D6.2 – COST/BENEFIT ANALYSIS AND BUSINESS MODELLING

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Short Description

Report on the cost/benefit analysis and the business models for the SEAM4US subsystems

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EXECUTIVE SUMMARY

The purpose of this document is to present the methodology and results of the cost benefit analysis and business model design for the SEAM4US project.

The SEAM4US system prototype is analysed in the first part of the deliverable. The system has been divided in 6 standalone subsystems that can seamlessly integrate into one. This division was initially presented in WP7 deliverables and is further pursued in this piece of work. The cost benefit analysis is entirely based on this approach. The six solutions are classified in two categories, monitoring and control.

- SEAM4US Environmental monitoring
- SEAM4US Occupancy monitoring
- Energy monitoring
- SEAM4US Lighting control
- SEAM4US Ventilation control
- SEAM4US Escalator control

The energy monitoring subsystem is not considered a SEAM4US direct solution, since it uses straight off-the-shelf technology to obtain energy consumption figures. Moreover, it is not essential to have a working SEAM4US implementation.

All of the subsystems have been analysed with the respective responsible partner in order to define the components that would be used in a final system. This work allowed for removing some of the components that were redundant on the prototype, like the installation of a dedicated SEAM4US PLC for each escalator and fan under SEAM4US control. It is this optimised version which is used in the cost benefit analysis.

Cost Benefit Analysis

The Cost Benefit analysis is based in different costs models. There is a cost model for each subsystem, including installation costs and development costs. The models are based on the costs incurred during the SEAM4US project for the hardware and installation, and have been adapted to fit the considerations of optimisation of the system, as explained in the previous paragraph. The models for development costs are the result of having each partner evaluate the necessary activities for a new deployment of each of the SEAM4US subsystems. There are two approaches for this last point: the first approach (called Pre Competitive) considers the current situation, which represents a system that still needs a significant amount of tailoring efforts to work in a new installation; the second approach (Industry) takes a step further to imagine a fully mature system, the development of which has reached a point that requires very little customisation effort.

To implement the cost models and be able to analyse multiple configuration scenarios of combinations of SEAM4US subsystems, in different facilities, a spreadsheet based tool has been created. With this tool more than a thousand scenarios for the pilot station have been analysed as a part of the sensibility analysis.

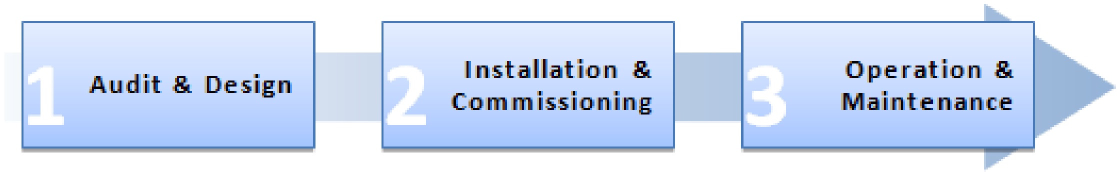
The results show that some of the configurations are viable under the right conditions. Electricity costs are the key factor in the equation. Current energy costs (around 0.14 €/kWh) are too low to generate a positive investment return in the short term, although it is reachable below the 10 year period for the whole system installation without the energy monitoring. The scenario rundown revealed that the most profitable system in absolute terms is the lighting control, while the Escalator control has proven very difficult to justify as a standalone solution. When considering the industry development costs hypothesis, however, the results are more optimistic. The whole system installation delivers good investment returns even at current costs of electricity. When installing only the lighting control, which also includes the occupancy monitoring system, the payback period is below the 2 year mark and the IRR for a 5 year period is a promising 43%.

Another aspect to take into account is the absolute power consumption of the devices under SEAM4US control. The SEAM4US deployment costs are mostly fixed and depend little on the energy consumption or the power of the equipment, thus scaling very well in big facilities. As an example, the ventilation control system results in not being profitable as a standalone in a 5 year span if only 2 fans are installed, but becomes absolutely positive for 4 of them.

Therefore, it can be said that the SEAM4US system has great potential, and can result in a clear benefit for a given set of conditions. The SEAM4US Configurator is a tool that allows to quickly analyse the suitability of a station in these terms.

Business model

Given the relatively positive outcome of the cost benefit analysis, the consortium arranged for a plan to exploit the SEAM4US System. The methodology used is the one presented by Alexander Osterwalder in his book *Business Model Generation*. It standardises the definition of a Business Model with nine Building Blocks: Customer Segments, Value Propositions, Channels, Customer Relationships, Revenue Streams, Key Resources, Key activities, Key Partnerships and Cost Structure. Each of the building blocks has been given answer to, so as to reach a satisfactory result.



The consortium has decided to not create a stable organisation, but rather implement the SEAM4US system into each partner's portfolio. This way, all of the partner act as a commercial agent. Once a new client has been found, each partner can participate in the project by making an offer tailored to the specifics of the case. The activities that would perform each of the partners have been defined and are in accordance to the tasks evaluated in the cost models. The SEAM4US consortium has experience and know how to perform the three stages of an energy efficiency project: design, deployment and operation. Whether the three of them are managed by the partners or only some of them will be decided in each contract.

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1. INTRODUCTION

This document reports over two subtasks in WP6, which have already been introduced also in the Marketing Plan deliverable within WP7. The first subtask focused the efforts on the cost benefit analysis and the opportunities opened by the project to TMB or other interested parties. The second subtask refines the business model that the consortium has agreed upon, built on the proposals already drafted in the aforementioned deliverables.

The system being developed by the SEAM4US consortium affects multiple layers inside the organization of the client, and its outcome has many repercussions in different departments. Thus, assessing the savings and the costs (the basis of the cost-benefit analysis) is not straight forward. Furthermore, every instance of the SEAM4US approach needs to be analysed individually and some tweaks need to be made to the system in order to adapt it at the new conditions.

The SEAM4US installation changes the operation of a station itself, adding software, hardware and new information to the status quo. This deliverable takes into account all the costs that would be incurred during the installation of a new instance of the SEAM4US system.

After a few months of effective operation and deployment of the system, TMB has been able to integrate the new devices into their regular maintenance operations. The project provided detailed handbook protocols for preventive and reactive maintenance of SEAM4US systems to that end (available in deliverable *D5.1.2 Final Energy management system deployment handbook*). The assessment by the maintenance department of the mentioned handbooks provided the necessary insight to evaluate the costs related to maintenance actions by the operator, who deemed them irrelevant, as the actions are not needed often and can be integrated in the current resource allocation.

Instead of focusing exclusively in Passeig de Gràcia and obtain a unique tailored result, the efforts have been directed at developing an application that will be able to analyse any station in TMB's network (or any station, actually) with little work. This means that, if the SEAM4US wants to be expanded, the algorithm will be ready to generate an assessment of which of the different products of the SEAM4USs are best recommended for a given station, with precise economic data backing up the decision.

In a single clause, our aim is to generate a reliable decision making tool for future economic assessments of the SEAM4US implementations. This tool would also provide added value to some of the alternatives in the Business Model.

1.1. Cost/Benefit Analysis

A lot of definitions and scopes are used under the phrase "Cost Benefit Analysis". In SEAM4US, we use an engineering point of view, which considers the costs and benefits of a change inside an organization to assess whether this change is worth it in terms of money; in other words, compare savings and costs.

The objectives of a cost benefit analysis strongly depend on its scope and the original inception of its elaboration. Furthermore, there are countless points of view to be taken in a cost benefit analysis, each of them with a purpose. As an example, the cost-benefit analysis carried out to assess the impact of a governmental programme places a lot of weight on sociologic indicators, while the inside cost benefit analysis of a small company regarding a project's perspectives will most likely prioritise economic and resource aspects.

Consequently, the objectives of the cost benefit analysis carried out in WP6 are adapted to fit the Description of Work document. The scope in this case is limited within the project reach, which translates in having excluded from the analysis the (rather positive) effects of the SEAM4US system in terms of overall primary energy savings and CO2 emissions reduction[1]. There are, however, a few words discussing the benefits and costs of the SEAM4US products regarding public image.

The objectives accomplished and presented in the first part of the deliverable are:

i. Design a comprehensive algorithm to aid TMB in the assessing of the SEAM4US products in future implementations
ii. Consider all involved costs and revenues
iii. Validate the algorithm with the pilot station

1.2. Business Model

The objective of the Business Model subtask is to identify a viable business model to exploit the results and knowledge created by the SEAM4US project. The basis of the Business Model have been established in *D7.3.3 Marketing Plan*, and this document refines the ideas there presented with concrete actions and roles for the consortium partners.

[1] A life cycle analysis was performed and presented in D6.1.2 – Final feasibility analysis, pilot planning and evaluation framework.

2. THE SEAM4US PROTOTYPE

The SEAM4US system that has been tested in PdG-L3 pilot is the first prototype of a concept and, as such, it needs to undergo some changes before it can be considered a definitive product. In previous deliverables in WP7 (D7.3 – Marketing Plan) the initial ideal of the final product has been already presented. In this document, however, we have gone a step further and every aspect of the deployment has been studied and reconsidered if necessary. Through a series of internal interviews, the lessons learned during these past three years have been used to improve the SEAM4US product in order to achieve two main objectives: optimise costs and improve the robustness of the system.

In this section, the prototype system is described and the components depicted. The concepts here presented will be later used in both following parts of the deliverable: Cost-Benefit Analysis and Business Modelling.

2.1. Pilot deployment

The SEAM4US pilot deployment has been divided in standalone solutions that can be classified according their main functionality: Control or Monitoring.

Monitoring: in the era of "Big Data", the information gathered by the monitoring systems can be really valuable for a client. Despite not being the main objective of the SEAM4US project, these solutions are an interesting outcome.

- SEAM4US Environmental monitoring
- SEAM4US Occupancy monitoring

Control: these solutions contribute directly in reducing the energy consumption of the client's facility.

- SEAM4US Lighting control
- SEAM4US Ventilation control
- SEAM4US Escalator control

The SEAM4US system has been fully described from hardware and software points of view in deliverables *D5.1.2 Final Energy management system deployment handbook* and *D4.2.2 Final system prototype* respectively. Furthermore, deliverables within WP3 have covered extensively the algorithms that drive the control of the devices. For a detailed explanation of how the system works, or the reason behind choosing each component, the reader is referred to the aforementioned deliverables.

In this brief section, and for the sake of document completeness, all the devices used in the pilot system are depicted in diagrams. First, by subsystems or subproducts, as they have been introduced in *D7.3.3 Marketing Plan*. Secondly, as a whole system in order to provide the big picture. Finally, the revised version is also introduced to be able to make comparisons between before and after. It is worth mentioning that there are two SEAM4US subsystems that are not listed above as standalone products, namely SEAM4US Core and SEAM4US Energy monitoring. Both of them have functions in the SEAM4US whole system or work together with other subsystems, but would not make sense to have them installed on their own. The former because acts as backbone of all the other subsystems; the latter because it uses off-the-shelf technology and its installation is completely optional.

2.2. SEAM4US Core

Most software components are installed in a single server (Dell R310) located in the operator's headquarters. This "brain" of the SEAM4US system is accompanied by a back-up hard drive installed to grant persistency of experimental data during pilot testing. This hard drive would not be needed in future deployments of the system, unless it is required by the client. Most of the SEAM4US objectives are knowledge oriented and deployed by means of software components. Thus, the server plays an essential role in the deployment and becomes the key device that delivers SEAM4US value.

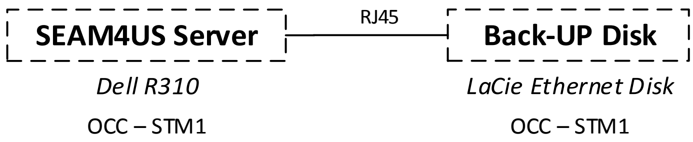


Figure 1 SEAM4US Core components

2.3. Energy monitoring

The energy consumption monitoring subsystem (Figure 2) accomplishes one function: measure energy savings to validate the system. Two kinds of energy meters were installed depending on the type of electrical load. Highly variable loads such the escalators required precise semi-fiscal meter (e.g. SOCOMEC DIRIS A10), capable of produce readings almost continuously. For more constant loads such as lighting, a more affordable solution was found (Enistic BBSP-SM16D + BBSP-SECL), still obtaining acceptable polling rates. Both types of implementation communicate with the dedicated SEAM4US server via IP protocol.

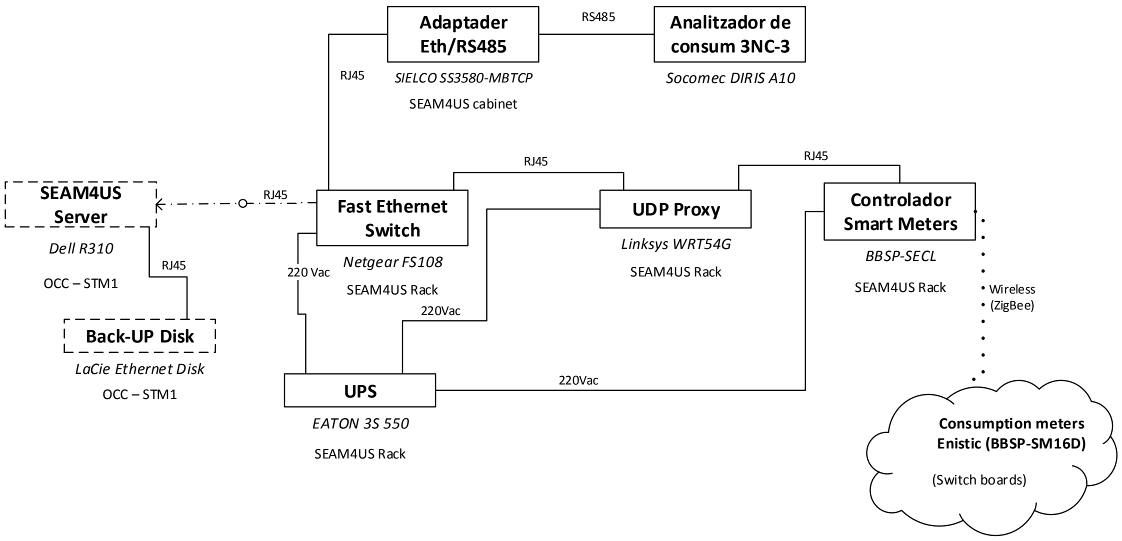


Figure 2 Energy monitoring deployment

2.4. Occupancy monitoring

The occupancy monitoring system (Figure 3) provides the raw information used by the occupancy prediction component and the control algorithms for the Lighting Control and Escalator Control components. Since it uses the existent CCTV installation, the intervention is minimal. The communication with the server is via IP protocol.

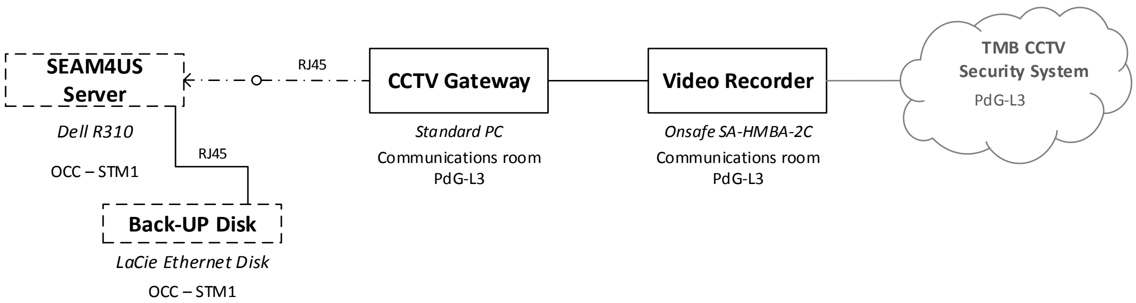


Figure 3 Occupancy monitoring deployment

2.5. Environmental monitoring

The environmental monitoring system is a tailored designed sensor network that provides the necessary awareness to the ventilation control algorithm. The network consists on a variety of nodes, which can be battery powered and wireless or DC powered with either serial or wireless communication. These nodes communicate amongst them and to a WSN gateway (Fit-PC2i), which sends the received data to the server via IP protocol.

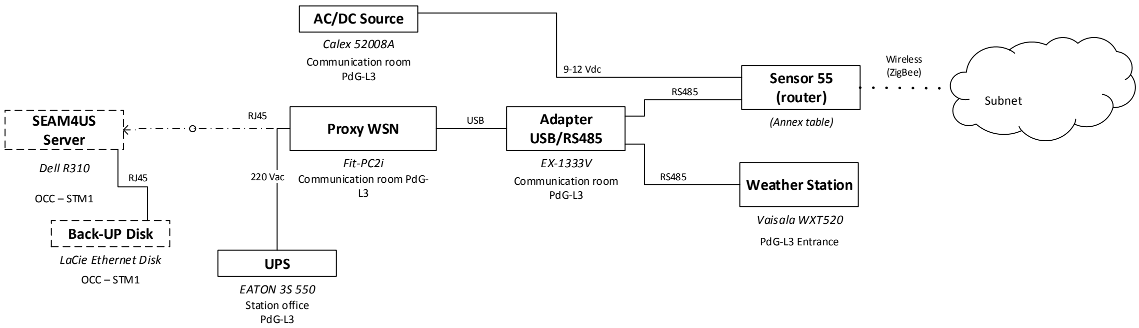


Figure 4 Environmental monitoring system deployment

2.6. Ventilation control

The control commands produced by the control algorithms of the components installed in the server are received by the fans through a dedicated (and redundant) PLC. Given the relevance of the fans in the operation of a metro station, their activity is remotely controlled using the current TMB SCADA (called CCIF). The communication between the server and the PLCs is achieved, again, via IP.

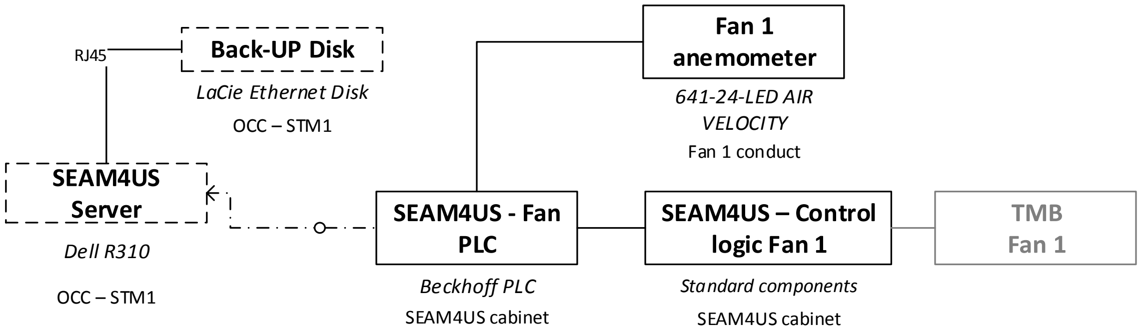


Figure 5 Ventilation control deployment

2.7. Escalator control

The escalator control (Figure 6Figure 7) works in a similar fashion as the ventilation control: a redundant PLC was installed in the station. This unit receives the control commands via IP from the server and transmits them to the escalator PLC. At the same time, the escalator provides feedback of the current running state.

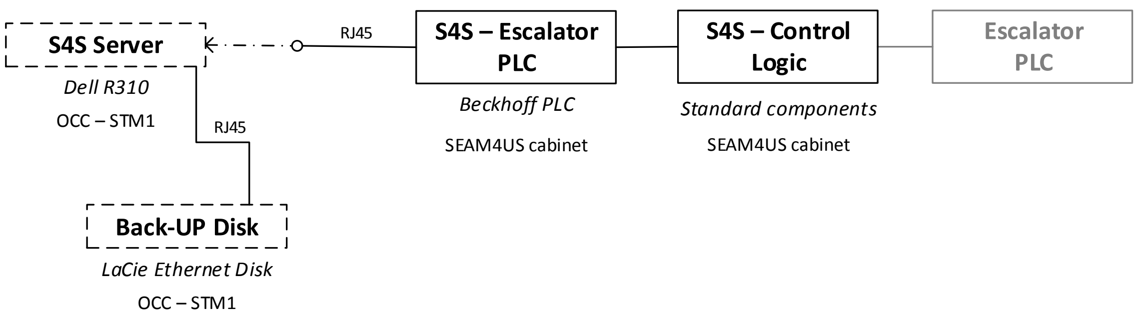


Figure 6 Escalator control deployment

2.8. Lighting control

The lighting control (Figure 7) relies on the possibility of digitally interface with the lighting system in the station. In the PdG-L3 application it has been used the DALI protocol, in combination with a local deployment of LED lamps. The communication is, once more, via IP protocol and an Ethernet-DALI (Orama Ethernet) gateway has been used.

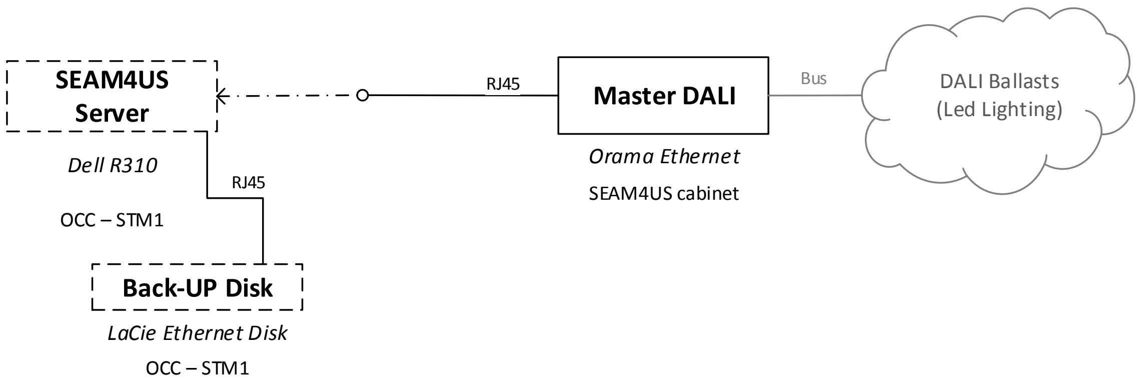


Figure 7 Lighting control deployments

2.9. SEAM4US system as a whole

Even though the SEAM4US can be installed as individual subsystems, it is as a whole that the system is better exploited - since subsystems like the occupancy detection and the backbone only need to be installed once.

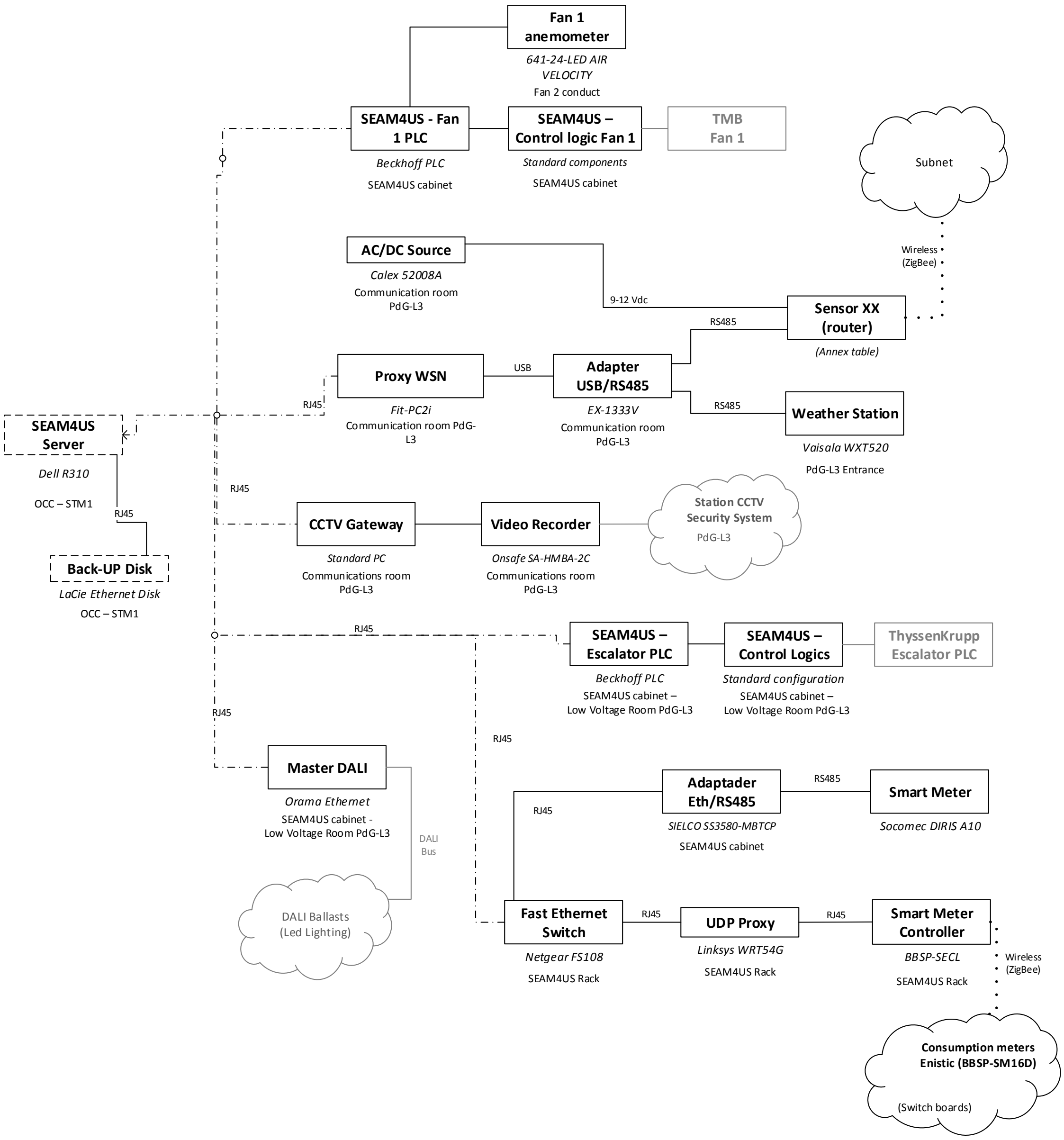


Figure 8 SEAM4US System deployed in PdG-L3

2.10. Improving the SEAM4US Prototype

As mentioned in the introduction of this document, the SEAM4US system installed in Passeig de Gràcia - Line 3 metro station does not fully represent a functional and cost efficient system. The first step to reduce costs in hardware was to analyse the devices that had been used for the pilot, and design a new setup that would provide the required functionality with minimum deployment, which also means reducing costs in installation and maintenance.

In this section the diagram in Figure 8 is presented again with the main changes (Figure 9). The list of the changes and the rationale behind them follows.

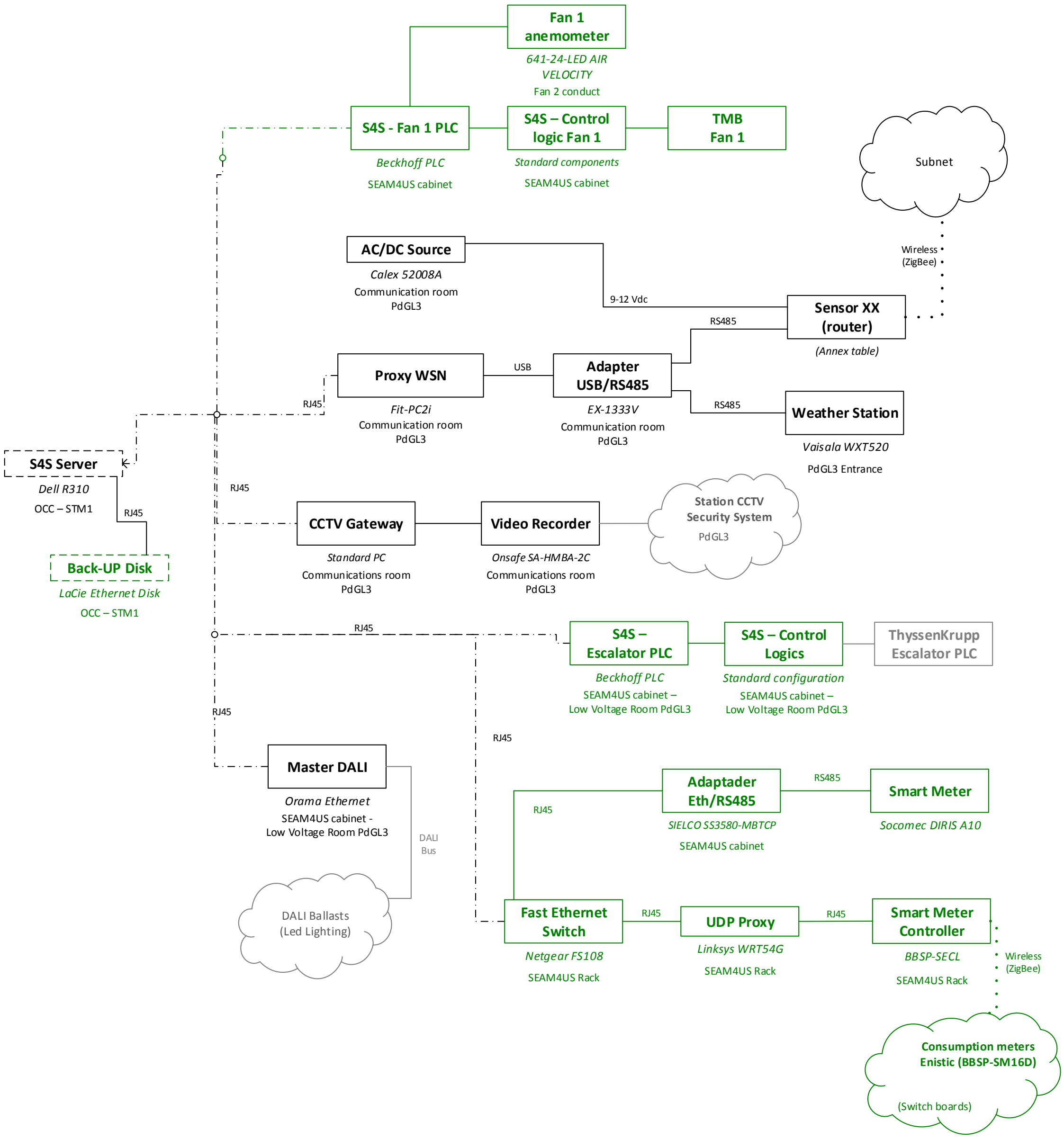


Figure 9 SEAM4US System device optimisation. Green figures are not strictly necessary for the system to work

SEAM4US Core

A dedicated SEAM4US Server needs to be installed. The model may vary, but the specifications must ensure the minimum requirements for the SEAM4US software to run. The BackUp Hard Disk is a safety measure for pilot validation and testing. It does not need to be installed in a reliable definitive setup.

Energy Monitoring

The Energy Monitoring subsystem is used for validation. A permanent setup is expensive to install and to maintain, while the data is not really needed for the correct performance of the system. A more suitable solution is to perform periodic energy audits to set energy baselines and assess savings performance.

Occupancy Monitoring

The Occupancy monitoring subsytem is already really cost efficient in terms of hardware. It takes advantage of the existing CCTV implementation and adds very little equipment to be able to process the images. No changes from the pilot can be really applied.

Environment monitoring network

The savings measures in the environmental monitoring network can be applied installing only the strictly necessary amount of sensors for each type. The pilot network was designed to provide redundancy of data for testing, validation and modelling purposes, but a final setup would need less nodes.

Ventilation control

The valuable SEAM4US contribution to the control of the ventilation relies on the modelling and the data obtained through the monitoring network. A robust implementation would not need to make use of dedicated PLCs, which means great savings in terms of equipment, communications network, installation and troubleshooting. The SEAM4US server would communicate the commands obtained by the control algorithms directly to the already existing SCADA, who would then pass them to the fans.

Escalator control

Escalators are, like the fans, currently implemented into a SCADA system. The optimal SEAM4US implementation would as well forego the installation of a new PLC and use the current communications setup to transfer the commands from the SEAM4US server to the escalators.

Lighting control

The lighting control subsystem relies on the existence of a DALI network (or any other lighting control protocol). Most stations do not have this technology available at the stations, however, the components that make it possible are consumables of the lighting system: ballasts/drivers. The recommendation is to postpone the installation of the SEAM4US lighting control component until the old drivers/ballasts need to be replaced, and replace them with the DALI compatible units. Besides this aspect, the only equipment necessary is the DALI master, which represents a small intervention.

PART 1: COST/BENEFIT ANALYSIS

3. COST-BENEFIT ANALYSIS

The cost-benefit methodology evaluates all the costs incurred for a SEAM4US implementation and compares it to the energy savings that it provides, in order to calculate usual economic appraisal indicators such as Net Present Value (NPV), Internal Rate of Return (IRR) or Payback Period.

On one hand, the objective of the SEAM4US system is to save energy, so the benefit considered is the value of the energy not used. On the other hand, the costs considered are those involved in the installation, deployment and commissioning of the system. Since the SEAM4US system has been created as a modular implementation, and also due to the fact that installation costs and energy savings depend heavily on the conditions of the station in which it is deployed, cost models have been created to be able to economically consider any subsystem combination in any given station. In this section the cost models for each subsystem's component is introduced, as well as the installation costs and the effort needed in development. It is also presented the energy consumption model.

These three models are combined in the SEAM4US Configurator, presented in section (4), which presents the spreadsheet application that has been created to perform quick and powerful appraisals.

For detailed costs of each component, please refer to Appendix 2 – Deployment costs.

3.1. SEAM4US Device Cost Model

3.1.1. SEAM4US core

The cost of the SEAM4US core includes purchasing and installation costs for the server.

Table 1 SEAM4US Core. Items relation

Concept	Design parameter	Optional	Model
SEAM4US server	1 per deployment	No	Dell R310
Backup Disk	1 per deployment	Yes	LaCie Ethernet Disk 2TB

3.1.2. Energy monitoring

The energy monitoring network shall not be considered a direct outcome of the SEAM4US project. There are plenty solutions in the market that cover the need of energy consumption monitoring. Actually, the SEAM4US pilot uses off-the-shelf technology to monitor energy consumption. Taking all this reasoning into account, it has been decided to include the energy monitoring as a distinct feature of the SEAM4US deployment, but only when it is used to validate the performance of the control components.

During the design stage, if the need for energy consumption monitoring is identified, the team will offer the possibility to monitor circuits that are not related to SEAM4US as an added value, had the client claim interest in it.

As it has been explained in section 2.3, the metering technology used depends on the characteristics of the load to monitor. For high variable loads (e.g. elevators), high precision semi-fiscal meters are needed. For more stable loads (e.g. lighting), meters with lower transferring rates provide excellent value.

Table 2 SEAM4US Energy Monitoring. Items relation

Concept	Design parameter	Optional	Model
Router (UDP Proxy)	Used as proxy for UDP broadcast to unicast conversion. One per Enistic deployment	No	WRT54GL
Fast Ethernet Switch	Necessary in case of having both systems (Enistic and Socomec)	No	-
Low rating clamps clamps	1 clamp per monitored cable	No	Enistic
Low rating meter	1 Enistic Smart Mater supports up to 15 Enistic clamps	No	Enistic SM16D
High rating meter	1 Smart meter per circuit	No	Socomec DIRIS A10
High rating clamps	1 clamp per monitored cable	No	Socomec TRB 60
RS485/Ethernet adapter	1 adapter can communicate with up to 32 high rating meters	No	SIELCO SS3580-MBTCP

3.1.3. Occupancy monitoring

The cost of implementing the occupancy monitoring system is contained on the hardware part, since it uses existing infrastructure.

Table 3 SEAM4US Environmental Monitoring. Items relation

Concept	Design parameter	Optional	Model
Video recorder	1 per station	No	LANACCESS Series Compact SA-HMBA-2C
Computer	1 per station	No	Standard Workstation

3.1.4. Environment monitoring network

Establishing the costs of the environmental monitoring network is not straight forward, as the system has been designed and assembled specifically for SEAM4US and PdG-L3 station, incurring in a wide variety of expenses. Furthermore, different installations will require a different set of sensor nodes depending on the characteristics of the facility. In order to provide an accurate cost estimate, the first step is to define the cost for each monitoring node, and thus the cost of the monitoring network.

The sensor network is designed based on 'basic' nodes, which differ from each other by the PCB design. Sensors can be added as extensions. There are some restrictions that limit the type of sensor attachable to each PCB (Table 20), which are also considered in the model. On top of that, depending on the sensors installed, the node might need line power supply or not. In a similar way, the number of WSN Gateways depend on the characteristics of the sensor network that they are managing.

Some elements do not depend on the characteristics of the station or the network, but on the geographical configuration of the facilities, like the need of a local weather station.

To the costs of the materials there have to be added the assembling expenses to obtain final costs for the equipment. One-time costs such as PCB design are left out of the model, since they were incurred in the project and they will not need to be incurred again.

Table 4 SEAM4US Environmental Monitoring. Items relation

Concept	Design parameter	Optional	Model
WSN Gateway	1 to supply 4 gateway nodes	No	Fit-PC2i
Power converter	Depends of number and type of node. One power converter can supply between 5 and 30 nodes.	No	Calex 52008A
Sensor nodes	Depends on the station configuration	No	Based on VTT AMPASE platform

3.1.5. Ventilation control

In order to ensure a safe testing experience, during the SEAM4US pilot two new PLC units were installed: one per each fan. The PLC would then interact with the existing PLC in order to send the SEAM4US commands. This redundant system provided extra robustness and reliability for the testing of the system, but added important installation costs.

A stable SEAM4US deployment would not need the new PLC (see section 2.10), but rather would use the current infrastructure to send the commands to the system. While saving money on new installations, this option requires some work in making sure that the existing deployment supports step-less control in its VFD.

The cost model provide the option to consider both alternatives: installing a redundant control system or using the current one.

Table 5 SEAM4US Environmental Monitoring. Items relation

Concept	Design parameter	Optional	Model
Ethernet TCP/IP Bus Coupler	1 per fan	Yes	Beckhoff - BK9050
2-channel digital input terminals 24 V DC	1 per fan	Yes	Beckhoff - KL1002
4-channel digital input terminal DC, filter 3	1 per fan	Yes	Beckhoff - KL1104
4-channel digital output terminal 24 V DC, 0.5	1 per fan	Yes	Beckhoff - KL2114
1-channel analog output terminal 0…10 V, 12 bit	1 per fan	Yes	Beckhoff - KL4001
1-channel analog input terminal 4…20 mA, differential input, 12 bit	1 per fan	Yes	Beckhoff - KL3021
Bus end terminal	1 per fan	Yes	Beckhoff - KL9010

3.1.6. Escalator control

With the same reasoning exposed in the previous point -Ventilation control-, the Escalator redundant PLC is included in the cost model.

Table 6 SEAM4US Environmental Monitoring. Items relation

Concept	Design parameter	Optional	Model
Ethernet TCP/IP "Compact" Bus Coupler	1 per escalator	Yes	Beckhoff - BK9050
4-channel digital input terminal DC, filter 3	1 per escalator	Yes	Beckhoff - KL1104
Bus end terminal	1 per escalator	Yes	Beckhoff - KL9010
4-channel digital output terminal 24 V DC, 0.5	1 per escalator	Yes	Beckhoff - KL2114

3.1.7. Lighting control

The lighting control subsystem also depends on the existing equipment. The SEAM4US solution is based on the DALI protocol, which requires wired bus connection to each luminaire and DALI compatible ballasts/drivers. While this provides virtually limitless control possibilities, it also implies that for a non-ready installation the retrofit costs will spike and are not recommended (if the only purpose is to make it compatible for SEAM4US control).

The SEAM4US advice for these cases depends on whether the lighting technology supports DALI (e.g. T8 or T5). For compatible technologies, the recommendation is to exhaust the current equipment lifecycle and purchase DALI compatible units in the next one. At the same time, use the resources employed to change the current ballasts to also layout the DALI bus wiring. For non-compatible technologies, the recommendation is to not install the SEAM4US lighting control system until a complete retrofit is scheduled for efficiency or image reasons.

In those cases in which the installation is DALI compatible from the start, the costs incurred in installing the SEAM4US system will be almost all dedicated to the occupancy monitoring system, an essential component to run the lighting control model.

Table 7 SEAM4US Environmental Monitoring. Items relation

Concept	Design parameter	Optional	Model
DALI/Ethernet gateway	1 gateway can manage up to 128 DALI units	No	ORAMA DALI/Ethernet

3.2. Installation cost model

The components listed in each of the SEAM4US subsystems need, of course, to be installed in the station (or other facilities). The experience of the pilot has revealed that installation costs in underground metro stations are conditioned by the normal service operation and must be performed during closing hours, which usually means 5 hours per night of effective work. This aspect slows the installation process and rises the costs, since night hours tend to be more expensive.

The installation cost model is based on the contracts signed during the deployment of the SEAM4US pilot. The items of the budgets have been revised and simplified following the same rationale already explained in point 2.10 of this document, section in which it is mentioned that some redundancy of systems shall be discouraged from an economical point of view. Nonetheless, the installation cost model is able to work with both premises: with or without redundancy of equipment.

Table 8 shows the items considered in the installation cost model, and what subsystems make use of each of them. Some of the items are used for more than one subsystem, while some others are exclusive. The amount of each item needed for a given installation will depend, then, in what and how many devices from each subsystem are installed.

Table 8 Installation cost model. Items vs Subsystem

Installation Items	SEAM4US Core	EnvMon	ConMon	OccMon	EscCon	FanCon	LigCon
Installation and connection of the "in-fan" anemometer to the PLC including all necessary accessories.							
Environmental Network commissioning							
Equipment installation and VideoMatrix reprogramming							
Escalator reprogramming by the Manufacturer							
Health & Safety coordination							
Installation and connection of the data transmission cables Jamak to the Wago connectors							
Installation labour							
Installation of current sensor							
Installation of environmental sensors							
Installation of one smart meter							
Installation one "in-fan" anemometer, including the necessary elements to hold, and completely installed.							
Network port certification							
Procurement and installation of afumex cables							
Procurement and installation of cable management: wiring ducts							
Procurement and installation of data transmission cables S/FTP (Screened Foiled Twisted Pair)							
Procurement and installation of IP55 junction boxes with DIN rail and Wago connectors							
Procurement installation of cable management: metal trays							
Provide and install a metallic cabinet, including all the specified components (1 PLC). Completely finished, including all necessary auxiliary elements							
System electrical certification by an authorised entity							
Ventilation VFD reprogramming							
Installation of the SEAM4US core system (done by the operator's resources)							

3.3. Development cost model

Development costs are the necessary actions needed to tailor the SEAM4US systems to a new metro station. Each partner of the consortium has contributed to this section by providing a list of the activities that they would need to carry out in order have the components working somewhere new. Two different estimations of effort for each task have been considered. The first one considers the SEAM4US system to not be fully industrialised yet, which means that some customization tasks will take much longer than the second estimation, which considers an almost off-the-shelf system. This latter hypothesis places itself in a fully finished research and development stage, so the system can be installed and reproduced with the minimum effort possible. The descriptions and an estimation of the effort in terms of person days (PD) for both hypotheses can be consulted in Table 18 (section 6.5).

Like the installation costs, not all the items are needed for any combination of the system. Table 9 shows the relation of activities and subsystems.

Table 9 Relation between activities and subsystems

Activity	*SEAM4US Core*	*EnvMon*	*ConMon*	*OccMon*	*EscCon*	*FanCon*	*LigCon*
System Supervision		■	■	■	■	■	■
Test Data Proxy		■					
Spatial Model		■		■	■	■	■
LinkSmart	■						
Requirements Engineering	■	■	■	■	■	■	■
Software Engineering	■						
Fan Control Specification						■	
Escalator Control Specification					■		
Lighting Control Specification							■
Fan Actuator + Proxy 1						■	
Fan Actuator + Proxy 2						■	
Escalator Actuator + Proxy 1					■		
Escalator Actuator + Proxy 2					■		
Lighting Actuator + Proxy 1							■
Lighting Actuator + Proxy 2							■
Deployment	■						

Activity	*SEAM4US Core*	*EnvMon*	*ConMon*	*OccMon*	*EscCon*	*FanCon*	*LigCon*
SCADA Integration							
Site survey							
Modelling							
Monitoring Customisation							
Control Customisation							
Smart meters parsing							
Storage Manager							
Database setup							
Database maintenance							
GUI adaptation							
GUI deployment							
TrainArrival							
Usermodel							
Environmental Network Design							
Energy Audit							
Energy Consumption monitoring system design and specifications							
Project Management							
CCTV-based occupancy detection system (HW)							
CCTV-based occupancy detection system (SW)							
Agent-based control system (fan)							
Agent-based control system (lights)							
Agent-based control system (escalator)							

3.4. Energy consumption model

The SEAM4US system main objective is to save energy, hence energy savings achieved via SEAM4US control will be the economic measure for the CBA results. The energy savings can be calculated as the difference of energy usage between before and after the commissioning of the SEAM4US systems, and it has been extensively reported in WP6 deliverable *D6.3 System Validation*.

To calculate the energy consumption baselines, two approaches have been used: for ventilation and lighting, the power of the equipment is the main driver to assess the consumption; for the escalator, however, we have chosen the height as the variable that provides consumption figures. To assess energy consumption in other stations than PdG-L3, baseline energy performance of the target equipment is estimated through the formulae presented in this section.

3.4.1. Ventilation consumption model

The ventilation consumption depends on two factors: the power of the fans and the speed at which they run. TMB's control policy is based on two different speeds. During the warm period the fans work at almost full speed (85% power), while during the colder period they run at 20% power. Taking into account a 1% factor for power line losses, the formula for the annual consumption is:

$$E[Wh] = FanNumber \cdot FanPower[W] \cdot 1.01 \cdot (20[week] \cdot 0.85 + 32[week] \cdot 0.2) \cdot 105 \left[\frac{h}{week}\right]$$

3.4.2. Escalator consumption model

Escalator consumption is deeply related to its usage patterns and is, therefore, very difficult to estimate. For the purpose of savings assessment, the consumption model uses an empiric expression obtained from the analysis of the detailed energy consumption of the escalators installed in PdG-L3.

$$E[kWh] = 638.42 \cdot EscalatorHeight + 10428$$

3.4.3. Lighting consumption model

The power absorbed by a lighting system remains quite constant during the lifespan of the equipment, and it is directly related to the consumption. Taking into account the losses due to ballast/driver and power distribution, the annual consumption of the lighting system results from the formula:

$$E[Wh] = LampPower[W] \cdot LampNum \cdot 150 \left[\frac{h}{week}\right] \cdot 52[week]$$

3.4.4. Electricity cost model

The way metro operators purchase electricity changes for each company, which means that costs may change from company to company, even in the same country. TMB, for example, takes the approach of making public calls for one or two yearlong contracts. Therefore, electricity costs are a variable in the models, so it can be adjusted to the conditions of each operator. The cost model uses to variables for electricity costs: initial cost per kWh and expected annual increase of this cost in %.

3.5. Description of identified benefits

3.5.1. SEAM4US Energy Savings

As it has been mentioned, the target benefit for this project was to achieve energy savings. There are two ways to calculate the energy savings: empirical measures or theoretical consumption estimations. In the context of the SEAM4US project, to prove that there are indeed energy savings, the first option has been chosen. The project is auditing the power lines before and after, creating a baseline for all the loads affected by the change, so there will be a benchmark to prove and quantify the energy reduction. The energy consumption values presented in *D6.3 System Validation* are used by the energy consumption model to obtain the energy savings for each system.

Table 10 Annualised energy savings obtained via SEAM4US control

Ventilation Control System	Escalator Control System	Lighting Control System
30 %	8.5 %	24 %

3.5.2. Other added value

The installation of the SEAM4US products can provide much more than energy savings. The key aspect that adds value is the fact that SEAM4US uses monitoring networks as input. Real time and historical environmental data from inside the station is information that is not easily accessible to metro operators, so beyond the usage of the SEAM4SU ventilation control system, this data can provide very good insight to the real conditions of the station, and evaluate other aspects such as, for example, the influence on pollutants and temperature of the model of the train that is running a line.

Another great information is the occupancy detection, and being able to analyse images from an analog network allows that, for a small investment, the operator can build historical trends and utilise this information for management or commercial purposes.

Evaluate the monetary value of this information is very difficult and will depend on each company. Thus, these aspects are kept out of the economical appraisal.

4. INVESTMENT APPRAISAL: SEAM4US CONFIGURATOR

The main outcome of subtask 6.1.1 in the Dow - Cost/Benefit analysis algorithm is a tool that implements the cost models mentioned in section 3 into a spreadsheet capable of calculate relevant economic indicators for any deployment configuration of the SEAM4US products in any future station. This tool has been named SEAM4US Configurator, and its main functionality is explained in this section.

4.1. Overview

The SEAM4US Configurator has been designed with the aim of providing a tool to economically evaluate a given deployment under given circumstances. It has been built upon the Microsoft Excel 2013 platform, a very common and spread software. It features a user friendly interface with the help of pop-up forms in some cases.

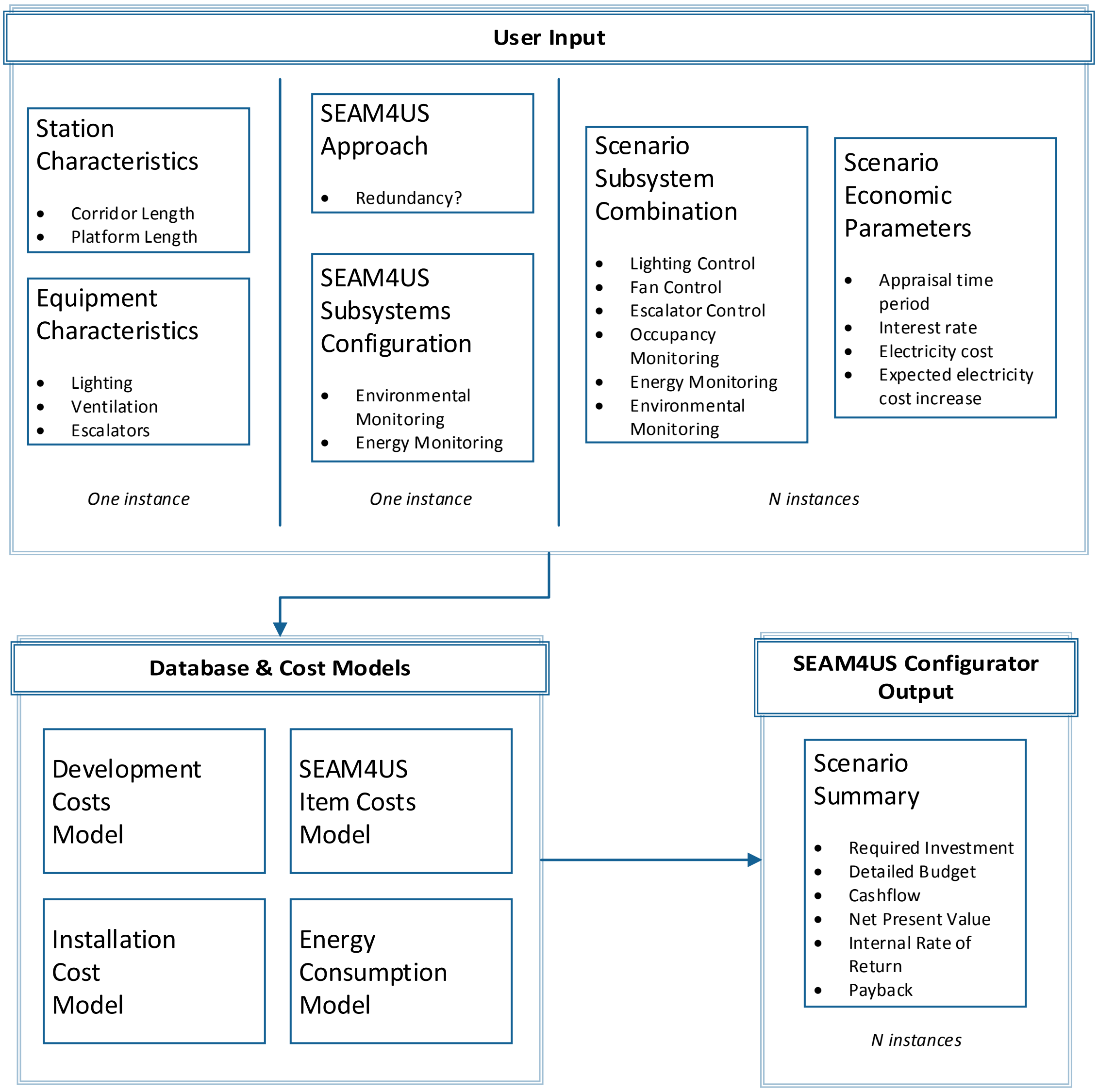


Figure 10 SEAM4US Configurator schematic diagram

Figure 10 shows the basic schematics of the system functionality. The application has been designed to be able to produce multiple SEAM4US configurations combined with multiple electricity cost assumptions, so before considering the implementation of the SEAM4US system into a new station, the feasibility study can be carried out quickly and reliably.

[2]The first step and also the most cumbersome part consists in introducing the information from the new station into the software. Station characteristics such as platform length and corridor length are used in the cost model to obtain estimates of installation costs. The user also needs to introduce the data regarding existing equipment in order to calculate the power consumption baseline.

Next step is to configure two of the SEAM4US monitoring subsystems. The environmental monitoring network needs to be tailored to the characteristics of the station, and for this purpose a dedicated form has been created, which facilitates the design thanks to the built-in restrictions of the sensor network (see deliverable *D5.1.2 Final Energy Management system deployment handbook* for further information on this topic). Also the energy monitoring network allows some customization, by adding new smart meters if it is wanted. The last choice available for the user is whether to opt for a redundant system (which uses a SEAM4US exclusive PLC for controlling each escalator and fan).

Once the station characteristics and the SEAM4US subsystems are configured, the application has all the data necessary for the scenario configuration. The application prompts a user form in which the user is asked to choose amongst the different SEAM4US subsystems, along with the economical parameters to perform the NPV, IRR and Payback calculations.

Finally, the user can consult the scenarios in detail in each worksheet, print them all at once in PDF or just compare the economical results quickly in the summary page.

4.2. Case study: PdG-L3

As a portrayal of the functionality of the SEAM4US Configurator, this section uses the data from the pilot station to obtain the results in a variety of scenarios.

4.2.1. Initial user input

4.2.1.1. Station characteristics

- Platform Length: 100m
- Corridor Length: 350m

4.2.1.2. Lighting equipment characteristics

- Group 1 - STI
    - Lamp power: 36W
    - Lamps per ballast: 2
    - Lamp number: 300
    - Circuit number: 11

[2] For a detailed manual please see Appendix 1

- Group 2 - Carandini
    - Lamp power: 36W
    - Lamps per ballast: 2
    - Lamp number: 352
    - Circuit number: 12
- Group 3 - LAMP
    - Lamp power: 36W
    - Lamps per ballast: 2
    - Lamp number: 118
    - Circuit number: 4

4.2.1.3. Ventilation equipment characteristics

- Group 1 – Station Fans
    - Fan number: 2
    - Fan Power: 15 000W

4.2.1.4. Escalator equipment characteristics

- Group 1 – Entrance escalator
    - Escalator number: 1
    - Height: 6.275m
- Group 2 – Platform escalator
    - Escalator number: 1
    - Height: 4.2m

4.2.1.5. SEAM4US Energy monitoring

- Low accuracy meters
    - Lighting circuits: 27
    - Fan circuits: 2
- High accuracy meters
    - Escalator circuits: 2

4.2.1.6. SEAM4US Environmental monitoring

The most sensor efficient network has been designed taking into account the knowledge gathered during the pilot to ensure the minimum feedback necessary to run the ventilation control.

- WSN Gateway: 1
- Power converter: 1
- Node network:
    - 11 Sensor nodes
    - 2 Fan sensors

4.2.2. Scenario configuration

The flexibility of the SEAM4US configurator (find a detailed manual in Appendix 1) allowed the creation of multiple scenarios and carrying out a sensitivity analysis of the system economic viability. As explained in section 3.3 and presented in Table 19, two different development costs are being considered.

For each of the both effort considerations, Pre Competitive and Industry, scenarios have been created that analyse the viability for different configurations of the SEAM4US systems. Moreover, each of these scenarios have been evaluated with different values for the cost of the kWh and the increase of this cost over the evaluation period, so their influence can be assessed.

For the sake of briefness, Table 11 presents the energy figures obtained through the SEAM4US Configurator, figures that don't depend on the scenarios.

Table 11 Energy performance of PdG-L3

	Lighting	Ventilation	Escalator
Consumption [kWh/y]	227,027	74,447	27,543
SEAM4US Consumption [kWh/y]	172,427	52,113	25,202
Savings [kWh/y]	**54,600**	**22,334**	**2,341**

Table 12 Sensitivity analysis parameters

Parameter	Range	
kWh Cost [€/kWh]	0.1	0.3
kWh Annual Cost increase [%]	2	15
Period [year]	5	7

Table 13 Configuration scenarios

Scenario	Lighting	Fan Control	Escalator Control	Occupancy Monitoring	Cons. Monitoring	Env. Monitoring
1						
2						
3						
4						
5						
6						
7						

The detailed results of the sensibility analysis are presented in Appendix 3. This section shows a representative portion of them.

4.3. Pre competitive results

The results of the analysis show that the feasibility of the Pre competitive scenarios strongly depend on the cost of the electricity.

The initial objective of the SEAM4US project, which had a 5% savings target, has proven to be too modest. The second objective, to obtain savings without affecting the operation of a station, has also been fulfilled. A third objective, to do so with minimum intervention to the station's current equipment, has also proved a success. All in all, however, it has not been possible to reach the point of industry-ready technology. The strongly tailored product that has been created during the SEAM4US project still requires costly development effort for a new installation.

The two scenarios presented in this section –Scenario 1 and 3, see Table 13- show some of the most favourable cases. It is fair to say that the current state of costs makes difficult to obtain benefits before the 10 year period, although it can be the case if the right conditions are given.

4.3.1. Scenario 1. All products installed

This scenario considers all subsystems of the SEAM4US system to be installed. For the current value of electricity (at around 0.14 €/kWh), the installation is not able to provide a return of investment in the period of 5 years. Even for 7 year span, the system only returns investment at the seventh year in the case of having an energy cost increase of 15% per year. Still looking into the seven year span, was the energy be a little more expensive (0.20 €/kWh), the return of the investment would be achieved. The initial investment for PdG-L3 would be **129,521€.**

Table 14 Pre Competitive, all products. Payback period

Electricity Cost [€/kWh]	Annual Electricity cost increase [%]			
	2%	5%	10%	15%
0.1	>7	>7	>7	>7
0.14	>7	>7	>7	7
0.2	7	7	6	5
0.25	6	5	5	4
0.3	5	4	4	4

Table 15 Pre Competitive, all products. IRR 7 years

Electricity Cost [€/kWh]	Annual Electricity cost increase [%]			
	2%	5%	10%	15%
0.1	-15%	-12%	-8%	-4%
0.14	-8%	-5%	-1%	4%
0.2	1%	4%	9%	14%
0.25	8%	12%	17%	22%
0.3	15%	18%	24%	30%

4.3.2. Scenario 3. Lighting system

The lighting system proves to be the most competitive single solution of the SEAM4US systems. With an initial investment of **68,919€,** the system produces positive returns in 7 years in most of the hypotheses, being the minimum conditions to have either current cost conditions with 5% of annual increase, or a little higher starting point (0.20€) and a mere 2% annual cost increase.

Table 16 Pre Competitive, only lighting. Payback period

Electricity Cost [€/kWh]	Annual Electricity cost increase [%]			
	2%	5%	10%	15%
0.1	>7	>7	>7	7
0.14	>7	7	6	6
0.2	6	5	5	4
0.25	4	4	4	4
0.3	4	3	3	3

Table 17 Pre Competitive, only lighting. IRR 7 years

Electricity Cost [€/kWh]	Annual Electricity cost increase [%]			
	2%	5%	10%	15%
0.1	-10%	-7%	-2%	2%
0.14	-1%	2%	6%	11%
0.2	10%	13%	18%	24%
0.25	18%	22%	28%	33%
0.3	27%	31%	37%	43%

4.4. Industry results

In the industry scenarios, the development costs haven cut down to a realistic level for a ready to market product in the world of IT. It is supposed that the system and the resources in charge of implementing it are mature enough to belong to a competitive sector.

In this case, the results are much more promising. Payback period remains under the five year threshold for Scenario 1 (all products installed), electricity cost at 0.14 €/kWh and annual increase of 2%, with an investment of **57,547€**. A 5 year period would deliver 8% of IRR.

To compare with the same scenarios than the previous section, Scenario 3 (only lighting and occupancy subsystems) also performs well. Electricity costs of 0.14 €/kWh and annual increase of 2% feature a 2 year payback period and 43% of IRR in 5 years, with an initial investment of **23,073€**

4.5. Results discussion

The cost benefit analysis of the SEAM4US system as a whole and as individual combinations has revealed a series of points, in the case of Pre Competitive conditions. For the pilot station it has been found that the Escalator control subsystem and the Ventilation control subsystem are viable as standalone installations. However, the Lighting control subsystem is; and the synergies are reflected in the fact that the whole system can be viable under certain energy costs conditions.

However, the analysis under industry development costs stage, reveals that the system can be viable as a whole, but some of the subsystems by themselves still are not completely viable. Namely: escalator control and ventilation control.

It is important to consider the scalability of costs with the electricity consumption. Most of the costs in the development part are not dependent or little dependent on the power installed in the facility. Once the SEAM4US system has been deployed, it makes a very small difference whether there are 2 fans or 10 fans, for example. In order to see whether the system would feature better, the SEAM4US configurator was used to analyse other power conditions. This scalability analysis was performed only for ventilation and escalator control. For ventilation, four fans were considered, as 30% of the stations in TMB Metro station network have this amount or more (see Figure 11, extracted from *D2.1.2 Final Joint Operation and System Requirements*). The results showed a 12% of IRR for a 5 year period, and a payback of 4 years. As a side note, it is worth mentioning that the tunnel fans have not been taken into account in the control system, but if they were, the savings likly ramp up.

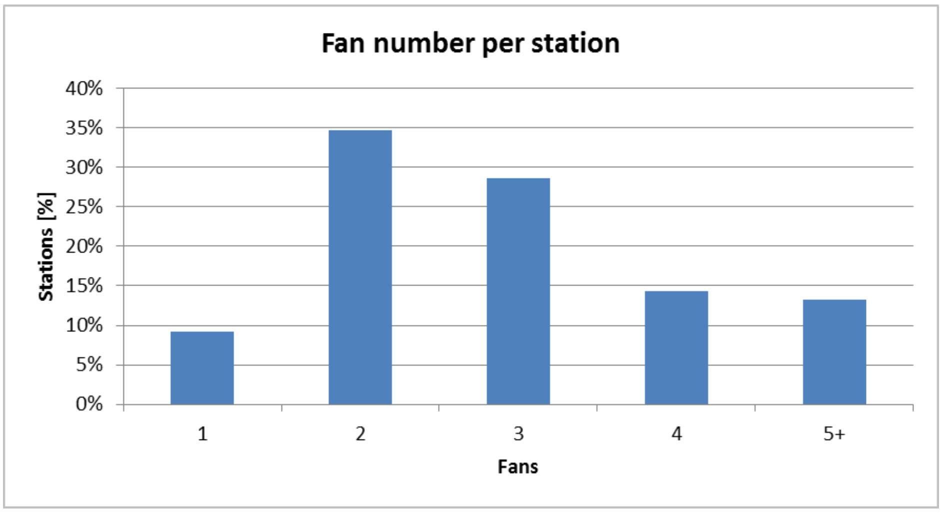


Figure 11 Number of fans distribution

For escalators the analysis revealed that even in the extreme case of having 12 escalators installed in a station, the return of the investment does not occur in a meaningful time period. This is due to the fact that the amount of energy savings in escalators is too small. However, if the occupancy monitoring system is to be installed anyway, considering the escalator control is an option.

PART 2: BUSINESS MODEL

5. BUSINESS MODELLING METHODOLOGY

The methodology applied to produce the business model is based on the book by Alexander Osterwalder *Business Model Generation*. The relatively new methodology offers a modern and intuitive approach to the business model creation, using a set of *Building Blocks* graphically interlaced in the *Business Model Canvas*.

5.1. Building Blocks

Defining the building model is defining the building blocks:

1. Customer Segments

An organisation servers one or several Customer Segments.

2. Value Propositions

It seeks to solve customer problems and satisfy customer needs with value propositions.

3. Channels

Value propositions are delivered to customers through communication, distribution, and sales Channels.

4. Customer Relationships

Customer relationships are established and maintained with each Customer Segment.

5. Revenue Streams

Revenue streams result from value propositions successfully offered to customers.

6. Key Resources

Key resources are the assets required to offer and deliver the previously described elements…

7. Key activities

…by performing a number of Key Activities.

8. Key Partnerships

Some activities are outsourced and some resources are acquired outside the enterprise.

9. Cost Structure

The business model elements result in the cost structure.

5.2. Business Model Canvas

The Business Model Canvas is the tool used to ensemble the building blocks described in the previous section. It aids the designer(s) of the business model to understand and share the ideas in a systematic way.

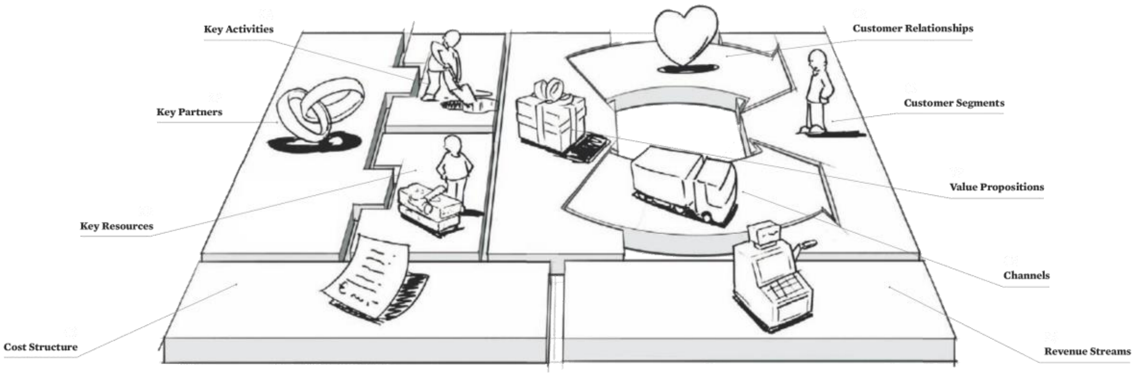


Figure 12 Artistic representation of the building blocks prior to form the canvas[3]

The business model canvas reflects the relationships' importance amongst the different building blocks. The closer they are, the more dependant they become from each other. This way, we can see, as an example, how the Customer Segments building block is strongly related to the Revenue Stream (being it the source most of the times) and the Channels and Customer Relationship blocks. However, Customer Segments share little with the Key Partners building block, hence the distance between them.

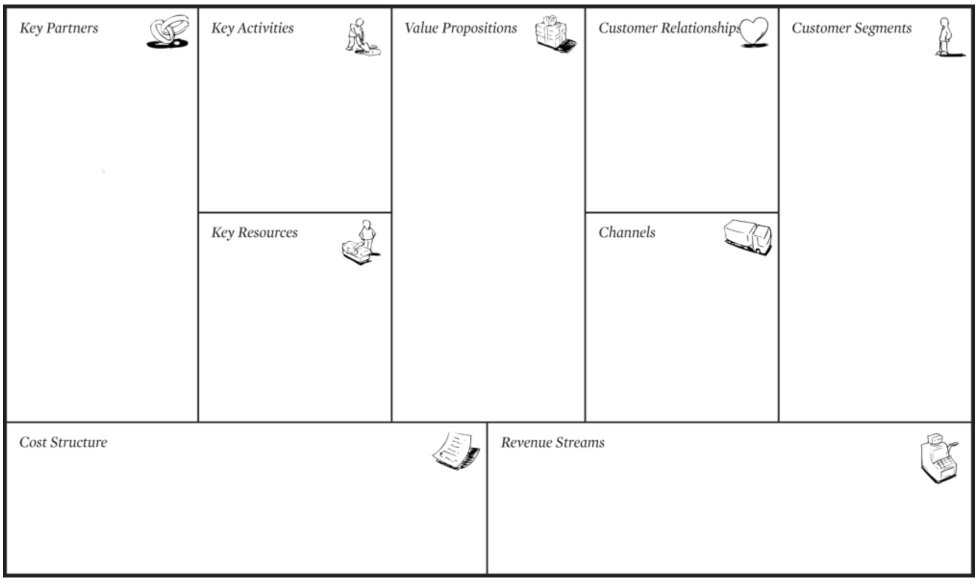


Figure 13 Business Model Canvas as issued in Business Model Generation[3]

[3] *Business model generation : a handbook for visionaries, game changers, and challengers*, Alexander Osterwalder, Hoboken, NJ: John Wiley & Sons 2010

6. SEAM4US BUSINESS MODEL: BUILDING BLOCKS

6.1. Customer Segments

It is clear from the inception of the SEAM4US project that the potential customer for their outcomes would not be the mass market. The original niche market target formed by metro operators could perhaps be expanded to include other large facilities managers, such as airports or shopping malls.

Following the analysis conducted in the Passeig de Gracia Line 3 station we have understood that the characteristics that make such energy efficiency interventions possible are also present in other similar environments: large passenger traffic, a closed environment where artificial light is used, ventilation systems are present to increase comfort as well as important elevation systems. Many places have the same characteristics but the more interesting ones are probably airports. This similarity is an opportunity to export and apply the experience built on the metropolitan networks. The airport market is quite interesting, in Europe there are 142 airports with more than 2.000.000 passengers per year, and these facilities are spread over the territory in 32 countries Europe wide. On average European airports carry 10.000.000 passengers per year, from 2.100.000 for the airport of Brindisi (ITA) up to 69.400.000 for the Airport of London-Heathrow (UK), for a total of 1.450.000.000 passengers. These numbers show how widespread, vast and important airport facilities in Europe are and how appealing this market is for the products promoted by the SEAM4US Project. Other sectors such as subterranean parking lots have issues regarding CO_2 emission management; there is a great opportunity for ventilation optimization. Other areas with a lot of human passage (shopping malls) could also represent a great opportunity for implementing the SEAM4US solution on lighting systems.

In Europe, there are 71 subway networks in 20 countries. They represent more than 3000 km of tunnels and railway lines. Overall, there are more than 4000 stations distributed over more than 260 lines. Of these 71 networks, three were created before 1900 and, eight, after 2000. It would be easy to think that the oldest lines may need more improvement than the more recent ones, due to technological progress and better planning and management. It is partially true that there is larger space for improvement in energy efficiency on the older networks, nevertheless, energy management has not always been on top of the list of the key aspects to monitor for the sake of comfort not even in terms of the newer networks (the choice to install air conditioning or not for example). On the other hand, even an old network, interested by a strong and continuous maintenance policy adopted over the decades, may have reached a certain level of efficiency making further improvements a real challenge.

Targeted customer segments of the SEAM4US products can be organized according to different aspects. On one hand, they can be classified by the facility they intent to have the SEAM4US products installed on; on the other hand, they can be also classified by their core business.

By facility:

- Underground metro stations
- Airports

By clients' core business:

- Metro operators
- Airport operators
- Facility operators
- Energy Service Companies

6.2. Value Propositions

The SEAM4US solution seeks to bring innovation to the Building Management System market. SEAM4US offers the possibility to improve current control protocols by adding the prediction factor to the real time monitoring, which provides a framework capable of issuing fine control commands to ventilation systems, lighting systems and escalators in order to adapt their performance to fulfil the requirements without exceeding nor failing to reach the desired control objectives.

The SEAM4US products cover different needs and in different degree:

- Energy costs reduction by energy consumption reduction
- Environmental indicators monitoring
- Passenger density monitoring

The first need that SEAM4US aims to cover is the impact of energy costs. Metro's energy bill can represent a big share of global operating costs; as shown in Figure 14, nowadays energy costs are typically 20% of an Asian metro's operating costs. This compares with only 5% to 10% in Europe and North America. Energy costs are likely to rise as electricity production becomes de-carbonized (through increased nuclear and renewable generation and carbon-capture), as carbon pricing and taxes are deployed and fossil fuel sources become depleted. Ensuring that low-energy consumption is designed into new metros and then adapting electricity use, as new technologies become available, would be a prudent strategy. Existing metros should implement energy and carbon reduction strategies to minimize carbon footprints and energy costs. To understand its energy consumption, each subway network must be analysed and audited, as it is really difficult to export the results amongst stations from different networks. The SEAM4US approach is prepared to such challenge as it is totally new in its holistic management of energy efficiency through traffic monitoring and modelling, and flexibility has been a prime driver during the development.

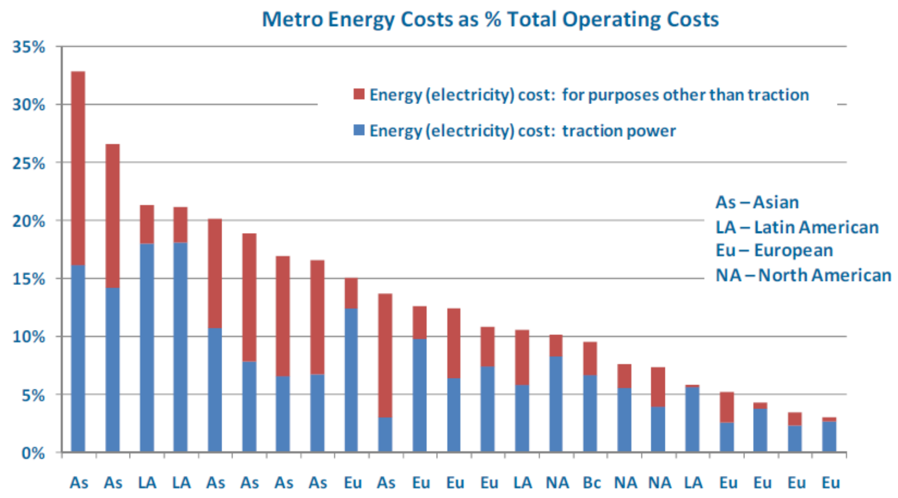


Figure 14 CoMET and NOVA metro energy costs as a percentage of total metro operating costs[4]

The second and third need relate to the possibility of installing only part of the SEAM4US components in order to use the sensing networks to gather information. Reliable and real-time feedback of key environmental indicators or passenger density is information already valuable for a facility or a business manager.

SEAM4US components have already been introduced in the first part of the document. In section 3.1 the reader can check which of the components fulfils each of the aforementioned needs.

6.3. Customer Relationships and Channels

It has been agreed upon, that the SEAM4US products will be introduced to the service portfolios of each partner in the current consortium. After first contact is established and the parties have come to an agreement, the relationship will be naturally maintained since the deployment of an instance of the SEAM4US solution implicates an intense and intricate relationship between the parties, given the fact that it is not an off-the-shelve product that can be self-installed.

In other words, the process to place in the market the SEAM4US solutions will be integrated into the business-as-usual of the different partners. Of course, the SEAM4US website will remain open to further reference for any interested organisation or individual.

In a similar fashion, the channels to provide the value proposition to the customer segments must be conceived as individual and tailored responses to each SEAM4US deployment.

For each installation of the SEAM4US solutions, individual contracts will be signed, which will include the details of distribution channels.

[4] This chart seeks to show the impact of energy costs in percent of metro's operating costs in different countries, and has been reproduced from an analysis conducted by the researchers of the Railway and Transport Strategy Centre at Imperial College London on behalf of the CoMET and Nova Benchmarking Groups. It is important to bear in mind the fact that costs tend to be very different depending on the country (and continent) for both labour and energy. Therefore, this portrayal of information is just informative and must be considered as such.

6.4. Revenue Streams

In the current period of economic crisis, when most subway networks live on public funding and respond to public shareholders, a distinction must be made between countries where public spending is even more closely monitored (Spain, Greece, Italy) and countries where there still is a dedicated budget for investment (Germany, UK). This distinction does not question the need for energy efficiency, but stresses where the SEAM4US approach should be tailored to networks' needs, especially from an investment point of view.

An underground network located in a country where budget allocation and public spending is cut will have difficulty in terms of investing in new installations. This is where the SEAM4US approach should be supported by privately owned companies such as Energy Services Companies (E.S.Cos) through tools like project financing and long term contracts. E.S.COs are defined as commercial businesses providing a broad range of comprehensive energy solutions including designs and implementation of energy savings projects, energy conservation, energy infrastructure outsourcing, power generation and energy supply, and risk management[5]. Looking at this potential market through the outsourcing point of view, countries such as the United Kingdom, Germany, France, Italy and Spain are key targets for proposing this kind of solution given that their public administrations are already accustomed to service externalization.

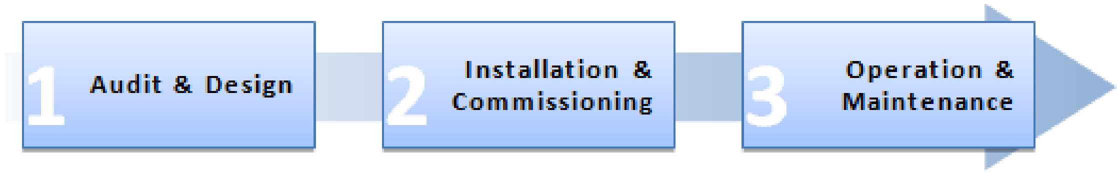


Figure 15 Stages of a SEAM4US deployment, from cradle to end of use

The implementation of the SEAM4US project requires a series of stages (Figure 15) that go from the audit and design to the maintenance operation. The SEAM4US project has proved that the consortium partners are capable of fulfilling each of the stages successfully. However, the business model has been designed to consider other scenarios as well, in which only some of the stages are performed. As explained in section *6.3 Customer Relationships and Channels*, each implementation of the SEAM4US solutions will undergo its own negotiation process, which will result in a contract. In such contract pricing and services will be detailed. The costs of deployment of the SEAM4US solutions is variable, and has been discussed in section 3 of this document. Following there is a description of the different Revenue Streams that are considered in the business model.

1. **Auditing and Design:** This stage comprises the initial steps of the SEAM4US implementation. The customer is provided with a thorough energy audit of their facilities and a finished design of the system implementation including the software components needed to run the SEAM4US.

[5] For more information, see http://www.greenbiz.com/news/2008/04/13/escos-and-utilities-shaping-future-energy-efficiency-business or http://www.energyservicescoalition.org/resources/whatis.htm.

- Pricing: the price of this approach is directly related to the man-hours used for the auditing and design activities. The amount of work involved in designing hardware and software architecture is mostly determined by the complexity of the facility under study.

2. **Engineering Procurement and Construction (EPC)**: this approach includes the previous items, but carries on with the design and deploys the system. The customer is provided with the installed system already commissioned and ready to run.

   - Pricing: the extra price of this approach (compared to the Audit and Design) is determined by the installation and commissioning costs.

3. **Energy Service Company (ESCo)**: this approach executes the two previous stages, but assumes the costs and risks in exchange of a long lasting contract with the customer directly related to the obtained energy savings. This type of contract requires strong financial power from the part of the installer, who benefits from scale economies and cost optimization to be able to offer conditions that are attractive enough to the customer.

   - Pricing: pricing policies can be based on many different factors that modify the investment, the annual fee, and the total duration of the contract. The investment depends mainly on the complexity and amount of equipment to be installed. The annual fee and the length of the contract will depend on the margins of cost savings arising from interventions and the willingness of the customer to benefit from the very beginning of a reduction of the energy bill (at the expense of the length of the contract that inevitably you will have to stretch to allow the service provider to obtain a return on the investment made).

6.5. Key activities

The key activities for the business model involves all partners listed in Table 19, and are presented in Table 18.

Table 18 Key activities for the SEAM4US Business Model

Activity	*Partner*	*Description*	*Pre Competitive*	*Industry*
System Supervision	FIT	Software Component that supervises all other software components and alarms subscribers of a mailing list if malfunctions occur. In addition, a daily summary is generated. Finally, each supervision cycle is logged so that malfunction can be analysed through the loggings in retrospective. Excludes: Implementation of the Supervisable interface by components	1PM for adjustment, deployment and testing	1 PD

Activity	***Partner***	***Description***	***Pre Competitive***	***Industry***
Test Data Proxy	FIT	Software Component that generates test data for sensors	5PD for adjustment, deployment and testing	5 PD
Spatial Model	FIT	Software library that provides a generic way to model the spaces in the station, their attributes, and links between spaces. Excludes: The spatial model itself, which is provided by a JSON file and has to be created separately	1PD for deployment and testing	1PD
LinkSmart	FIT	Middleware that takes care of eventing and networking. Defines the central development environment in Seam4us.	1PM for adjustment, deployment and testing	5PD
Requirements Engineering	FIT	Formulation, documentation and maintenance of software requirements using Volere standard. Necessary software tools are provided, configured and administrated.	Depending on accuracy 0,5-4PM	0
Software Engineering	FIT	Collective term for actions which are needed to make the software components work as a whole system. For example, interface definition, architecture design, data flow specification, software-hardware assignment, ...	Depending on system scale 0.5-PM	0
Fan Control Specification	FIT	Specification of the installation for fan control, including schematics and specification of all devices	1PM for each specification	1PD
Escalator Control Specification	FIT	Specification of the installation for escalator control, including schematics and specification of all devices	1PM for each specification	1PD
Lighting Control Specification	FIT	Specification of the installation for lighting control, including schematics and specification of all devices	1PM for each specification	1PD
Fan Actuator + Proxy 1	FIT	Programming and Testing of the Fan PLC	1PM + 1PD for each additional installation	0
Fan Actuator + Proxy 2	FIT	Integration of the Fan PLC into the system, if not done through SCADA	0.5PM	0
Escalator Actuator +	FIT	Programming and Testing of the Escalator PLC	0.5PM + 1PD for each	0

Activity	*Partner*	*Description*	*Pre Competitive*	*Industry*
Proxy 1			additional installation	
Escalator Actuator + Proxy 2	FIT	Integration of the Escalator PLC into the system, if not done through SCADA	0.5PM	0
Lighting Actuator + Proxy 1	FIT	Programming and Testing of the DALI Gateway	0.5PM + 2PD for each additional installation	2 PD
Lighting Actuator + Proxy 2	FIT	Integration of the DALI Gateway into the system, if not done through SCADA	0.5PM	2 PD
Deployment	FIT	Setting up the machines, deploying the software, network/firewall configuration and testing	1PM	0
SCADA Integration	FIT	Integration of the SEAM4US control output as an input to the existing SCADA system	1PM	5 PD
Site survey	UNIVPM	On-site survey of environmental parameters, data acquisition and organization	0.5PM	5 PD
Modelling	UNIVPM	Station and device modelling, model calibration and model reduction	0.5PM	5 PD
Monitoring Customisation	UNIVPM	Customization of the monitoring function and of the spatial model	1/8 PM	0
Control Customisation	UNIVPM	Customization of the control policies	1/8 PM	1 PD
Smart meters parsing	CNet	Software adaptation to access data from energy smart meters and store it in the Storage Manager	1PM	0 PD
Storage Manager	CNet	Install IIS. Subscribes on events from LinkSmart and converts and passes them through the interface used by the end application.	1/4 PM	0
Database setup	CNet	Install SQL server, setup tables etc.	0.5PM	1 PD
Database maintenance	CNet	Make sure that everything runs smoothly. Keep indexes up to date.	1 PD / month	2 PD
GUI adaptation	CNet	Adapt the graphical user interface to fit the new facility.	1PM	5 PD
GUI deployment	CNet	Test and deploy final GUI	5 PD	1 PD
TrainArrival	UniK	The TrainArrival rises an event when a train arrives in the	2 PD	2 PD

Activity	*Partner*	*Description*	*Pre Competitive*	*Industry*
		station.		
Usermodel	UniK	The user modelling studies the user behaviour and activities in a given environment. On basis of the knowledge acquired a strategy is developed for detecting the user's and group goals and plans from an ongoing activity. Furthermore, concepts and solutions for predictive user modelling in terms of user activity, status and group affiliation over the time are developed. The final solution provides predictive user activities and contexts, which allows to proactive influence the system, for instance, to perform energy management.	1.5PM	15 PD
Environmental Network Design	VTT	Includes survey of the station to design. Sensor allocation and distribution + Specifications design. Setup and commissioning	0.5PM	5 PD
Energy Audit	UPC/ Cofely	On-site survey: equipment energy specifications reporting and consumption patterns layout. Identification of inefficiencies	0.5 PM	3 PD
Energy Consumption monitoring system design and specifications	UPC/ Cofely	Design and construction project of the energy consumption monitoring system	2 PD	2 PD
Project Management	Cofely/ TMB	Project management duties	2PM	20 PD
CCTV-based occupancy detection system (HW)	ALM	This activity includes the consultancy, deployment and testing of the HW for the CCTV-based occupancy detection system. It assumes that an existing CCTV infrastructure is already in place. It includes maintenance for 5 years and it excludes material costs.	1PM	5 PD
CCTV-based occupancy detection system (SW)	ALM	This activity includes the consultancy, development, deployment and testing of the SW for the CCTV-based occupancy detection system. It assumes that the relevant HW infrastructure is already in place.	2PM	5 PD

Activity	***Partner***	***Description***	***Pre Competitive***	***Industry***
		It includes all costs of licensing for ALM software and excludes all non-ALM licenses.		
Agent-based control system (fan)	ALM	This activity includes the consultancy, development, deployment and testing of the SW for the agent-based control system for the ventilation. It assumes that the relevant HW infrastructure is already in place. It includes all costs of licensing for ALM software and excludes all non-ALM licenses.	1.5PM	1 PD
Agent-based control system (lights)	ALM	This activity includes the consultancy, development, deployment and testing of the SW for the agent-based control system for the illumination. It assumes that the relevant HW infrastructure is already in place. It includes all costs of licensing for ALM software and excludes all non-ALM licenses.	1PM	1 PD
Agent-based control system (escalator)	ALM	This activity includes the consultancy, development, deployment and testing of the SW for the agent-based control system for the escalator. It assumes that the relevant HW infrastructure is already in place. It includes all costs of licensing for ALM software and excludes all non-ALM licenses.	1PM	1 PD

6.6. Key Resources

The business model proposal that is being presented is based on the existing departments of the SEAM4US project partners (see Table 19). As such, the different resources that are exclusively dedicated to produce and deliver the value proposition will be allocated on demand, only when the need arises and according to the key activities described in the previous section of this document.

The resources needed to keep the SEAM4US products on the market will be supported by the current infrastructure of the different partners of the project, without allocating new resources to the solely aim of maintaining the SEAM4US business model running.

6.7. Key Partners

The main partners that will take part in a hypothetical future implementation of the project will be, of course, the same companies, research institutes and universities that have taken part in the development of the SEAM4US system (Table 19). However, if one partner was unavailable or a deal could not be cut, a new partner would be seek in order to fill the spot, unless the responsibilities were shared amongst remaining partners.

Table 19 SEAM4US relation of partners

Industrial Companies		
Cofely Italia SpA	Italy	Service company in energy-efficient system management sector
Ferrocarril Metropolita de Barcelona SA	Spain	Large metro network operator
CNet Svenska AB	Sweden	System integrator
Almende B.V.	Netherlands	Experts in user and agent-based scheduling modelling
Research Organizations and Universities		
Università Politecnica delle Marche	Italy	Building and environmental physics experts
Universitat Politècnica de Catalunya	Spain	Experts in Building construction and management
Fraunhofer Gesellschaf	Germany	Research and development experts in middleware
Universitaet Kassel	Germany	Experts in user and agent-based scheduling modelling
VTT Technical Research Centre of Finland	Finland	Experts in sensor and communication networks

6.8. Cost Structure

Following the one project - one consortium approach, the cost allocation of every SEAM4US implementation will vary depending on the project specifications. Furthermore, with this approach there are no extra operational costs to be considered outside the partners' organisations, since the commercial actions will be included within their current service portfolios.

During the negotiation phase that will occur prior the signature of a contract, each partner will establish their costs and make offers accordingly. For the Cost Benefit Analysis algorithm estimation of pricing and costs have been used to obtain reliable results. Effort needed for each activity, however, has been estimated and detailed in section 6.5. Labour costs have been not included in this document, as they are prone to change depending on the conditions of each project.

7. CONCLUSIONS

For all the control systems, we have found a hardware solution that interfaces with current equipment of the station. The only exception is the lighting control, which depends on being able to dim the lamps. While most of the fluorescent lamp types (at present the most usual in metro stations) can be dimmed, they need a specific kind of ballast that will probably need to be installed. Nevertheless, given the current trend of lighting technology fluorescent lamps will rapidly become obsolete, so that any future lighting renovation will be based on led technology. The software developed under SEAM4US works seamlessly with current operator's facility management systems. The deployment of both hardware and software can be done without interrupting the operation of the station in any way, with a minimum intervention time.

A decision support tool, the SEAM4US Configurator, has been created to be able to economically assess any implementation of the SEAM4US system, and has been validated with the SEAM4US pilot. For the pilot station, the cost of the hardware and its installation is small in comparison to the value of the energy savings that provides and the important information it gathers. Using the SEAM4US Configurator, however, we have found that tailoring the SEAM4US technology to different contexts still requires a fair amount of system reconfiguration; the costs of which surpass the deployment ones. This document presents two hypotheses for future implementations costs, the first one depicts the current state of the development and considers the costs of deploying it into a new station. The second hypothesis extrapolates the SEAM4US development up to the point at which the SEAM4US system has progressed enough to be a mature industrialised (off-the-shelf) product. In this case, the hardware costs do not change, but reconfiguration costs are reduced significantly. While in the first scenario, Pre Competitive, it is difficult to reach the context conditions that would make SEAM4US profitable in a reasonable period of time; the second scenario delivers a much more quick return of the investment and depicts a rather profitable business case.

The key aspect in the SEAM4US viability is the energy savings value. Power consumption plays a great part, since the development and deployment costs scale very little with the energy consumption. Therefore, for larger stations with a greater amount of devices, the SEAM4US solution becomes more profitable than in smaller stations, given the fact of the significance of fix costs.

Regarding the Business Model, all partners of the consortium have agreed on a framework for future collaborations in SEAM4US deployments, were any operator interested in it. This arrangement provides enough flexibility to allow for the intervention of other parties in the project. The business model is based on the commercial networks and portfolios of the two big partners, TMB and Cofely, and each new deployment will be managed in a contract basis. Each partner will be free to present a detailed offer, but the SEAM4US Configurator will be available as a quick and first project appraisal.

The final conclusion is that the SEAM4US system is a step into the right direction in terms of profitability for energy efficiency in underground stations. Another iteration of the pilot focused on automating the customisation process would deliver a ready to market system capable of providing payback periods of around two years, given current electricity costs conditions in Europe. Nonetheless, the SEAM4US consortium is ready and eager to find new customers interested in installing the system in their facility, and we have an agreement as to how organise ourselves in such occasion.

8. GLOSSARY AND ABBREVIATIONS

- **Baseline**: the status-quo condition of PdG-L3 station, prior SEAM4US implementation.
- **CCTV**: Closed Circuit TV.
- **Control Subsystem**: it refers to all the components needed for controlling the pilot: Controllers, Prediction Models, Device Proxies (software) and Actuators (hardware)
- **Core System**: basic hardware parts of the system (Server and Back-up HDD)
- **LinkSmart Middleware**: the platform on which the SEAM4US System is based. It provides the components Network Manager, Device Manager, Event Manager, Data Storage, History Acquisition.
- **Monitoring Subsystem**: it refers to all the components needed for monitoring the pilot: Monitoring Models, Device Proxies (software) and Sensors (hardware)
- **PdG-L3**: Passeig de Gracia - Line 3 (pilot station).
- **SEAM4US System**: is the whole system, including all the components included in the SEAM4US System Architecture (User Interfaces, Controllers, Models, Device Proxies, System Supervision, LinkSmart Middleware, Sensors, Actuators)
- **SEAM4US**: Sustainable Energy mAnageMent for Underground Stations

APPENDIX 1 – SEAM4US CONFIGURATOR HANDBOOK

In the main body of the document the funcionality and an example of use of the application have been provided. In this appendix there is presented a step-by-step manual to handle the SEAM4US configurator.

The tool proposed by the SEAM4US project is based on a Microsoft Excel spreadsheet. This tool was preferred to others due to the relatively low amount of data that needs to be handled and also keeping in mind the possibility of being used by typical excel users.

8.1. Home screen

The home screen is presented by the worksheet "Launch". This will be the reference user interface during the whole process.

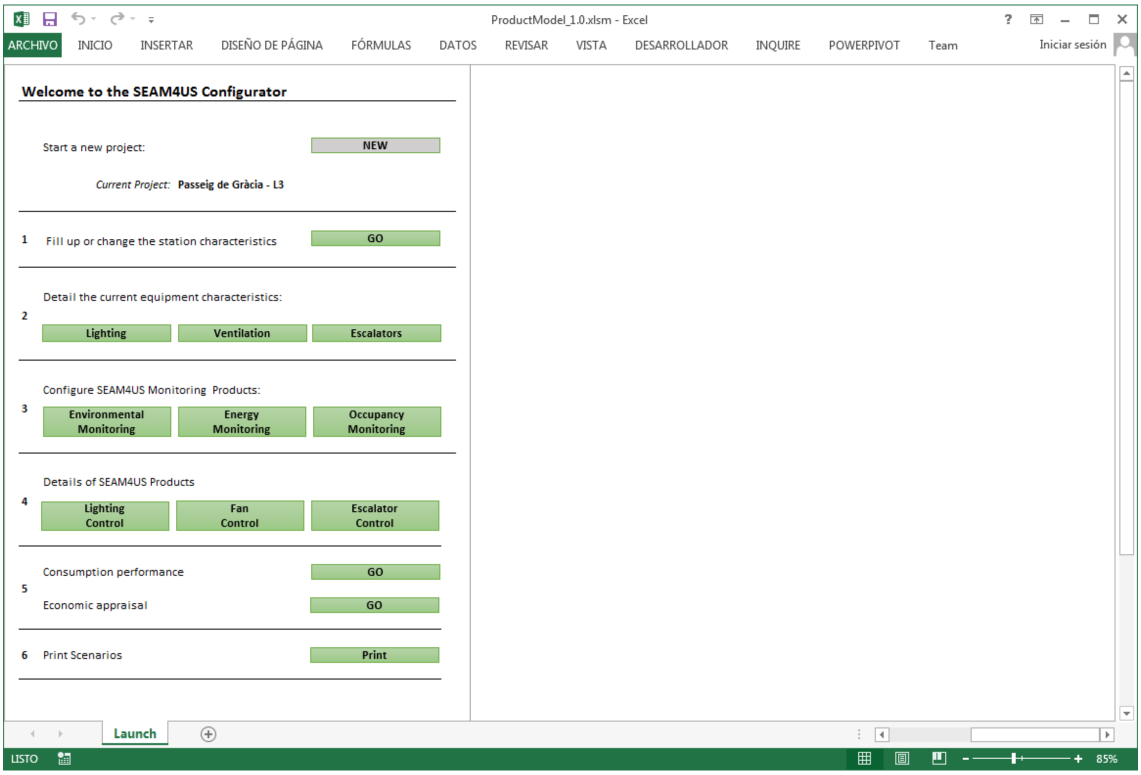


Figure 16 SEAM4US Configurator. Launch screen

8.2. Data introduction

8.2.1. General information

Data introduction begins with the station characteristics. To get to it, click on the GO button in the #1 row (Figure 16). The user will be presented with a form to fill. For the calculations, it is important to fill up the values for Corridor Length and Platform Length. Also, the general information will be useful to identify the project. After any changes, click the UPDATE/SAVE button to refresh the information. It is also the place to indicate whether redundancy on equipment needs to be considered (Figure 17).

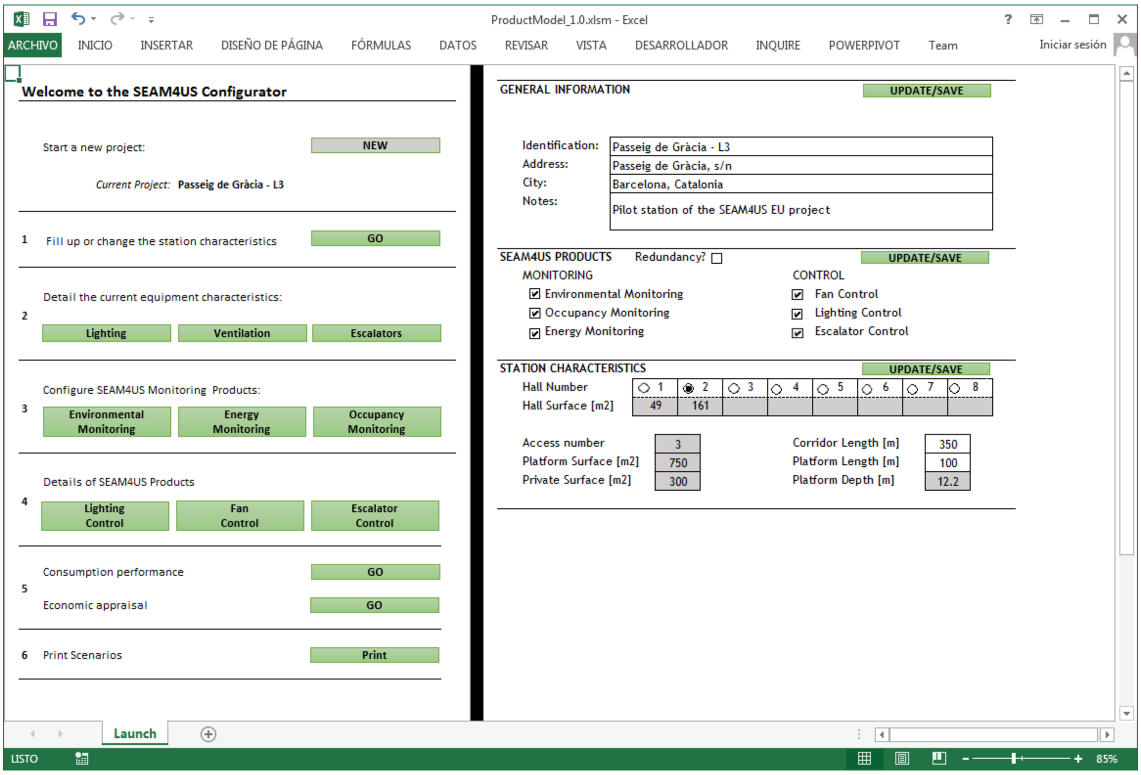


Figure 17 SEAM4US Configurator. Station characteristics

8.2.2. Existing equipment

To introduce the specifications of the existing equipment, the user is provided with dedicated user forms for each type of equipment (Figure 18). To access the forms, click on the respective buttons in row #2 of the left user interface. The equipment has to be grouped according to power or other features (Figure 19, Figure 20 and Figure 21). For example, in the case of lighting, we have different types of lamps in the station, so one group is created for each of them. In a similar fashion, escalators that not cover the same exact height with the same power will need different groups.

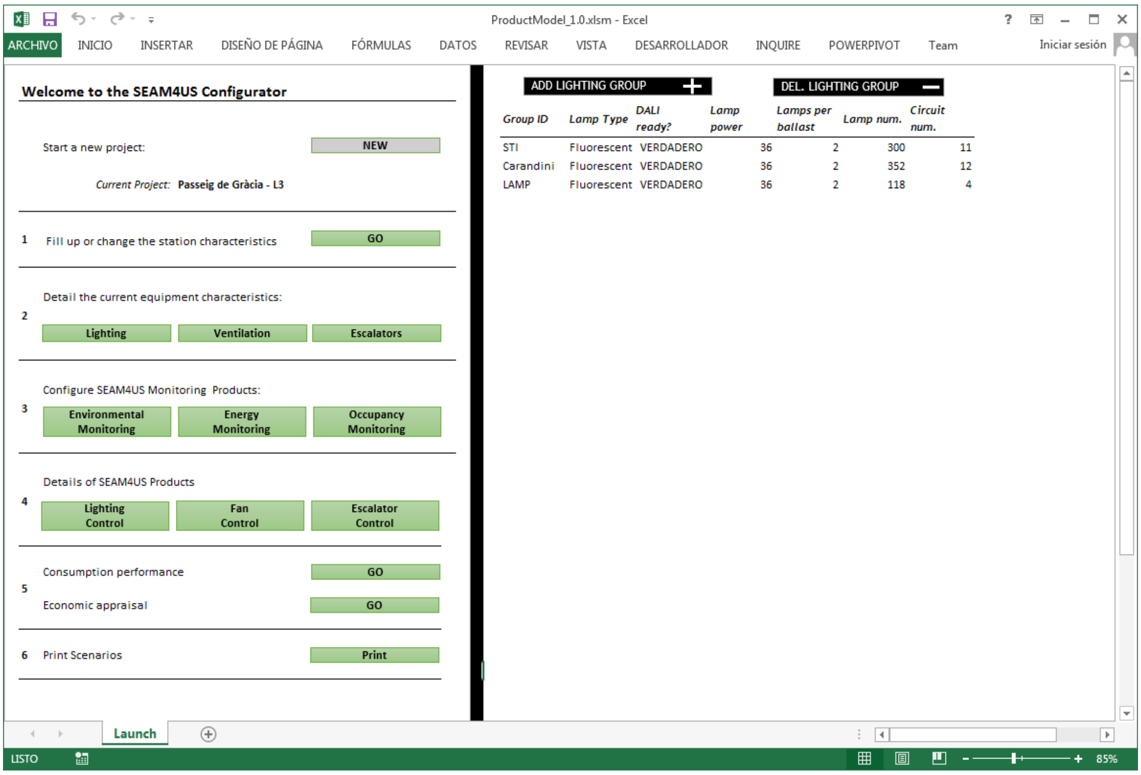


Figure 18 SEAM4US Configurator. Existing equipment introduction

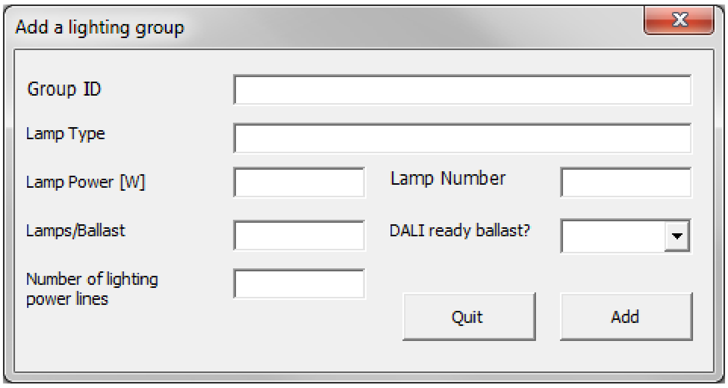


Figure 19 SEAM4US Configurator. Add lighting group form

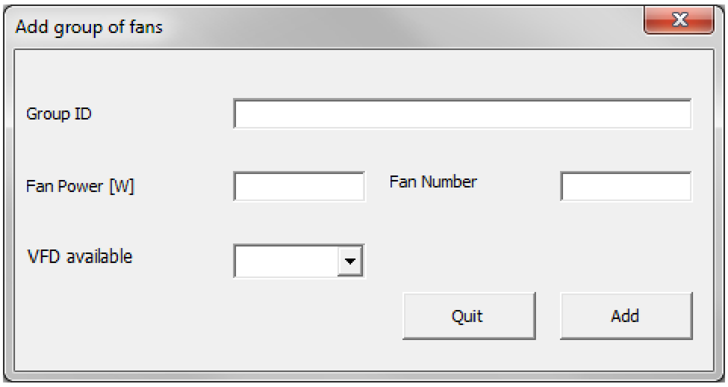


Figure 20 SEAM4US Configurator. Add fan group form

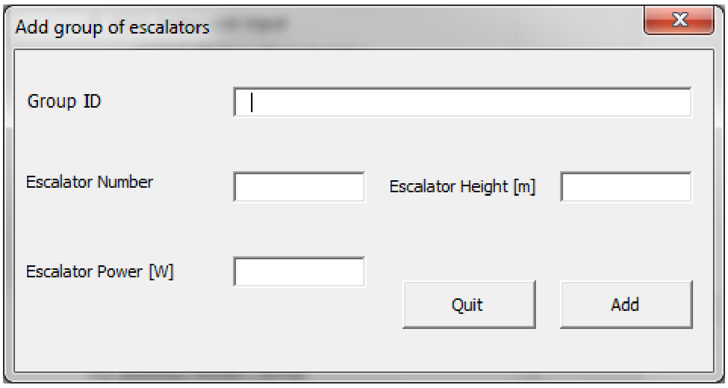


Figure 21 SEAM4US Configurator. Add escalator group

8.2.3. SEAM4US Environmental monitoring

The SEAM4US Environmental monitoring subsystem has to be configured if it wants to be included in the economical appraisal. The user can click on the row #3 button Environmental Monitoring (Figure 22) to access the possibility of launching the Node Configurator.

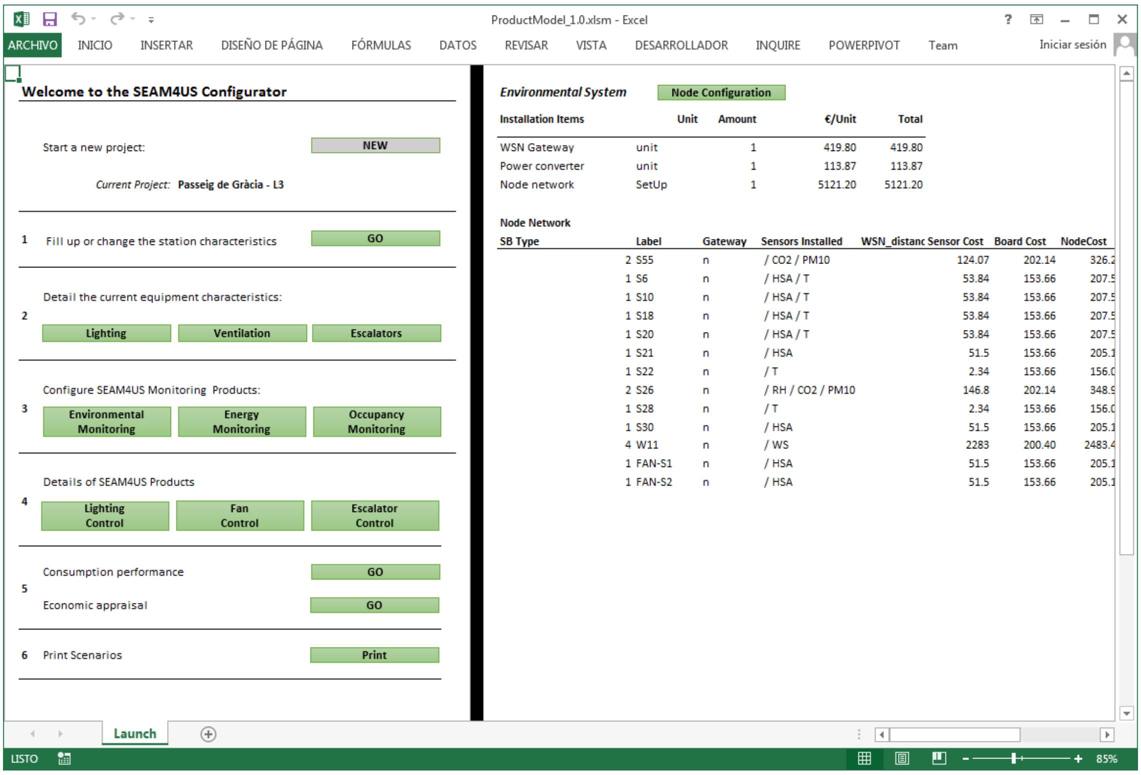


Figure 22 SEAM4US Configurator. Environmental Monitoring page

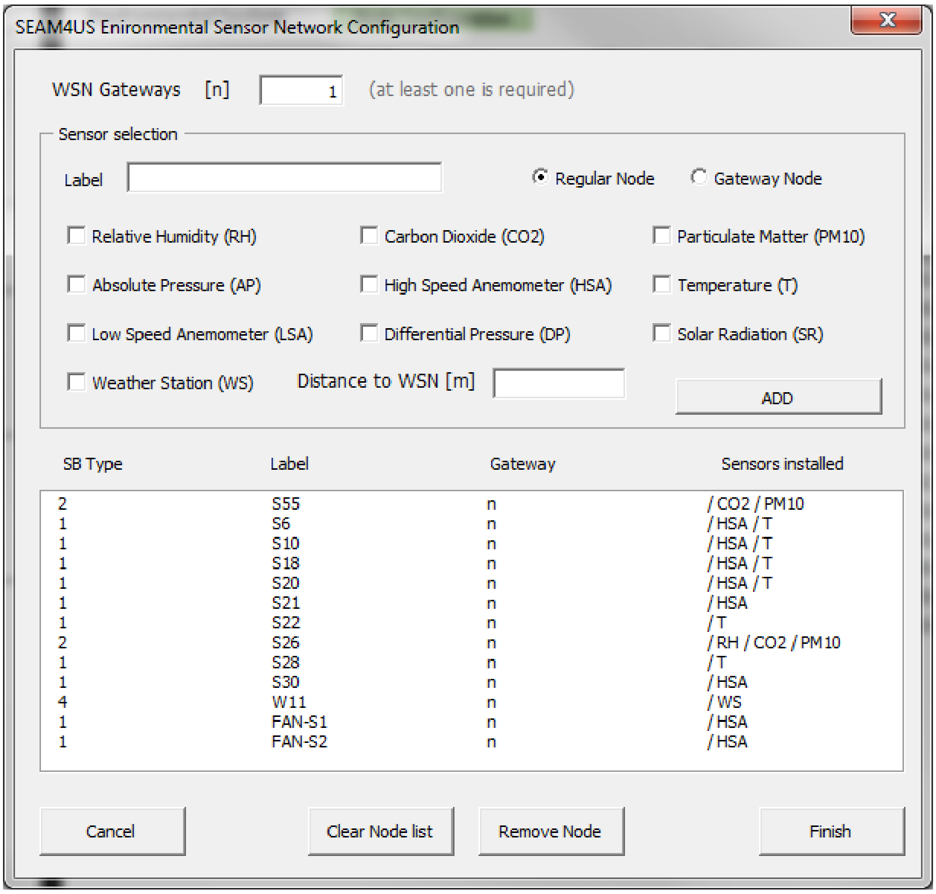


Figure 23 SEAM4US Configurator. Node configuration dialog

According to design specification of the AMPASE environmental monitoring platform, there is a compatibility between sensors, and not all the sensors can be attached within the same PCB. The dialog box already implements the limitation, which is presented in Table 20.

Table 20 Sensor compatibility for each type of PCB

	RH	CO2-1	PM-1	AP	HSA	STs	AT	STa	LSA	DP	Solar	CO2-2	PM2
PCB1													
PCB2													
PCB3													
WS													

8.2.4. SEAM4US Energy monitoring

The energy monitoring page is reached through the respective button in row #3. The user is then prompt with the dialog box (Figure 24) asking him whether we wants to monitor any extra circuit, depending on the type (high accuracy or low accuracy).

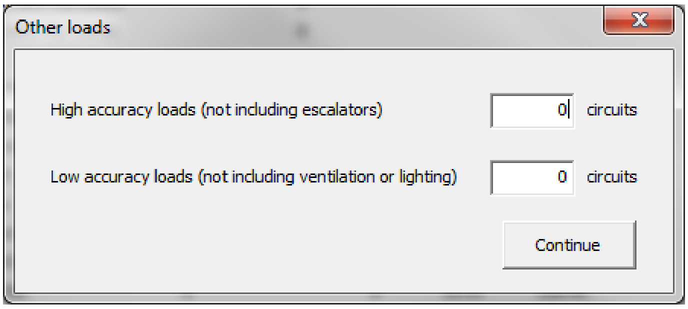


Figure 24 SEAM4US Configurator. Other loads to be included in the Energy Monitoring

8.2.5. Consumption Performance

In this page the user can check the annual consumption of the installed equipment by groups (Figure 25). It is reached via the button in row #5.

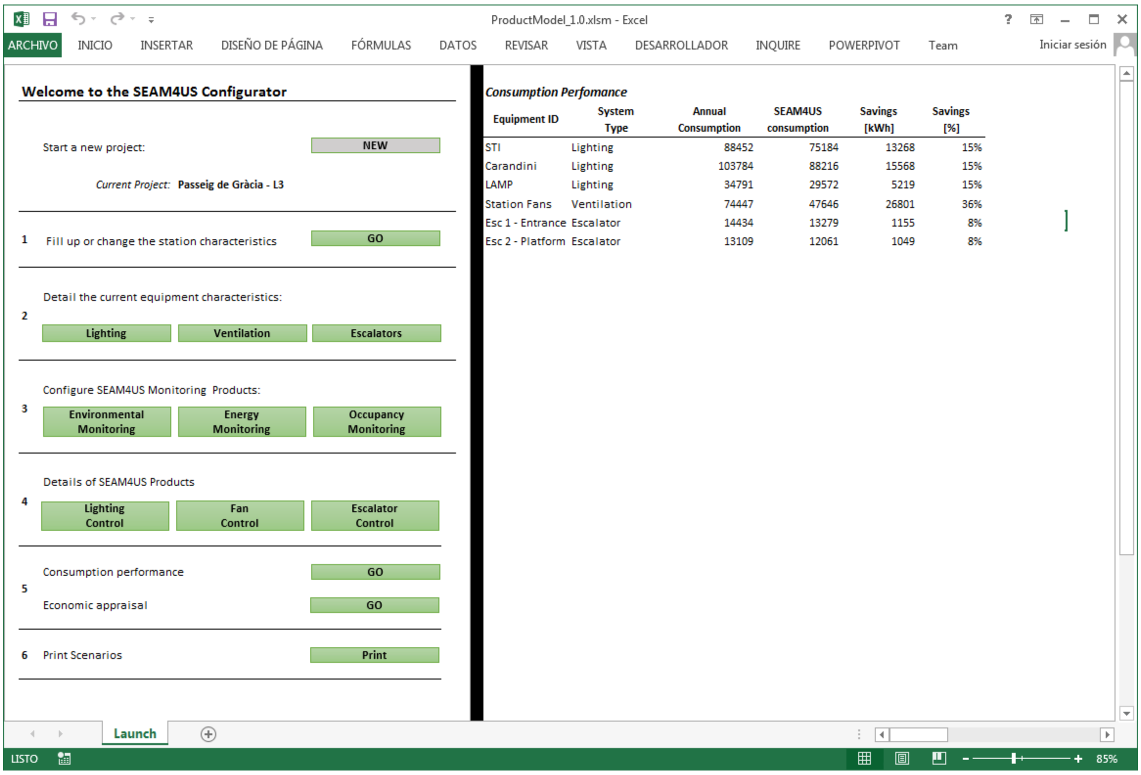


Figure 25 SEAM4US Configurator. Consumption performance

8.2.6. Scenario appraisal

When all the information has been introduced into the spreadsheet the user can design different scenarios to evaluate the economic performance of the hypothetical configurations. On top of that, detailed budget are created.

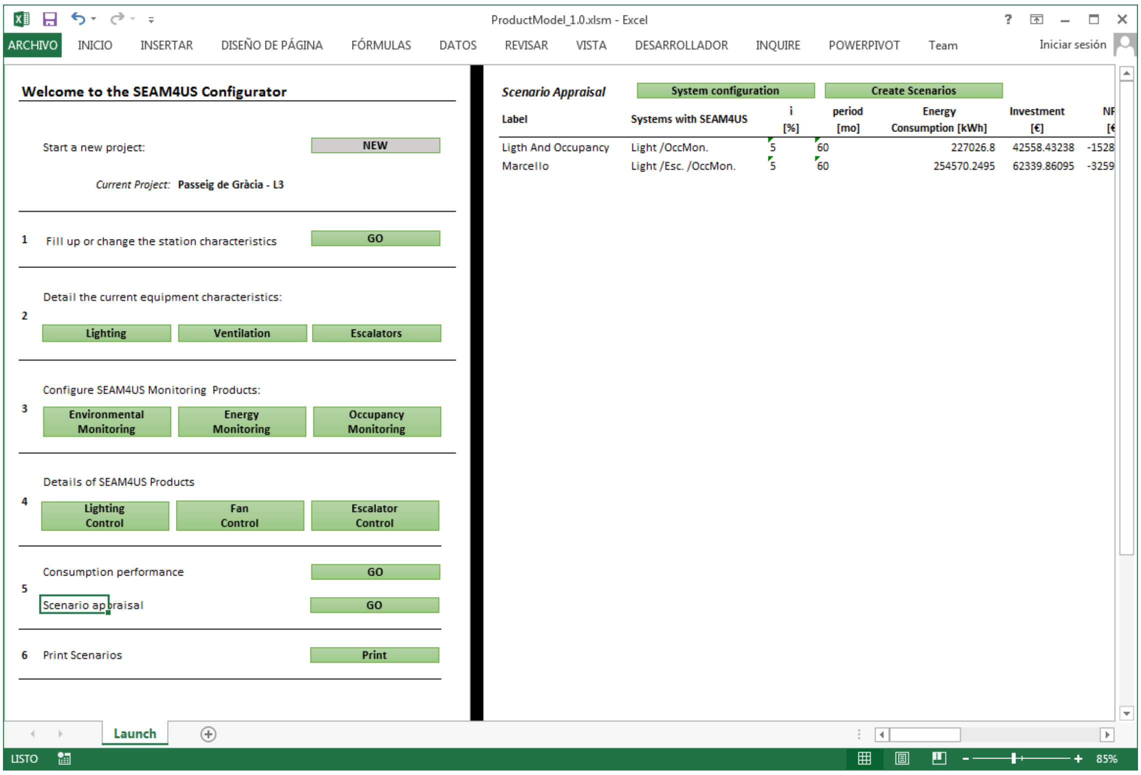
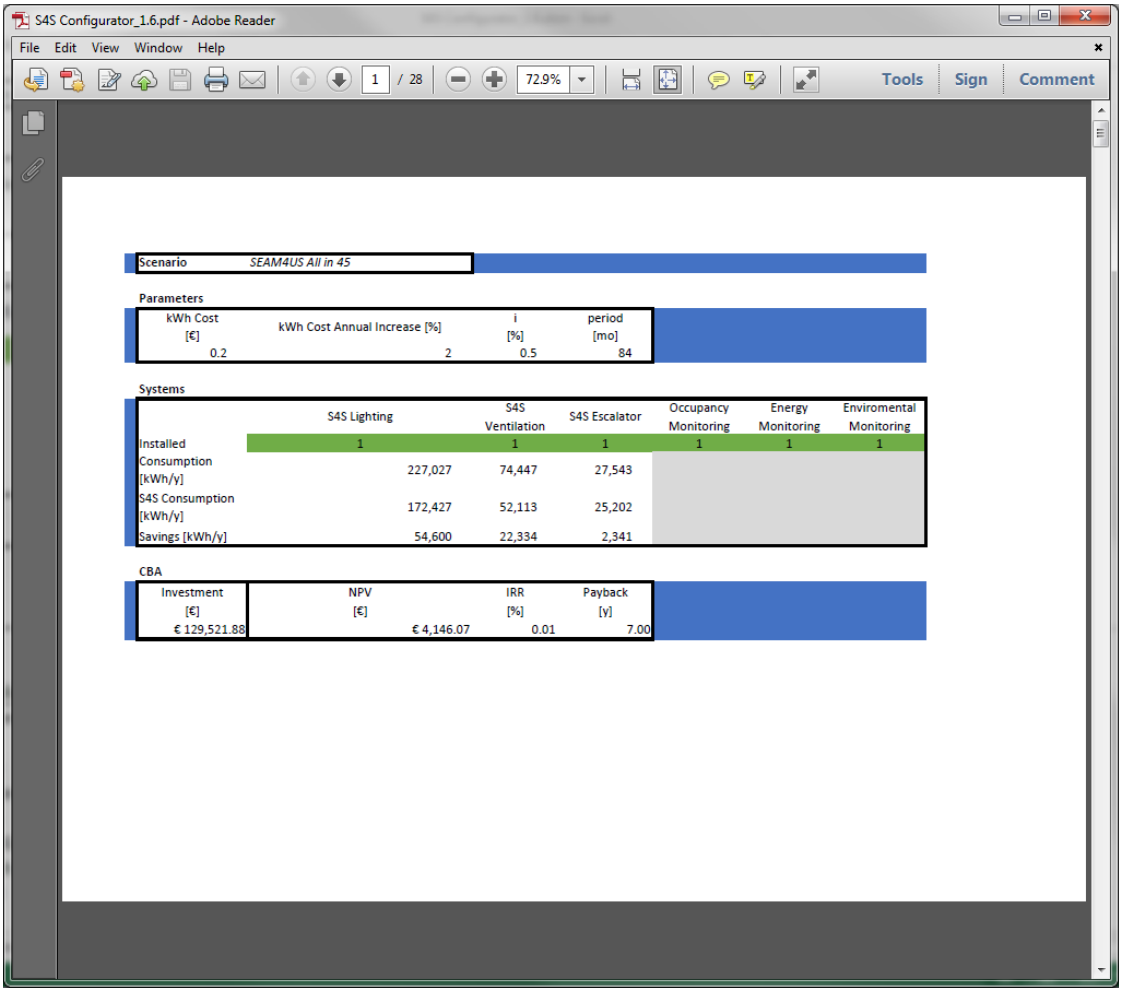


Figure 26 SEAM4US Configurator. Scenario Appraisal

To start the process the user must click the System configuration button to get directed to the user form (Figure 29) in which he can choose amongst SEAM4US subsystems and also introduce the economic parameters for each scenario. Once is added, it cannot be modified and to change it is necessary to remove it and create it again.

The user can review the scenarios in the main page before hitting the button Create Scenarios (Figure 26), which will create one worksheet per scenario. In these sheets the complete summary of the scenario is provided, along with the detailed budget and cash flow for the project. There's also the option to print into PDF files each of the scenario sheets, by pressing the respective button in the left UI PRINT button, row #6.



Scenario	SEAM4US All in 45

Parameters

kWh Cost [€]	kWh Cost Annual Increase [%]	i [%]	period [mo]
0.2	2	0.5	84

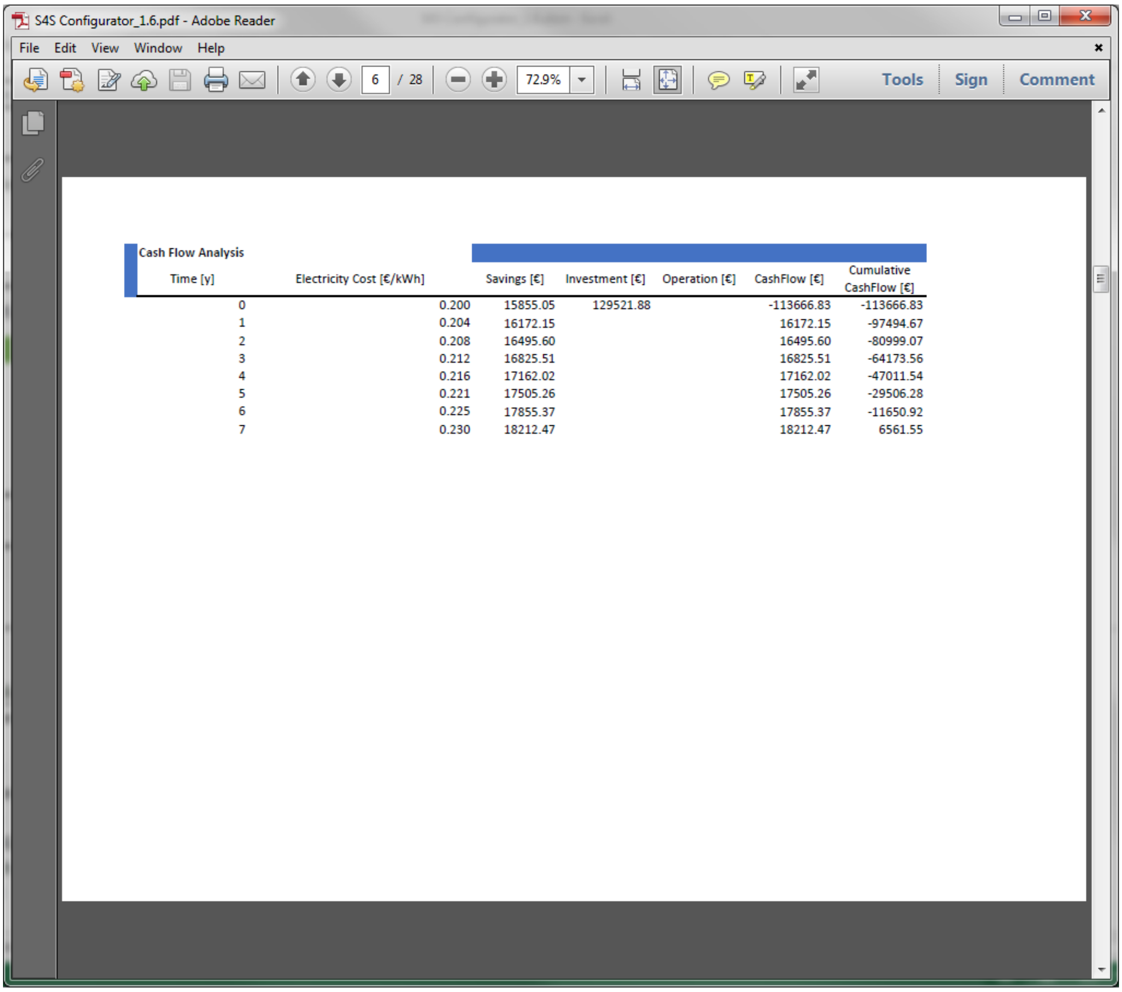
Systems

	S4S Lighting	S4S Ventilation	S4S Escalator	Occupancy Monitoring	Energy Monitoring	Enviromental Monitoring
Installed	1	1	1	1	1	1
Consumption [kWh/y]	227,027	74,447	27,543			
S4S Consumption [kWh/y]	172,427	52,113	25,202			
Savings [kWh/y]	54,600	22,334	2,341			

CBA

Investment [€]	NPV [€]	IRR [%]	Payback [y]
€ 129,521.88	€ 4,146.07	0.01	7.00

Figure 27 Screenshot of the Scenario PDF Output



Time [y]	Electricity Cost [€/kWh]	Savings [€]	Investment [€]	Operation [€]	CashFlow [€]	Cumulative CashFlow [€]
0	0.200	15855.05	129521.88		-113666.83	-113666.83
1	0.204	16172.15			16172.15	-97494.67
2	0.208	16495.60			16495.60	-80999.07
3	0.212	16825.51			16825.51	-64173.56
4	0.216	17162.02			17162.02	-47011.54
5	0.221	17505.26			17505.26	-29506.28
6	0.225	17855.37			17855.37	-11650.92
7	0.230	18212.47			18212.47	6561.55

Figure 28 Screenshot of the Scenario PDF Output

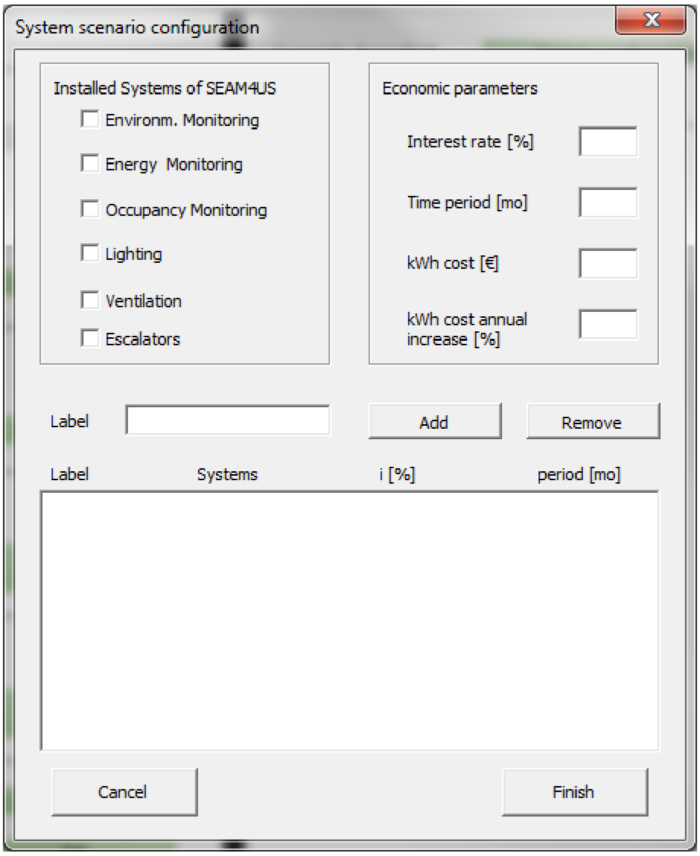


Figure 29 SEAM4US Configurator. Scenario configurator

APPENDIX 2 - DEPLOYMENT COSTS

In the following table the costs considered for hardware and installation are detailed.

Table 21 Installation costs: hardware and deployment

Installation Items	Unit	€/Unit
SEAM4US server	u	1762.00
BackUp Disk	u	450.00
WSN Gateway	u	419.80
Power converter	u	113.87
Node network[6]	Setup	~6000.00
Router WRT54GL	u	40.00
Ethernet Switch 8-port	u	20.00
Enistic SM16D	u	203.90
Enistic Clamp	u	13.80
Enistic Controller	u	117.39
Socomec DIRIS A10	u	130.00
Socomec TRB 60	u	16.05
RS485/Ethernet adapter	u	196.00
Video recorder LANACCESS Series Compact SA-HMBA-2C	u	1660.00
Computer (functional name?)	u	510.00
DALI/Ethernet gateway	u	1350.00
Beckhoff - BK9050 Ethernet TCP/IP “Compact“ Bus Coupler for up to 64 Bus Terminals (255 with K-bus extension)	u	168.00
Beckhoff - KL1002 2-channel digital input terminals 24 V DC	u	24.92
Beckhoff - KL1104 4-channel digital input terminal DC, filter 3	u	23.52
Beckhoff - KL2114 4-channel digital output terminal 24 V DC, 0.5	u	35.28
Beckhoff - KL4001 1-channel analog output terminal 0…10 V, 12 bit	u	100.00
Beckhoff - KL3021 1-channel analog input terminal 4…20 mA, differential input, 12 bit	u	94.00
Beckhoff - KL9010 Bus end terminal	u	9.46
Fan anemometer 641-24-LED AIR VELOCITY TRANSMITTER	u	660.00

[6] The cost of the node network depends on the configuration. There is no set cost for each node. See section 3.1.4.

Beckhoff - BK9050 Ethernet TCP/IP “Compact“ Bus Coupler for up to 64 Bus Terminals (255 with K-bus extension)	u	168.00
Beckhoff - KL1104 4-channel digital input terminal DC, filter 3	u	23.52
Beckhoff - KL9010 Bus end terminal	u	9.46
Beckhoff - KL2114 4-channel digital output terminal 24 V DC, 0.5	u	35.28
Installation and connection of the "in-fan" anemometer to the PLC including all necessary accessories.	u	524.36
Environmental Network commissioning	u	250.00
Equipment installation and VideoMatrix reprogramming	u	400.00
Escalator reprogramming by the Manufacturer	u	2500.00
Health & Safety coordination	u	300.00
Installation and connection of the data transmission cables Jamak to the Wago connectors	u	50.12
Installation labour	h	25.10
Installation of current sensor	h	25.10
Installation of environmental sensors	u	45.00
Installation of one smart meter	u	31.80
Network port certification	u	38.39
Procurement and installation of afumex cables	m	1.49
Procurement and installation of cable management: wiring ducts	m	4.68
Procurement and installation of data transmission cables S/FTP (Screened Foiled Twisted Pair)	m	11.93
Procurement and installation of IP55 junction boxes with DIN rail and Wago connectors	u	41.77
Procurement installation of cable management: metal trays	m	20.00
Provide and install a metallic cabinet, including all the specified components (1 PLC). Completely finished, including all necessary auxiliary elements	u	1143.00
System electrical certification by an authorised entity	u	330.00
Ventilation VFD reprogramming	u	462.00
Installation of the SEAM4US core system (done by the operator's resources)	h	0.00

APPENDIX 3 - PDG-L3 SEAM4US CONFIGURATOR SENSITIVITY ANALYSIS

In this appendix are presented all the tables resulting from the sensitivity analysis introduced in section 4.2.2 of this document.

8.3. Pre Competitive results

8.3.1. Scenario 1. All Products

- **Investment:** 129,521€
- **Interest:** 0.5%
- **Period:** 7 years

Table 22 Pre Competitive. Scenario 1

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	**5%**	**10%**	**15%**
Net Present Value [€]				
0.1	-62,688	-55,221	-40,647	-22,961
0.14	-35,954	-25,501	-5,097	19,663
0.2	4,146	19,080	48,229	83,599
0.25	37,563	56,230	92,666	136,879
0.3	70,980	93,381	137,104	190,160
Payback [y]				
0.1	-	-	-	-
0.14	-	-	-	7
0.2	7	7	6	5
0.25	6	5	5	4
0.3	5	4	4	4
IRR [%]				
0.1	-15%	-12%	-8%	-4%
0.14	-8%	-5%	-1%	4%
0.2	1%	4%	9%	14%
0.25	8%	12%	17%	22%
0.3	15%	18%	24%	30%

8.3.2. Scenario 2. All but energy monitoring

- **Investment:** 121,486€
- **Interest:** 0.5%
- **Period:** 7 years

Table 23 Pre Competitive. Scenario 2

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	5%	10%	15%
Net Present Value [€]				
0.1	-54,652	-47,185	-32,611	-14,926
0.14	-27,919	-17,465	2,939	27,698
0.2	12,182	27,115	56,264	91,635
0.25	45,599	64,266	100,702	144,915
0.3	79,016	101,416	145,139	198,195
Payback [y]				
0.1	-	-	-	-
0.14	-	-	7	6
0.2	7	6	5	5
0.25	5	5	5	4
0.3	4	4	4	4
IRR [%]				
0.1	-14%	-11%	-7%	-3%
0.14	-6%	-3%	1%	6%
0.2	3%	6%	11%	16%
0.25	11%	14%	19%	25%
0.3	18%	21%	27%	33%

8.3.3. Scenario 3. Lighting and Occupancy

- **Investment:** 68,918€
- **Interest:** 0.5%
- **Period:** 7 years

Table 24 Pre Competitive. Scenario 3

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	5%	10%	15%
Net Present Value [€]				
0.1	-22,887	-17,744	-7,706	4,474
0.14	-4,474	2,726	16,779	33,831
0.2	23,144	33,430	53,506	77,867
0.25	46,160	59,017	84,112	114,563
0.3	69,175	84,604	114,717	151,259
Payback [y]				

0.1	-	-	-	7
0.14	-	7	6	6
0.2	6	5	5	4
0.25	4	4	4	4
0.3	4	3	3	3
		IRR [%]		
0.1	-10%	-7%	-2%	2%
0.14	-1%	2%	6%	11%
0.2	10%	13%	18%	24%
0.25	18%	22%	28%	33%
0.3	27%	31%	37%	43%

8.3.4. Scenario 4. Ventilation Control

- **Investment:** 61,000€
- **Interest:** 0.5%
- **Period:** 7 years

Table 25 Pre Competitive. Scenario 4

Electricity Cost [€/kWh]	**kWh price annual increase**			
	2%	**5%**	**10%**	**15%**
		Net Present Value [€]		
0.1	-42,171	-40,068	-35,962	-30,979
0.14	-34,640	-31,695	-25,946	-18,971
0.2	-23,342	-19,135	-10,923	-958
0.25	-13,928	-8,669	1,596	14,053
0.3	-4,513	1,798	14,116	29,063
		Payback		
0.1	-	-	-	-
0.14	-	-	-	0
0.2	-	-	-	7
0.25	-	-	7	6
0.3	-	7	6	6
		IRR [%]		
0.1	-24%	-21%	-18%	-14%
0.14	-18%	-16%	-12%	-8%
0.2	-11%	-9%	-4%	0%
0.25	-6%	-3%	1%	6%
0.3	-2%	1%	6%	11%

8.3.5. Scenario 5. Escalator control

- **Investment:** 58,945€
- **Interest:** 0.5%
- **Period:** 7 years

Table 26 Pre Competitive. Scenario 5

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	5%	10%	15%
Net Present Value [€]				
0.1	-56,972	-56,751	-56,321	-55,798
0.14	-56,182	-55,873	-55,271	-54,540
0.2	-54,998	-54,557	-53,696	-52,651
0.25	-54,011	-53,460	-52,384	-51,078
0.3	-53,024	-52,363	-51,071	-49,504
Payback				
0.1	-	-	-	-
0.14	-	-	-	-
0.2	-	-	-	-
0.25	-	-	-	-
0.3	-	-	-	-
IRR [%]				
0.1	-49%	-47%	-45%	-42%
0.14	-46%	-44%	-42%	-39%
0.2	-43%	-41%	-38%	-35%
0.25	-40%	-39%	-36%	-33%
0.3	-38%	-36%	-33%	-30%

8.3.6. Scenario 6. Lighting and Ventilation Control

- **Investment:** 108,791€
- **Interest:** 0.5%
- **Period:** 7 years

Table 27 Pre Competitive. Scenario 6

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	5%	10%	15%
Net Present Value [€]				

0.1	-43,930	-36,684	-22,540	-5,377
0.14	-17,986	-7,841	11,960	35,988
0.2	20,930	35,423	63,710	98,036
0.25	53,360	71,476	106,836	149,743
0.3	85,790	107,529	149,961	201,450
Payback				
0.1	-	-	-	-
0.14	-	-	7	6
0.2	6	6	5	5
0.25	5	5	4	4
0.3	4	4	4	3
IRR [%]				
0.1	-12%	-9%	-5%	-1%
0.14	-4%	-1%	3%	8%
0.2	6%	9%	14%	19%
0.25	14%	17%	23%	28%
0.3	21%	25%	31%	37%

8.3.7. Scenario 7. Escalator and Lighting Control

- **Investment:** 81,614€
- **Interest:** 0.5%
- **Period:** 7 years

Table 28 Pre Competitive. Scenario 7

Electricity Cost [€/kWh]	**kWh price annual increase**			
	2%	**5%**	**10%**	**15%**
Net Present Value [€]				
0.1	-33,609	-28,245	-17,777	-5,074
0.14	-14,407	-6,898	7,757	25,541
0.2	14,396	25,123	46,059	71,465
0.25	38,399	51,807	77,978	109,735
0.3	62,401	78,491	109,896	148,004
Payback				
0.1	-	-	-	-
0.14	-	-	7	6
0.2	6	6	5	5
0.25	5	5	4	4
0.3	4	4	4	3

IRR [%]				
0.1	-12%	-10%	-5%	-1%
0.14	-5%	-2%	3%	8%
0.2	5%	8%	14%	19%
0.25	13%	16%	22%	27%
0.3	21%	24%	30%	36%

8.4. Industry results

8.4.1. Scenario 1. All Products

- **Investment:** 57,546€
- **Interest:** 0.5%
- **Period:** 5 years

Table 29 Industry. Scenario 1

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	**5%**	**10%**	**15%**
Net Present Value [€]				
0.1	-8,171	-4,329	2,780	10,854
0.14	11,579	16,959	26,910	38,214
0.2	41,205	48,890	63,107	79,254
0.25	65,892	75,499	93,270	113,454
0.3	90,580	102,108	123,433	147,654
Payback [y]				
0.1	-	-	5	5
0.14	4	4	4	4
0.2	3	3	3	3
0.25	2	2	2	2
0.3	2	2	2	2
IRR [%]				
0.1	-5%	-2%	2%	7%
0.14	8%	12%	17%	22%
0.2	29%	32%	39%	45%
0.25	47%	51%	58%	66%
0.3	68%	73%	81%	89%

8.4.2. Scenario 2. All but energy monitoring

- **Investment:** 50,640€
- **Interest:** 0.5%
- **Period:** 5 years

Table 30 Industry. Scenario 2

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	**5%**	**10%**	**15%**
Net Present Value [€]				
0.1	-1,264	2,578	9,687	17,760
0.14	18,486	23,866	33,817	45,121
0.2	48,111	55,797	70,013	86,161
0.25	72,799	82,406	100,177	120,361
0.3	97,487	109,015	130,340	154,561
Payback [y]				
0.1	-	5	5	4
0.14	4	4	3	3
0.2	3	3	2	2
0.25	2	2	2	2
0.3	2	2	2	1
IRR [%]				
0.1	0%	2%	7%	12%
0.14	15%	18%	24%	29%
0.2	38%	42%	49%	56%
0.25	61%	66%	73%	81%
0.3	88%	94%	103%	112%

8.4.3. Scenario 3. Lighting and Occupancy

- **Investment:** 23,073€
- **Interest:** 0.5%
- **Period:** 5 years

Table 31 Industry. Scenario 3

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	**5%**	**10%**	**15%**
Net Present Value [€]				
0.1	10,933	13,580	18,475	24,036
0.14	24,536	28,241	35,095	42,880

0.2	44,940	50,233	60,025	71,146
0.25	61,943	68,560	80,799	94,701
0.3	78,947	86,887	101,574	118,256
Payback [y]				
0.1	4	3	3	3
0.14	2	2	2	2
0.2	2	2	2	1
0.25	1	1	1	1
0.3	1	1	1	1
IRR [%]				
0.1	19%	22%	28%	34%
0.14	43%	48%	55%	62%
0.2	90%	95%	104%	114%
0.25	148%	155%	167%	180%
0.3	251%	261%	279%	296%

8.4.4. Scenario 4. Ventilation Control

- **Investment:** 30,340€
- **Interest:** 0.5%
- **Period:** 5 years

Table 32 Industry. Scenario 4

Electricity Cost [€/kWh]	**kWh price annual increase**			
	2%	**5%**	**10%**	**15%**
Net Present Value [€]				
0.1	-16,429	-15,347	-13,344	-11,069
0.14	-10,865	-9,349	-6,546	-3,361
0.2	-2,519	-353	3,652	8,201
0.25	4,437	7,143	12,150	17,836
0.3	11,392	14,640	20,648	27,471
Payback				
0.1	-	-	-	-
0.14	-	-	-	-
0.2	-	5	5	5
0.25	5	4	4	4
0.3	4	4	3	3
IRR [%]				
0.1	-23%	-21%	-17%	-13%

0.14	-14%	-12%	-8%	-3%
0.2	-3%	0%	5%	10%
0.25	6%	9%	15%	20%
0.3	15%	19%	24%	30%

8.4.5. Scenario 5. Escalator control

- **Investment:** 18,318€
- **Interest:** 0.5%
- **Period:** 5 years

Table 33 Industry. Scenario 5

Electricity Cost [€/kWh]	**kWh price annual increase**			
	2%	**5%**	**10%**	**15%**
Net Present Value [€]				
0.1	-16,860	-16,746	-16,536	-16,298
0.14	-16,277	-16,118	-15,824	-15,490
0.2	-15,402	-15,175	-14,755	-14,278
0.25	-14,673	-14,389	-13,864	-13,268
0.3	-13,943	-13,603	-12,973	-12,258
Payback				
0.1	-	-	-	-
0.14	-	-	-	-
0.2	-	-	-	-
0.25	-	-	-	-
0.3	-	-	-	-
IRR [%]				
0.1	-52%	-50%	-48%	-45%
0.14	-47%	-46%	-43%	-41%
0.2	-43%	-41%	-38%	-35%
0.25	-39%	-37%	-34%	-31%
0.3	-36%	-34%	-31%	-28%

8.4.6. Scenario 6. Lighting and Ventilation Control

- **Investment:** 46,214€
- **Interest:** 0.5%
- **Period:** 5 years

Table 34 Industry. Scenario 6

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	5%	10%	15%
	Net Present Value [€]			
0.1	1,703	5,432	12,331	20,166
0.14	20,870	26,091	35,749	46,718
0.2	49,621	57,079	70,876	86,546
0.25	73,579	82,902	100,148	119,737
0.3	97,538	108,726	129,421	152,927
	Payback			
0.1	5	5	4	4
0.14	4	3	3	3
0.2	2	2	2	2
0.25	2	2	2	2
0.3	1	1	1	1
	IRR [%]			
0.1	2%	5%	10%	15%
0.14	18%	22%	27%	33%
0.2	44%	48%	55%	62%
0.25	69%	74%	82%	90%
0.3	100%	106%	116%	126%

8.4.7. Scenario 7. Escalator and Lighting Control

- **Investment:** 27,499€
- **Interest:** 0.5%
- **Period:** 5 years

Table 35 Industry. Scenario 7

Electricity Cost [€/kWh]	kWh price annual increase			
	2%	5%	10%	15%
	Net Present Value [€]			
0.1	7,966	10,726	15,832	21,631
0.14	22,152	26,016	33,164	41,283
0.2	43,431	48,951	59,162	70,761
0.25	61,163	68,064	80,828	95,326
0.3	78,896	87,176	102,493	119,891
	Payback			

0.1	4	4	4	3
0.14	3	3	3	2
0.2	2	2	2	2
0.25	1	1	1	1
0.3	1	1	1	1
IRR [%]				
0.1	12%	15%	21%	26%
0.14	32%	36%	43%	49%
0.2	68%	73%	81%	90%
0.25	108%	115%	125%	135%
0.3	168%	176%	189%	202%