056	3242,538	5587,1424	1496,556	2643,9156	598,6224	5487,372	0	7133,5836	0	37064,70
C. CapEx cost, 20 years				**Unit**												
VH		Vibration harvesters		EUR	49489,668	70385,3056	35742,538	61587,142	16496,556	29143,916	6598,6224	60487,372	0	78633,584	0	408564,70
DH		Displacement harvesters		EUR	0	0	0	0	0	0	0	0	0	0	0	0,00
RH		Variable reluctance harvesters		EUR	0	0	0	0	0	0	0	0	0	0	0	0,00
SP		Solar Panels		EUR	0	0	0	0	0	0	0	0	0	0	0	0,00
WT		Wind turbines		EUR	0	0	0	0	0	0	0	0	0	0	0	0,00
C.		**CapEx (Material + Labour)**	**408.565**	**EUR**	49489,668	70385,3056	35742,538	61587,142	16496,556	29143,916	6598,6224	60487,372	0	78633,584	0	408564,70
		Cost per km	7.295,80	EUR												7295,80
D. OpEx, 20 years			**per TEH**	**Unit**												
VH	**OpEx(%)j,TEH**	% of CapEx	0%	%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	C(Bat)j,TEH	Battery maintenance	10	Eur/year	900,00	1280,00	650,00	1120,00	300,00	530,00	120,00	1100,00	0,00	1430,00	0,00	7430,00
DH	**OpEx(%)j,TEH**	% of CapEx	10%	%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	C(Bat)j,TEH	Battery maintenance, mean	20	Eur/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
RH	**OpEx(%)j,TEH**	% of CapEx	N/A	%												0,00
	C(Bat)j,TEH	Battery maintenance	N/A	Eur/year												0,00
SP	**OpEx(%)j,TEH**	% of CapEx	10%	%	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	C(Bat)j,TEH	Battery maintenance	20	Eur/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
WT	**OpEx(%)j,TEH**	Maintenance 2 h every 2 - 5 years, mean	0,67	Eur/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	C(Bat)j,TEH	Battery maintenance	20	Eur/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	c_{team}	Cost of maintenance team	48,46	eur/h	48,46	48,46	48,46	48,46	48,46	48,46	48,46	48,46	48,46	48,46	48,46	533,06
		Number of hours of maintenance per year	1													
D.		**OpEx(Maint+Bat)**	**128.921**		**Matteo Ferraris:** Which number can we put here?	00	650,00	1120,00	300,00	530,00	120,00	1100,00	0,00	1430,00	0,00	7430,00
		Cost per km/1 year	Price/km/YEAR	eur/km												6,63
		Cost per km/20 years	Price/km*20 YEARS	eur/km												132,68
		CAPEX + OPEX	**537.486**	**EUR**	50389,67	71665,31	36392,54	62707,14	16796,56	29673,92	6718,62	61587,37	0,00	80063,58	0,00	537.486
E. Additional costs															Check:	415994,70
	Geo₁	**Geographical parameter (Remote area + 10%), areas with (**	10%	%	50389,668	78831,8362	36392,538	62707,142	16796,556	29673,916	6718,6224	61587,372	0	80063,584	0	591.234
	Geo₂	**Geographical parameter (Area with difficult access + 20%)**	20%	%	50389,668	78831,8362	36392,538	75248,571	16796,556	35608,699	6718,6224	61587,372	0	80063,584	0	644.983
F. THEFT																
F.	**OpEx(tft)TEH**	Thefts (for Solar panels only) per year	20%		0	0	0	0	0	0	0	0	0	0	0	0,00

G. Dismantling Cables (CapEx)				Unit		
	μ	Minutes for dismantling of 1 mt of cables (work and transportation to the disposal, that will be equal to dismantling)	*0,035*	*minute/mt*		
	ν	Meter of dismantling in terms of percentage of renewable cables on the total length of the route, per year (thefts are not be considered here)	*80%*	*5-10%*		
		Total mt of cables to be dismantled in all the route, per	***44.800***	*mt*		
		Total minutes for dismantling cables in all the route, per year	*1568*	*minutes*		
		Total hours for dismantling cables in all the route, per	*26,13333333*	*hours*		
	β	Labour cost per hour	*65,55*	*eur/mt*		
		Total Labour Cost for substituting cables per year in all the route per year	***1713,04***	***EUR***		
	γ	Unit cost of installation for 1 mt of cable	*16*	*eur/mt*		
		Total cost for to substitute material in all the route per year	*716800*	*EUR*		
		Total Cost for to maintenance of cables in all the route per year	***718513,04***			
G.	**CapEx(DisCab)**	**NPV (DisCables)**	***718.513***			
TOTAL COST OF OWNERHSIP					**1.309.747**	***EUR***
TOTAL KILOMETRIC COST					**23.388,35**	***eur/km***
H. Revenues from cables						
		Price of cables (copper) per ton	**5750**	***eur/ton***		
	p(cab-cop)	**Price of cables (copper) per kg**	**5,75**	***eur/kg***		
	w(cab-cop)	**Weight of cable per mt**	**0,317**	***Kg/mt***		
	%(cop)	**Percentage of copper in 1 mt of cable**	**10%**	***%***		
		Total weight of cables to be dismantling	**102074**	***Kg***		
H.	**Rev(cab)**	**Revenues from selling cables (copper) per ton**	***58.693***	***EUR***		
TOTAL COST OF OWNERHSIP (net with the revenues from cables)					**1.251.055**	***EUR***
TOTAL KILOMETRIC COST					**22.340,27**	***eur/km***

8 CONCLUSION

The present deliverable is referred to the WP6 - D6.1 “Analysis of the Economic Models Energy Harvesting System” - in the framework of the project ETALON, which is a Shift2Rail project complementary to X2Rail-1 and X2Rail-2. ETALON focuses on the adaptation of energy harvesting methodologies for trackside and on-board signalling and communication devices, being the project scope divided into two work-streams. The WP6 and the D6.1 correspond to the second work-stream focuses on the development of competitive energy harvesting solutions for enhancing trackside object controller deployment, with the vision to minimizing trackside infrastructure, especially cabling.

This work is one of the first steps and tempts to build an architecture of the current energy systems, deployed along the routes in many EU countries, and the future energy harvesting systems to be deployed according to the future technologies that can permit the migration towards this green and more economically friendly energy systems. The D6.1 is also a work about the building of new possible economic models useful for a better analysis of the economic viability of the future EH systems.

As this WP6 represents the first stage of the project, the model would not have the to provide precise results and conclusions, since at this stage of ETALON many information are still pending and many inputs should be validated in a more detailed way at the end of the project. This is a methodology about how to build a set of scenarios, a set of algorithm to help partners along the duration of the project for making decision about the economic viability of the migration. For this reason, we will provide also a guide book and an excel file to be used for the partners in order to better estimate all the scenarios.

In our deliverable, after making an analysis of the current energy systems and the main items involved in the economic computation of the total cost of ownership for IMs, we have built a more plausible and feasible architecture for future EH systems by considering two main technologies: LTE and WSN deployment. In our model, we considered 5 main types of EH technologies: vibration harvester, displacement harvester, variable reluctance harvester, solar panel and wind turbines.

From this, we selected a set of inputs and parameters relevant both from technical and economic point of view, according to the opinion and consideration coming from the Partners of the Consortium and from the literature. For each of these values, we collect primary and secondary data and information useful for the economic simulation. However, we remind to the future steps of the project for a more detailed and clear evaluation of the model, since many new information and data can arise during the following of the project.

We built a spreadsheet where we simulate the three main scenarios: scenarios 0, the counterfactual one (AS-IS), and the scenario with LTE and SWN (TO-BE) where more than EH system can be used in a centralised or decentralised way.

The output of this deliverable is the models and methodology to evaluate the economic opportunity to migrate towards a new system of energy useful for a decision maker.

Our first findings show that EH can be more viable with respect the current energy powering systems by considering the TCO. The reasons seem to be not much in the CapEx items, but in the OpEx of the future systems that can be more lower that the OpEx of AS-IS scenario, where theft of cables and maintenance of cable cover a high portion of expenditure.

These results require to have a more deep analysis during the next months and it will be a goal of the dissemination activities to use this model and make simulation and sensitivity analysis to make the model more robust and clear.

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