D6.3 – LLs Monitoring program and associated execution plan

PROBONO - The Integrator-centric approach for realising innovative energy efficient buildings in connected sustainable green neighbourhoods - has received funding from the European Union's Horizon 2020 Europe Research and Innovation programme under Grant Agreement No 101037075. This output reflects only the author's view, and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Deliverable nº:	**D6.3**
Deliverable name:	**LLs Monitoring program and associated execution plan**
Version:	**Final**
Release date:	**07/06/2024**
Dissemination level:	**Public**
Status:	**Final**
Authors:	**CARTIF**

This project has received funding from the European Union's Horizon 2020 Europe Research and Innovation programme under Grant Agreement No 101037075. This output reflects only the author's view, and the European Union cannot be held responsible for any use that may be made of the information contained therein.

Document history:

Version	Date of issue	Content and changes	Edited by
0.1	20/06/2023	Table of Content	CARTIF
0.2	29/09/2023	Contributions to general sections	CARTIF
0.3	29/09/2023	Contributions to Living Labs specific KPIs and monitoring periods	LLs leaders: ACC/DCN, UCD, SONAE/CAPW, SERCO, AU, CTU,
0.4	31/10/2023	Contributions to social KPIs section	SIN
0.5	08/03/2024	Contributions to social KPIs specific KPIs	LLs leaders: ACC/DCN, UCD, SONAE/CAPW, SERCO, AU, CTU,
0.6	08/03/2024	Contributions to Living Labs specific construction monitoring plans	
0.7	08/03/2024	Contributions to Living Labs specific operational monitoring plans	
0.8	15/03/2024	Aggregation of all the contributions and addition of all the missing information in general sections	CARTIF
0.9	During March	Review process	CAPW and INLE
1.0	April and May	Applying the review comments to the final report	CARTIF
1.1	07/06/2024	Final version ready for submission	CARTIF

Contributors:

Partner	Contributor
CAR	Javier Antolín (CARTIF) Álvaro Corredera (CARTIF) Julia Vicente (CARTIF)
ACC	Loredana Donatelli (ACC) Leire Domínguez (ACC R&D)
UCD	Stephen Curran (UCD)
SONAE / CAPW	Catarina Soares (SONAE) Benedita Ferreira (CAPW)
SERCO	Laurence Marzell (SERCO)

Partner	Contributor
AU	Gustaf Lohm (AU) Carl Peter Schultz (AU)
CTU	Jiri Tencar (CTU)
DCN	Javier Dorao (DCN)
TPF	Martin de Bellefroid (TPF)
SIN	Sidsel Bruun (SIN)

Peer reviewed by:

Partner	Reviewer
CAPW	Benedita Ferreira
INLE	Marina Laskari

Deliverable beneficiaries:

WP / Task
WP2, WP3, WP4, WP5, WP7

DEFINITIONS[1]

A Green Building (GB) (new or retrofit) is a building that, in its design, construction and operation, reduces or eliminates negative impacts, and can create positive impacts, on the climate, social, and natural environment. GBs preserve precious natural resources and improve quality of life[2]. Specifically, this means that GBs should be very energy efficient, use extensively the potential of locally available renewable energy, use sustainable materials, and aim for a low environmental impact over the entire life cycle. GBs offer their users and residents a healthy climate and a high quality of stay, they are resilient e.g., to environmental change and contribute to social inclusion.

Green Neighbourhoods aligned with the European Green Deal[3], is a set of buildings over a delimited area, at a scale that is smaller than a district, with potential synergies, in particular in the area of energy. A green neighbourhood is a neighbourhood that allows for environmentally friendly, sustainable patterns and behaviours to flourish e.g., bioclimatic architecture, renewable energy, soft and zero-emission

[1] Please refer to the last submitted reports for the latest status of the definitions

[2] https://www.worldgbc.org/what-green-building

[3] European_Green_Deal_EN_200710_fin

mobility etc. Green neighbourhoods are the building blocks of Positive Energy Districts (PEDs)[4] by implementing key elements of PED energy systems. For example, the exchange of energy between buildings increases the share of local self-supply with climate-neutral energy and system efficiency. They also provide the technical conditions to enable Citizen Energy Communities[5] and Renewable Energy Communities[6] to be implemented.

Green Buildings and Neighbourhoods (GBN) in PROBONO are GBs integrated at delimited area or district level with green energy and green mobility management and appropriate infrastructure supported by policies, investments and stakeholders' engagement and behaviours that ensures just transition that maximize the economic and social benefits considering a district profile (population size, socio-economic structure, and geographical and climate characteristics). Delivered in the right way, GBN infrastructure is a key enabler of inclusive growth, can improve the accessibility of housing and amenities, reduce poverty and inequality, widen access to jobs and education, make communities more resilient to climate change, and promote public health and wellbeing.

DGNB certification serves as a quality stamp ensuring the state of the building for buyers. The Green Building Council Denmark (2010) established the German certification DGNB meaning 'German Society for Sustainable Buildings'. The Danish version of DGNB was created to obtain a common definition of what sustainability is towards and making it measurable. A consortium of experts was established from all parts of the construction sector. DGNB had to be reshaped for the Danish standards, practice, traditions, and laws but is now available to certify any construction project. They chose DGNB as an innovation-forward and sustainable future guarantee. DGNB diversifies itself by focusing on sustainability and not just the environment. DGNB creates a standardized framework for the construction operations conditions and creates a common language which facilitates communication between professions and helps organize and prioritize the efforts in long and complicated development phases.

Life cycle assessment (LCA)[7] is a tool used for the systematic quantitative assessment of each material used, energy flows and environmental impacts of products or processes. LCA assesses various aspects associated with development of a product and its potential impact throughout a product's life (i.e., cradle to grave) from raw material acquisition, processing, manufacturing, use and finally its disposal. In PROBONO, LCA represents the statement of a building's total energy, resource consumption and environmental impact in the manufacture, transport, and replacement of materials and for its operation over its expected life. Social life cycle assessment (S-LCA)[8] is a method to assess the social and sociological aspects of products, their actual and potential positive as well as negative impacts along the life cycle. Life-cycle costing (LCC)[9] considers all the costs incurred during the lifetime of the product, work, or service.

---

[4] SET-Plan Action 3.2: https://setis.ec.europa.eu/system/files/setplan_smartcities_implementationplan.pdf

[5] Internal Electricity Market Directive (EU) 2019/944 5 Renewable Energy Directive (EU)

[6] Renewable Energy Directive (EU) 2018/20012018/2001

[7] https://op.europa.eu/en/publication-detail/-/publication/16cd2d1d-2216-11e8-ac73-01aa75ed71a1/language-en

[8] https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/social-lca/

[9] https://ec.europa.eu/environment/gpp/lcc.htm

Table of contents

List of Figures

List of Tables

Abbreviations and Acronyms

Acronym	Description
BIPV	Building Integrated Photovoltaic
BER	Building Energy Rating
BEMS	Building Energy Management System
COP	Coefficient of Performance (S-COP: Seasonal)
DHC	District Heating and Cooling
DSS	Decision Support System
DT	Digital Twin
EER	Energy Efficiency Ratio (S-EER: Seasonal)
EPD	Energy Performance Declaration
EV	Electric Vehicle
GA	Grant Agreement
GBN	Green Building Neighbourhood
GHG	Green House Gas
GSPF	Global Seasonal Performance Factor
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
KPI	Key Performance Indicator
LC	Life Cycle
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LL	Living Lab
M&V	Measurement and Verification
PCM	Phase Change Material
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
PV	Photovoltaic
RER	Renewable Energy Ratio
s-LCA	Social Life Cycle Assessment
S2V	Solar to Vehicle
SPF	Seasonal Performance Factor
V2G	Vehicle to Grid
WP	Work Package

Executive summary

PROBONO aims to turn six European district and site level areas into Green Building Neighbourhoods (GBN). Acting as the PROBONO Living Labs (LLs), two large-scale demonstrators are located in Madrid and Dublin and four business-focused demonstrators are located in Porto, Brussels, Aarhus and Prague. The PROBONO LLs will provide both an experimentation and innovation environment and testbed for GBN innovative solutions. Although having a distinct scope, each LL will follow a common process, starting with the GBN transition and strategic plan definition in WP1 (Macro-Knowledge Base and GBN Framework), the social innovations and stakeholders engagement activities in WP2 (Social and Behavioural Innovations) and the specification and selection of the maturing innovation technologies from WP3 (PROBONO Smart Green Building Construction and Renovation) and WP4 (Energy Monitoring and Clean Energy Production, Storage and Distribution), considering all the digitalization aspects in WP5 (Digitalisation for data driven GBN human-centred design and construction / renovation and operations optimisation) through the definition and deployment of the specific Digital Twins of each LL, going through the monitoring and evaluation in WP6 (Monitoring and evaluation of the project's Living Labs), the implementation of all the actions in WP7 (Living Labs GBN Implementation) and ending with the dissemination, communication and replicability actions in WP8 (Communication & Dissemination, Capacity Building, & Recommendations) and WP9 (Replicability, Exploitation & Commercialisation). WP6 "Monitoring and evaluation of the project's Living Labs" aims to define the evaluation framework and monitoring approach to be applied in each of the PROBONO LLs in order to collect all the necessary data to deploy the assessment activities and therefore to know the effectiveness of impacts achieved in each of the LLs once the innovations have been implemented.

The specific objectives of WP6 are the following and each of the objectives is aligned with each one of the WP6 tasks.

- Definition of the LLs evaluation framework based on Key Performance Indicators (KPIs), Measurement and Verification (M&V) plans and Life Cycle (LC) methodologies. T6.1. This work is reported in D6.1 PROBONO Evaluation Framework.
- Baseline calculation for the Living Labs prior the implementation of the actions. T6.2. This work is reported in D6.2 Baseline Evaluation.
- Monitoring program definition and associated execution plan for each Living Lab. T6.3. This work is reported in this deliverable D6.3.
- LLs impact assessment under operational and life cycle perspectives. T6.4. This work will be reported in future deliverables of the project within WP6.

D6.3 "LLs Monitoring program and associated execution plan" formulates the findings of Task 6.3 containing the monitoring program and associated execution plans for each LL. LLs monitoring plans will allow to collect all the necessary data from the Living Labs in order to perform the assessment activities and calculate the specific KPIs defined in the Evaluation Framework defined in T6.1-D6.1.

T6.3 "Monitoring program definition and associated execution plan" is composed by two sub-tasks:

- Subtask 6.3.1. Definition of the monitoring requirements to guarantee that all the necessary variables for each of the LLs as considered in the Evaluation Framework (T6.1) are gathered.

- Subtask 6.3.2. Definition of the monitoring plans for each Living Lab including monitoring specifications, location, number of sensors, etc. allowing then their subsequent correct deployment under WP7 “Living Labs GBN Implementation”.

This report includes the complete monitoring plans for each of the Living Labs covering both construction and operational stages. In addition, this report presents the basis for the associated monitoring execution plans for the Living Labs. Detailed information for the monitoring execution plans for each Living Lab will be collected through the next steps of the project and reported in WP7 LLs specific deliverables. The execution plans once completed will allow to follow closely the correct and successful implementation of the monitoring plans in the Living Labs.

The monitoring and execution plans enable the collection of the necessary data and information to perform a rigorous evaluation of the project demonstration activities during the construction and operational stages of the Living Labs.

1 Introduction

1.1 Mapping PROBONO Outputs

The purpose of this section is to map PROBONO's GA commitments, both within the formal deliverable as well as the task description, against the project's respective outputs and work performed.

GA Component Title	GA Component Outline	Respective Document Chapter(s)	Justification
TASK			
Task 6.3 Monitoring program definition and associated execution plan	This task establishes the Monitoring and Execution Plans of the Living Labs. Monitoring data will be collected through monitoring devices and stored in the LLs DT platforms (WP5). The selection of the specific solutions, acquisition, installation and commissioning of the monitoring equipment is done in the Living Labs.	Section 3, 4 and 5	Monitoring plans for each of the Living Labs have been defined considering construction and operational stages as are the two stages covered within the project timeline. Monitoring plans consider the specific monitoring/metering requirements to collect all the relevant data for all the variables needed for the KPIs calculation and therefore cover the complete requirements of the PROBONO Evaluation Framework as defined in D6.1. The plans will be the basis for the later activities related with monitoring deployment (WP7) and data collection/processing (WP5) for each of the Living Labs. The associated execution plans for the Living Labs will be completed based on the templates created as part of this task.
	Define the requirements of monitoring and metering to guarantee that all the necessary variables for each of the LLs as considered in the Evaluation Framework (T6.1) are gathered.		
	Provide monitoring execution plan for each of the LLs allowing their subsequent correct deployment. The monitoring and execution plan enables the collection of the necessary data and information to perform a rigorous evaluation of the project demonstration activities.		
	At least 1 year of full monitoring data after the implementation of the actions is foreseen for each LL.	Section 4	Section 4 shows a tentative Gantt for all the Living Labs showing the timing to conduct the monitoring activities for both construction and operational stages.
DELIVERABLE			
D6.3: LLs Monitoring program and associated execution plan This report formulates the findings of T6.3 containing the planned activities and procedures for implementing the monitoring program in each of the LLs.			

Table 1: Adherence to PROBONO's GA Deliverable & Task description

1.2 Purpose and scope of the document

This document defines the monitoring program and associated execution plan for each of the LLs.

Figure 1 shows the WP6 workflow. T6.3 establishes the Monitoring and Execution Plan of the Living Labs based on the Evaluation Framework needs identified in T6.1 "LLs Evaluation Framework". T6.2 "Baseline calculation" defined the reference situation for each Living Lab and already identified some preliminary information about baseline monitoring systems already existing in the Living Labs. Effectively, T6.3 "Monitoring program" aims to look into the details of the currently existing systems and identify the additional ones needed to cover the complete assessment needs of the project. T6.4 "Impact assessment" will deploy the impact assessment activities thanks to data collected from the monitoring systems deployed in the Living Labs as defined in the monitoring plans.

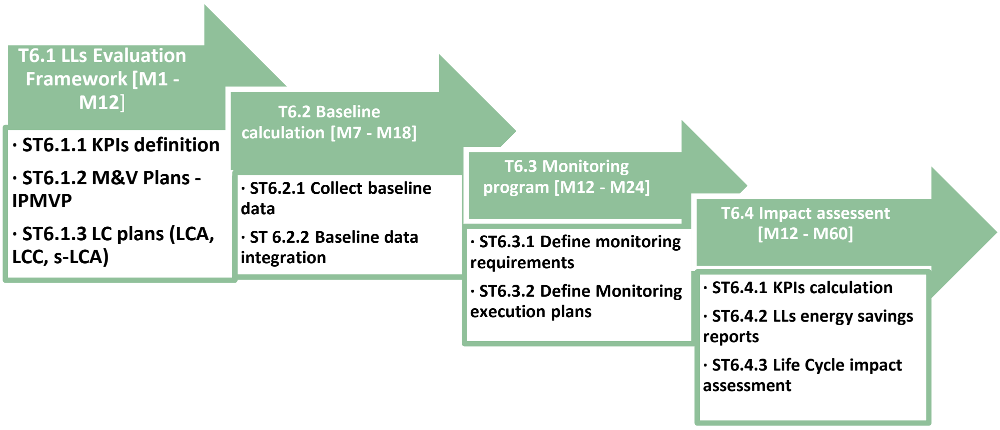


Figure 1: WP6 workflow

The main links of this specific T6.3 with other WPs are the following:

- The specific monitoring plans for each LL are based on the assessment needs identified in T6.1 "PROBONO Evaluation Framework" and the additional needs coming from the innovative solutions (WP3 "PROBONO Smart Green Building Construction and Renovation"/WP4 "Energy Monitoring and Clean Energy Production, Storage and Distribution").
- WP7 "Living Labs GBN Implementation" will deploy the monitoring plans in each LL based on the inputs from T6.3. This stage covers the selection, purchase, installation and commissioning of the monitoring systems for each Living Lab.
- WP5 "Digitalization for data driven optimization" will deploy all the infrastructure needed to collect (data base), process (quality and completeness) and calculate & visualize the KPIs for each of the Living Labs based on the Evaluation Framework needs and the requirements identified in the monitoring plans here defined.
- WP2 "Social and behavioural innovations" will deploy the social KPIs in each LL related with s-LCA.

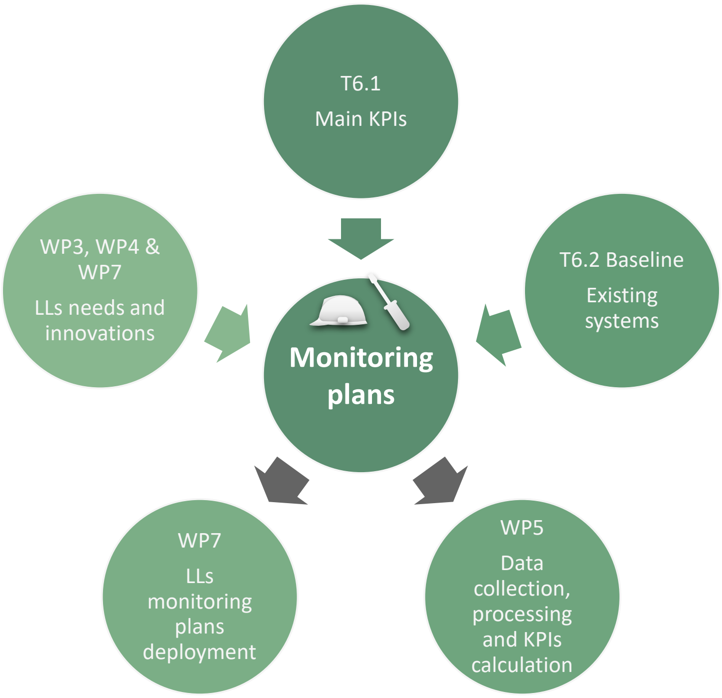


Figure 2: T6.3 main links with other Project activities

1.3 Structure of the document

Deliverable D6.3 is structured in seven different main sections. Section 1 is dedicated to the introduction. Section 2 is the one defining the monitoring plan definition and approach within the PROBONO project together with an introduction to the GBN social KPIs. Section 3 presents the monitoring execution plan to be followed in each of the Living Labs. Section 4 summarizes all the applicable KPIs (Main KPIs, Technical innovation KPIs and Social KPIs) for each of the Living Labs setting the basis for the next sections. Sections 5 and 6 collect all the relevant information for the definition of the construction and operational monitoring plans for each of the Living Labs. Finally, section 7 reports the conclusions and next steps.

1.4 Contribution to creating GBN

D6.3 collects all the information about the Living Labs monitoring plans and requirements in order to be able to deploy in the next steps of the project the complete Evaluation Framework as defined in T6.1. LLs are part of the GBN global concept. Thanks to the definition of the monitoring plans and their later deployment in the real demo-sites, it will be possible to collect real data and validate the performance of the Living Labs and the PROBONO innovations and therefore to validate part of the GBN concept. It is essential to emphasize the needed link with the replication and exploitation activities in WP9 "Replicability & Exploitation" in order to be able to analyse the global impact of these actions at a GBN level.

2 Monitoring plan definition and approach

2.1 Monitoring plan definition

Monitoring plans are designed to oversee and assess various aspects of a building, innovative system, innovative process, etc over the project timeline. Monitoring plans outline the approach, methods, and tools to be used for tracking and evaluating specific parameters or activities. These plans are established before the implementation of the innovative actions in the Living Labs (WP7 "Living Labs GBN Implementation") and are adaptable to changing conditions (if needed).

The main purposes of the PROBONO LL monitoring plans are the following:

- Performance evaluation: assessing how well an innovative system, building, or innovative process is meeting predefined goals and objectives.
- Risk management: allowing the identification of issues for timely intervention and mitigation.
- Resource optimization: allowing to manage the resources in an efficient way based on real-time information.
- Continuous improvement: by learning from monitoring outcomes and adjusting strategies accordingly.
- Planning and Preparation of execution plan by defining objectives, assessing requirements and identification stakeholders.
- Design of Monitoring System: selecting technologies, designing the architecture and communication protocol thresholds and alarm setting.
- Implementation and Deployment: buying and installing of the hardware and sensors, configuration and programming the control and monitoring algorithm and testing the whole integration.
- Operation and Maintenance: commissioning, continuous monitoring, preventive maintenance and identifying resolve any issues or anomalies in the monitoring system.
- Evaluation and Improvement: by learning from monitoring outcomes and adjusting strategies accordingly.

2.2 Monitoring plan approach

The main focus of the LLs monitoring plans is to cover the requirements identified in D6.1 "PROBONO Evaluation Framework". The Evaluation Framework defined in T6.1 identified 20 main KPIs selected to monitor and assess the impact achieved in each of the Living Labs for each of the 10 Expected Impacts of the PROBONO project as indicated in section 4, in addition to some additional KPIs coming from the technical WPs (WP3 - Smart Green Building. Construction and Renovation and WP4 - Energy Monitoring and Clean Energy Production, Storage and Distribution) and the other non-technological WPs (WP1 - Macro-Knowledge Base and GBN Framework, WP2 - Social and Behavioural Innovations, WP8 - Communication & Dissemination, Capacity Building, & Recommendations and WP9 - Replicability, Exploitation & Commercialisation).

It is relevant to remark that the purpose of the monitoring plans described here is to cover the requirements for the final assessment of the main KPIs (those defined to assess the 10 Expected Impacts) and the technical KPIs of the final selected innovative technologies in the Living Labs (WP3 and WP4). In addition, social innovations will be also measured and validated as indicated in sub-section 2.3. The rest of the non-technical KPIs identified in T6.1 and related with other WPs (WP1, WP8 and WP9) will be calculated through these non-technical specific WPs.

In PROBONO there are two main monitoring approaches considering the different stages covered through the project: construction and operation.

- **Monitoring for the construction period.** The construction monitoring plan needs to be deployed before the construction period to allow the monitoring and impact assessment of construction activities during the construction period → The results of the construction monitoring will be reported in the following deliverables D6.4 and D6.5 "Monitoring and Impact Assessment of Construction Activities".
- **Monitoring for the operational period.** The operational monitoring plan needs to be deployed before the reporting period (after the implementation of the Living Labs innovations) to allow the monitoring and impact assessment of the operational activities during the reporting period → The results of the operational monitoring will be reported in the following deliverables D6.6 and D6.7 "Monitoring and Impact Assessment of Operation Activities".

In the following figure it is possible to see the stages covered through the PROBONO project and the main assessment activities involved in each of them. Beyond the timeline of the PROBONO project, Life Cycle assessment methods (LCA/LCC/s-LCA) will derive their final results from the inputs coming from the stages covered by PROBONO (Construction and Operation), plus some hypothesis needed to cover the phases beyond the project scope. All the final impacts achieved through all the phases of the project will finally be reported in D6.8 "Final Project Evaluation" at the end of the project.

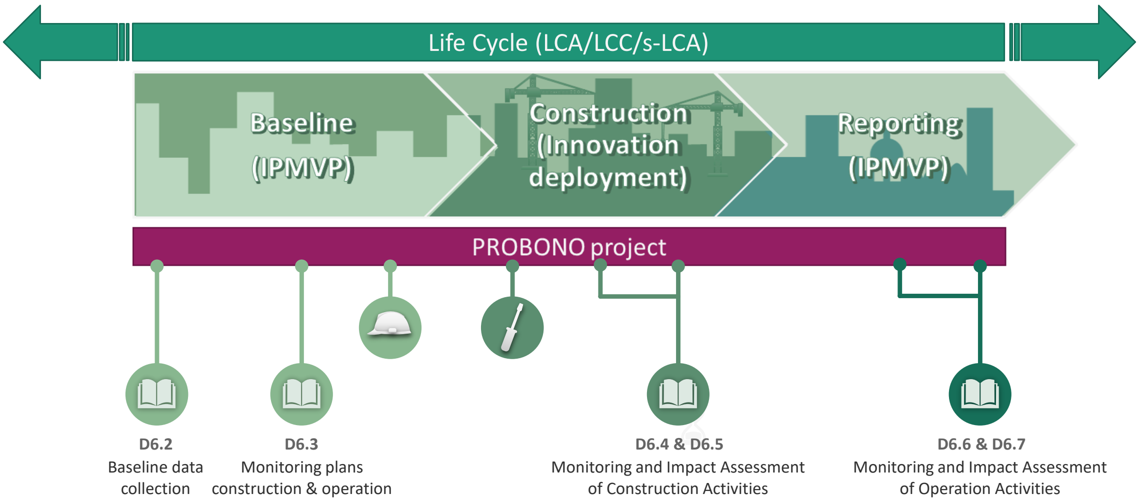


Figure 3: PROBONO Assessment stages

Together with the construction and operational monitoring plans, in PROBONO there will also be a social monitoring program to assess the effectiveness of the social actions implemented in the Living Labs (See sub-section 2.3).

To define the monitoring plans for the Living Labs, two templates have been created and shared with the Living Labs teams to collect all the necessary information to have complete plans for the construction and operational period:

- **Monitoring plan PROBONO Living Labs template**: to collect all the necessary monitoring requirements for the calculation of the Main KPIs associated with the PROBONO impacts for both constructive and operational stages. This template collects information about all the variables needed for the Main KPIs calculation with their measurement units, equipment needed, No. of units, specific location, data source, frequency, and their current monitoring availability.

Main KPI	Phase affected	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Need it?	Available?
Main KPI 1. Primary energy consumption	Use stage	Electrical - Energy consumption for building 1	kWh	Wattmeter	1	Electric box in the header of the building	Meters	Daily	Yes	No
		Electrical - Energy consumption for building 2	kWh	Wattmeter	1	Main electric box	Meters	Daily	Yes	Yes
		Thermal energy - Natural gas boiler consumption for building 1	m^3	Other	1	Natural gas inlet pipe to the boiler	Meters	Daily	Yes	No
		Thermal energy - Biomass boiler for building 2	kWh	Heatmeter	1	Biomass boiler water outlet pipe	Meters	Daily	Yes	No
Main KPI 2. Operational cost of energy	Use stage	Option A - Energy Consumption	kWh							
		Option A - Energy service maintenances cost	€							
		Option B - Electricity & fuel bills	€	None	-	-	Bills/Invoices	Monthly	Yes	Yes
Main KPI 3. Cost along the life cycle (LCC)	Construction stage	Invoices of innovations/materials	€	None	-	-	Bills/Invoices	Yearly	Yes	No
		Construction and deconstruction/demolition costs	€							
		Refurbishment costs	€							
		Construction project budget	€							
Main KPI 4. Energy demand	Use stage	Option A - Energy simulation model	kWh	Software	-	-	Simulation	Monthly	Yes	No
		Option B - Useful energy provided by energy systems	kWh							
		Option C - Energy consumption considering systems performances	kWh							
Main KPI 5. BER (Building Energy Rating)	Use stage	Energy Performance of the building	A-G	Software	-	-	Software	Yearly	Yes	No
Main KPI 6. Renewable energy production	Use stage	Electricity - PV	kWh	Wattmeter	2	Electricity box dedicated to the PV panels	Meters	Monthly	Yes	No
		Electricity -Wind	kWh							
		Thermal - Solar	kWh	Heatmeter	1	Thermal energy meter in the outlet of the solar thermal panels	Meters	Monthly	Yes	No
		Thermal - Biomass	kWh							
		Thermal - Geothermal	kWh							
Main KPI 7. Self-consumption ratio	Use stage	Renewable energy production - Electricity	kWh							
		Renewable energy production - Thermal	kWh							
		Energy consumption - Electricity	kWh							
		Energy consumption - Thermal	kWh							
Main KPI 8. Final energy consumption	Use stage	Electricity - Energy consumption	kWh							
		Thermal (fuel) - Energy consumption	kWh							
Main KPI 9. CO_2 emissions operational stage	Use stage	Final Energy consumption (KPI8)	kWh							
		Renewable production (KPI6)	kWh							
		Energy exported (Electrical & Thermal)	kWh							
Main KPI 10. GHG emissions along the life cycle (LCA)	Construction stage	Building description (location, climate zone, type of use, …).	-							
		Bill of materials	-	Software	-	-	Software	Once before and after	Yes	No
		Environmental Product Declarations (EPDs)	-	None	-	-	Other	Once after	Yes	No
Main KPI 11. Embodied energy	Construction stage	Information about local context (e.g., energy matrix)	-							
		Bill of materials (Inventory list)	-							
		Environmental Product Declarations (EPDs)	-							
Main KPI 12. Air pollutants operational stage	Use stage	Natural gas consumption	m3	Other	-	Natural gas pipe for boiler 1	Meters	Monthly	Yes	No
		Biomass consumption	kg	None	-	Biomass consumption entering biomass boiler	Bills/Invoices	Monthly	Yes	No
Main KPI 14. Shortened construction/retrofitting time	Construction stage	Construction progress with related to plan	Days ahead							
		Construction/retrofit phase duration	Days							
		In-situ construction/retrofit duration for similar project. Baseline	Days							
Main KPI 15. Shortened construction/retrofitting cost	Construction stage	Operational cost in construction/retrofit phase	€							
		In-situ construction/retrofit cost for similar project. Baseline	€							
Main KPI 16. Thermal comfort – Occupant perception	Use stage	Perception of the indoor temperature by occupants in building 1	Likert	None	10 surveys	-	Survey	Once before and after	Yes	No
		Perception of the air speed by occupants in building 1	Likert	None	10 surveys	-	Survey	Once before and after	Yes	No
		Perception of the humidity by occupants in building 1	Likert	None	10 surveys	-	Survey	Once before and after	Yes	No
Main KPI 17. Indoor air quality (IAQ) – Occupant perception	Use stage	Perception of the air quality by occupants in building 1	Likert	None	10 surveys	-	Interview	Once before and after	Yes	No
		Perception of the ventilation quality by occupants in building 1	Likert	None	10 surveys	-	Interview	Once before and after	Yes	No
Main KPI 18. IEQ – Acoustic comfort – Occupant perception	Construction&Uses stages	Perception of indoor noise by occupants.	Likert							
		Perception of outdoor noise by occupants	Likert							
Main KPI 19. EQ - Dust Quality - Occupant perception	Construction stage	Perception of dust levels by occupants or people involved during the construction process	Likert							
		Perception of allergens levels by occupants or people involved during the construction process	Likert							
Main KPI 20. IEQ – Visual comfort – Occupant perception	Use stage	Perception of lighting levels	Likert							
		Perception of artificial lighting quality	Likert							
		Perception of natural lighting quality	Likert							

Figure 4: Living Labs monitoring plan template (with some examples)

- **Monitoring plan PROBONO Innovations template**: to collect all the necessary monitoring requirements for the calculation of the technical KPIs associated with each of the project innovations covering both construction and operational stages. This template collects information about the specific KPIs used for the validation of the performance of individual innovative technologies, the phase affected (construction and/or operation), the variables needed, measurement units, equipment, No. of units, specific location, data source, frequency and their current monitoring availability.

TECHNOLOGIES/INNOVATIONS	Provider	KPI associated	Phase affected	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Need it?	Available?	Comments
Innovation 1	-												
Innovation 2	-												
Innovation 3	-												
Innovation 4	-												
Innovation 5	-												
Innovation 6	-												

Figure 5: Technical innovations monitoring plan template

2.3 GBN Social KPIs

This sub-section introduces and summarizes the social KPIs relevant for a Green Building Neighbourhood, suggested in D6.1 and represented in Table 2 below. The table shows the following:

- The first column shows the three *categories* of GBN social KPIs; Indoor Environmental Quality, Social Performance and Public Behaviour.

  While the IEQ KPIs are relevant for human wellbeing at the level of *buildings*, the categories of Social Performance and Public Behaviour are relevant in the context of *neighbourhoods*. Hence, when defining Living Lab specific KPIs, the aim is to include KPIs for both the building and neighbourhood level.
- The second column divides the categories of the first column into *subcategories*, aiming to capture all aspects of a GBN.
- The third column suggests relevant *Key Performance Indicators* for each subcategory.
- The fourth column suggests *measures* for the KPIs.
- The fifth column lists the *sources* for the measures and KPIs.

The table lists examples, methods and tools to quantify, measure and monitor the KPIs. However, some of these tools are very comprehensive and measuring on a larger scale where the impact of PROBONO activities cannot be expected to be visible, let alone isolated from other impacting factors and societal developments. Hence, when defining the social KPIs for each Living Lab, the approach has been to break down the subcategories and KPIs into actionable, measurable indicators that PROBONO activities can expect to impact. These social KPIs for each Living Lab are detailed in the corresponding chapters of Section 3.

Category	Subcategory	KPI	Measure	Sources
Indoor Environmental Quality	**Indoor air quality**	Carbon Dioxide (CO_2)	Ppm/Ventilation rate	(ISO 16798-1-2019)
	Thermal comfort	Predicted Mean Vote Predicted Percentage Dissatisfied Temperature Relative Humidity	Percentage of dis/satisfaction	(ISO 7730)
	Acoustic comfort	Sound Pressure Level	Noise rating	(EN 16798)
	Dust quality	Biological allergens	NIOSH Survey	(Schuh, 2000)
	Visual comfort	Illuminance Daylight factor	Light total Percentage of daylight in room	(EN12665) (Mardaljevic, 2012)
Social Performance	**Equity**	Access to services Affordability of energy Affordability of housing	GIS based assessment Income share spent on energy	(HQI, 2007) (Plan SEI, 2020) (Thema, 2020)

Category	Subcategory	KPI	Measure	Sources
	Community People	Democratic legitimacy Living conditions Social cohesion Personal safety Energy consciousness	Share of housing cost overburden BREEAM Survey HQI Survey Scanlon Foundation survey Eurostat metrics survey TPB Likert survey	(BRE, 2012) (HQI, 2007) (Markus, 2018) (EC, 2020) (Paul, 2016)
Public Behaviour	Company rewards Market acceptance	Branding Reputation Social responsibility Marketing adv Percentage of green buildings Behavioural barriers	Survey-based study Survey / metric availability Survey-based study Survey-based study m^2 of certified green buildings Survey-based study	(Zhao, 2019) (Zhao, 2019) (Zhao, 2019) (Zhao, 2019) (Fuerst, 2014) (Hoffman, 2008)

Table 2: Social Key Performance Indicators defined in the PROBONO categories. Based on Salom et al. (2021). First published in D6.1

3 Monitoring execution plan

The Monitoring Execution Plan is essential for ensuring that monitoring activities are conducted efficiently and effectively, providing reliable data that can be used to make informed decisions, enhance operations, and achieve compliance with the Grant Agreement requirements.

It is a detailed framework designed to systematically capture and analyse data related to specific project activities or operational processes. This plan specifies the methods, tools, and protocols used to conduct monitoring activities effectively, ensuring that all necessary data is collected to assess performance, compliance, and efficiency.

The Monitoring Execution Plan for the PROBONO project is designed to ensure that all monitoring activities align with the project’s overarching aim to transform European district and site-level areas into model green building neighbourhoods. This plan is a cornerstone of the project’s strategy to evaluate innovative solutions in real-world settings, capturing data crucial for assessing the effectiveness of energy-efficient technologies and sustainable practices.

Incorporating a Status Phase table and a Gantt Chart into the Monitoring Execution Plan for the PROBONO project provides a structured and visual approach to managing and monitoring the implementation of sustainable technologies across Green Building Neighbourhoods (GBN).

The aim of this report is to create the basis for the specific monitoring execution plans through the creation of some templates to be shared with the Living Labs teams. These templates will be shared with the Living Labs teams in order to be completed by them and all the relevant information about the final execution plans associated with each Living Lab will be reported under the specific LLs reports in WP7 “Living Labs GBN Implementation”.

Here’s how each component functions within the framework of the plan:

3.1 Monitoring execution plan - Status phase

The Status Phase is an essential element of the Monitoring Execution Plan that provides a detailed snapshot of the current state of the monitoring Living Lab at various stages:

1. **Planning and Preparation**

Establish the groundwork for the monitoring activities by setting objectives, defining key performance indicators (KPIs), and identifying the necessary resources and stakeholders.

Includes the development of project timelines, budgets, and staffing plans. This phase also involves conducting initial stakeholder consultations to ensure that all necessary requirements and expectations are aligned.

- **Define Objectives (Done in D6.1 PROBONO Evaluation Framework):** Specific objectives are established based on the desired outcomes of the PROBONO project. These objectives guide the entire monitoring process and are aligned with the project's overall goals to enhance green building practices.
- **Assess Requirements (This is part of this report):** This involves a thorough assessment of the technical, financial, and environmental requirements necessary for the monitoring activities. It includes identifying the scope of monitoring, the technologies needed, and the environmental impacts to be monitored.

- **Budget Availability (Done through the project coordination activities in WP10 “Project Management”):** A crucial step where the budget is reviewed and confirmed to ensure that sufficient funds are available to cover all planned activities without disruption.

2. Design of Monitoring System (Done through WP7 “Living Labs GBN Implementation” activities by each Living Lab).

Design the technical aspects of the monitoring system that will be used throughout the project.

- **System Design:** The architecture of the monitoring system is designed, including its components and how they interact. This design ensures that the system can handle the expected data volume and variety.
- **Hardware and Software Selection:** Select the most suitable hardware and software that meet the project’s requirements for accuracy, durability, and efficiency.
- **Sensor Deployment Plan:** Strategically plan where and how sensors and other monitoring instruments will be deployed across the project sites.
- **Communication Protocols:** Establish the rules and methods for data transmission to ensure that data collected by sensors is reliably and securely transmitted to the data processing centres.

3. Acquisition, Implementation, and Integration (Done through WP7 “Living Labs GBN Implementation activities” by each Living Lab)

Acquire and deploy the designed monitoring systems into the operational environment.

- **Hardware Acquisition:** Purchase or lease the monitoring equipment identified in the design phase.
- **Hardware Installation:** Physically install the monitoring devices at the designated project sites.
- **Software Development:** Develop or configure the software that will be used to collect, store, and analyse the data.
- **Integration with Systems:** Seamlessly integrate the monitoring systems with existing IT infrastructure to ensure coherent data flow and processing.
- **Testing and Validation:** Conduct extensive testing to ensure the systems work as intended and validate their accuracy and functionality.

4. Operation and Maintenance (Done through WP7 “Living Labs GBN Implementation activities” by each Living Lab)

Ensure that the monitoring systems operate smoothly and maintain them for optimal performance throughout the project lifecycle.

- **Commissioning:** Begin official operation of the monitoring systems after ensuring all systems are functional and integrated.
- **Continuous Monitoring:** Regular monitoring to continuously collect data as per the project’s monitoring plan.
- **Preventive Maintenance:** Routine maintenance to prevent any potential system failures and ensure longevity and accuracy of the monitoring equipment.
- **Troubleshooting:** Quick identification and resolution of any issues or anomalies that occur during the operation of the monitoring systems.

5. Data Collection and Analytics

Collect data as per the project’s monitoring protocols and analyse it to obtain insights and evaluate the project's impact.

- **Data Collection into the Global Platform (Done through WP5 “Digitalization for data driven optimization” activities):** Aggregate the data collected from different monitoring sites into a central platform where it can be managed and analysed.
- **Data Analysis - KPIs Calculation (Done through WP5 “Digitalization for data driven optimization” & T6.4):** Analyse the collected data to measure performance against the project’s Key Performance Indicators (KPIs). This analysis helps determine the effectiveness of the project's interventions and guides future project decisions.

3.2 Monitoring execution plan - Gantt Chart

The Gantt Chart complements the Status Phase table by providing a visual representation of the project timeline, including the start and end dates of all key activities and phases. It helps in the following ways:

- **Visual Timeline:** Shows the entire project duration at a glance, mapping out when specific tasks are scheduled to start and finish.
- **Dependency Tracking:** Illustrates how tasks are interdependent, highlighting the critical paths that could affect the project timeline.
- **Progress Tracking:** Allows for the ongoing monitoring of progress against the planned activities. Progress bars show what has been completed and what remains to be done.

Resource Allocation: Displays which resources are allocated to specific tasks, helping manage workload and expectations across the project team.

3.3 Monitoring Execution Plan Template

In the PROBONO project, these two phases (Status and Gantt Chart) are essential to ensure that the deployment and evaluation of energy-efficient and sustainable practices in Living Labs are systematic and effective. For this reason, we will create tables to document updates for the Living Labs, including the status of the LLs and the status of technological innovations. The Status Phase table provides a quick and current reference to manage and address immediate operational needs and challenges. Concurrently, the Gantt Chart offers a strategic perspective, facilitating during PROBONO project planning and coordination among multiple stakeholders.

Together, these two tables enable the project management team to:

- Ensure that all activities are aligned with the project’s strategic goals.
- Efficiently manage time and resources across different stages of the project.
- Quickly identify and mitigate risks that could derail project timelines or outcomes.
- Maintain clear communication and expectations among all project participants.

This structured approach to monitoring and execution not only enhances PROBONO project management efficacy but also supports the overarching goal of demonstrating and replicating successful green building strategies in urban environments across Europe.

It allows to the responsible to identify potential issues, optimize operations, and ensure that resources are used efficiently.

The LL leaders will have to fill two templates detailed below STATUS PHASE template (Figure 6) & GANTT CHART template (Figure 7).

3.3.1 Monitoring execution plan - Status Phase Template

It is divided in five phases:

1. Planning and Preparation: This phase focuses on the initial planning and preparation of the project. Objectives are defined, assessment requirements are established, and budget available
    1.1. Define Objectives: Identify specific aspects of the system or process to be monitored and the expected outcomes.
    1.2. Define Objectives: Determine the technical, operational, and resource requirements for implementing the monitoring system.
    1.3. Is the budget available? (Y/N): Establish a budget and allocate necessary human and material resources for carrying out the monitoring plan
2. Design of Monitoring System: The monitoring system is designed. This includes selecting technologies, defining the system architecture, and developing the detailed design of how the system will work
    2.1. System Design: Create the overall architecture and design of the monitoring system.
    2.2. Hard. Soft. Selection: Choose the appropriate hardware components and software platforms for data collection, processing, and visualization.
    2.3. Sensor Deployment Plan: Plan the deployment of sensors and monitoring devices in the target environment.
    2.4. Comm. Protocols: Define the communication protocols and interfaces for data transmission between sensors and the central monitoring system.
3. Acquisition, Implementation, and Integration: Devices are acquired, the design is implemented, and the elements of the monitoring system are integrated to ensure they function as a cohesive unit.
    3.1. Hardware acquisition: Acquisition sensors, monitoring devices, and necessary infrastructure components.
    3.2. Hardware Installation: Install sensors, monitoring devices, and necessary infrastructure components.
    3.3. Software Development: Develop or configure software modules for data collection, storage, analysis, and reporting.
    3.4. Integration with Systems: Integrate the monitoring system with other relevant systems, such as building management systems or IoT platforms.
    3.5. Testing and Validation: Conduct rigorous testing to ensure that the monitoring system functions correctly and meets the specified requirements.

4. Operation and Maintenance: This phase covers the ongoing operation of the system and its maintenance. It includes monitoring the system's performance, making necessary adjustments, and resolving any issues.
    4.1. Commissioning: Initiate the operation of the monitoring system in real-time and start collecting data.
    4.2. Continuous Monitoring: Regularly monitor the performance of the monitoring system and the quality of collected data.
    4.3. Preventive Maintenance: Conduct regular maintenance such as sensor calibration, software updates, and alarm review.
    4.4. Troubleshooting: Identify and resolve any issues or anomalies in the monitoring system in a timely manner.
5. Data Collection and Analytics: Collecting data generated by the monitoring system. The data is analysed to evaluate the effectiveness of the system and to inform future decisions.
    5.1. Data collection into the global platform: Continuously monitor and evaluate the performance of the monitoring system against predefined metrics and objectives.
    5.2. Data Analysis - KPIs calculation: Analyse collected data to identify trends, anomalies, and opportunities for optimization.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
3	Table 1: STATUS PHASES																				
4				1. Planning and Preparation			2. Design of Monitoring System (WP7)				3. Acquisition, implementation and Integration (WP7)					4. Operation and Maintenance (WP7)				5. Data collection and alalytics	
5				Define Objectives (D6.1)	Assess Requirements (D6.3)	Is the budget available? (Y/N) (WP10)	System Design	Hard. Soft. Selection	Sensor Deployment Plan	Comm. Protocols	Hardware adcquisition	Hardware installation	Software Developmen	Integration with Systems	Testing and Validation	Commissioning	Continuous Monitoring	Preventive Maintenance	Troubleshooting	Data collection into the global platform (WP5)	Data Analysis - KPIs calculation (WP5&WP6)
6	LL MONITORING	DUBLIN LL (only an example)	RESPONSIBLE	SERCO																	
7			STATUS	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	ON GOING	ON GOING	PENDING	PENDING
8	INDIVIDUAL TECHNOLOGIES MONITORING	2 Way EV Charging Infrastructure	STATUS	DONE	DONE	DONE	DONE	DONE	DONE	ON GOING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING
9		Battery Bank	STATUS	DONE	DONE	DONE	DONE	DONE	DONE	DONE	DONE	ON GOING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING	PENDING

Figure 6: Monitoring Execution Plan. Status Phase Template

The **LL leader** will fill rows 6 & 7: RESPONSIBLE and STAUTS for each phase:

- RESPONSIBLE: Indicate the internal/external company responsible for the action within the project. STATUS: Select from the list the actual status of this task: DONE, ONGOING, PENDING, or NOT APPLY. The background of the cell will change depending on the selection.
- The **Tech provider** will fill rows 8 (and next. one row for each individual technology monitored) STATUS: Select from the list the actual status of this task: DONE, ONGOING, PENDING, or NOT APPLY. The background of the cell will change depending on the selection.

3.3.2 Monitoring execution plan - Gantt Chart Template

The Gantt Chart shows the last 3 years of the project, with each year divided into quarters.

Each Responsible will have to update the current status or mark it as DONE if the activity is finished.

To complete the GANTT CHART considering the next aspects:

- Column B: show the five STATUS PHASES.

- Column C: will show the LL leader and the Technologies/Innovations monitored for each LL.
- Column D: All Technologies/Innovations monitored will be listed for each STATUS PHASE (1 to 5).
- Column E: Indicate the Responsible (Living Lab or Tech provider) who complete the GANT chart.

Table 2: GANTT CHART

			RESPONSIBLE	2024 Q1	2024 Q2	2024 Q3	2024 Q4	2025 Q1	2025 Q2	2025 Q3	2025 Q4	2026 Q1	2026 Q2	2026 Q3	2026 Q4
1. Planning and Preparation	LL Leader	DUBLIN LL (only an example)	UCD	DONE											
	Tech. 1	2 Way EV Charging Infrastructure	BOVLABS, CIDAUT	DONE											
	Tech. 2	Battery Bank	BEEPLANET	DONE											
2. Design of Monitoring System (WP7)	LL Leader	DUBLIN LL (only an example)	UCD	DONE											
	Tech. 1	2 Way EV Charging Infrastructure	BOVLABS, CIDAUT	DONE											
	Tech. 2	Battery Bank	BEEPLANET	DONE											
3. Acquisition, implementation and Integration (WP7)	LL Leader	DUBLIN LL (only an example)	UCD	DONE											
	Tech. 1	2 Way EV Charging Infrastructure	BOVLABS, CIDAUT												
	Tech. 2	Battery Bank	BEEPLANET												
4. Operation and Maintenance (WP7)	LL Leader	DUBLIN LL (only an example)	UCD												
	Tech. 1	2 Way EV Charging Infrastructure	BOVLABS, CIDAUT												
	Tech. 2	Battery Bank	BEEPLANET												
5. Data collection and alalytics	LL Leader	DUBLIN LL (only an example)	UCD												
	Tech. 1	2 Way EV Charging Infrastructure	BOVLABS, CIDAUT												
	Tech. 2	Battery Bank	BEEPLANET												

Figure 7: Monitoring Execution Plan. Gantt Chart Template

4 Living Labs specific KPIs

Figure 8, shows the summary of all the Main KPIs (those associated with the 10 PROBONO Expected Impacts) applicable to each of the Living Labs identifying the life cycle phases affected. The idea is to set the basis for the definition of the monitoring plans in the next sections (LLs construction monitoring plans in section 5 and LLs operational monitoring plans in section 6) needed for the KPIs calculation.

		IMPACT nº	IMPACT - stages					Madrid LL		Dublin LL		Porto LL		Brussels LL		Aarhus LL		Prague LL	
			Prod.	Cons.	Use	End	Bey.	Cons.	Use	Cons.	Use	Cons.	Use	Cons.	Use	Cons.	Use	Cons.	Use
KPI 1	Primary Energy Consumption	1																	
KPI 2	Operational cost of energy	2																	
KPI 3	Cost along the life cycle (LCC)																		
KPI 4	Energy demand	3																	
KPI 5	BER – Building Energy Rating																		
KPI 6	Renewable energy production	4																	
KPI 7	Self-consumption ratio																		
KPI 8	Final energy																		
KPI 9	CO2 emissions operational stage	5																	
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7																	
KPI 11	Embodied energy	6																	
KPI 12	Air pollutants operational stage	7																	
KPI 13	Replicability	8																	
KPI 14	Shortened construction/retrofitting time	9																	
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment																		
KPI 16	Thermal comfort – Occupant perception	10																	
KPI 17	IAQ Indoor Air Quality – Occupant perception																		
KPI 18	Acoustic comfort – Occupant perception																		
KPI 19	Dust quality – Occupant perception																		
KPI 20	Visual comfort – Occupant perception																		

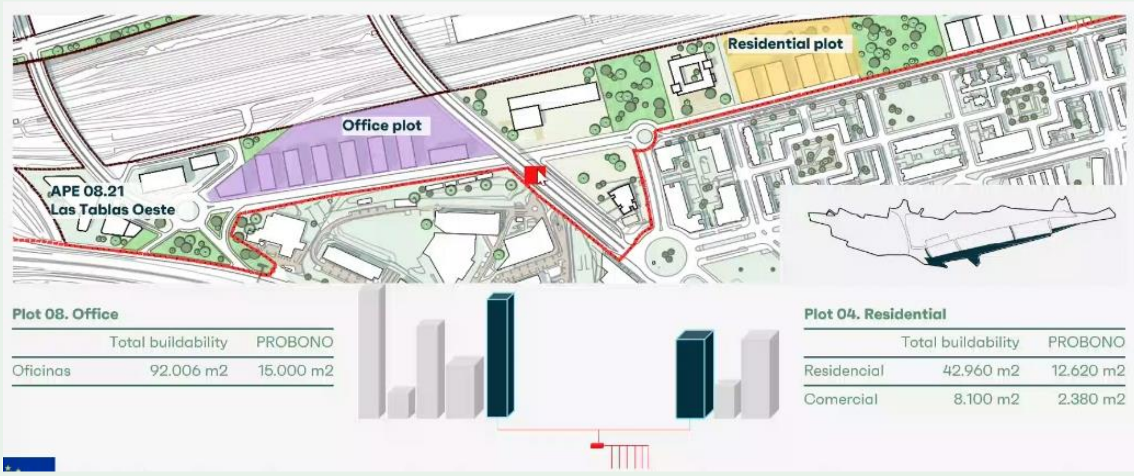
Figure 8: PROBONO Main KPIs (Whole life cycle) vs Living Labs; Blue cells represent the whole life cycle perspective while Orange cells represent only construction and operation stages considered within PROBONO timeline. Cross-out cells indicate deviations from the initial plan, reported in D6.1.

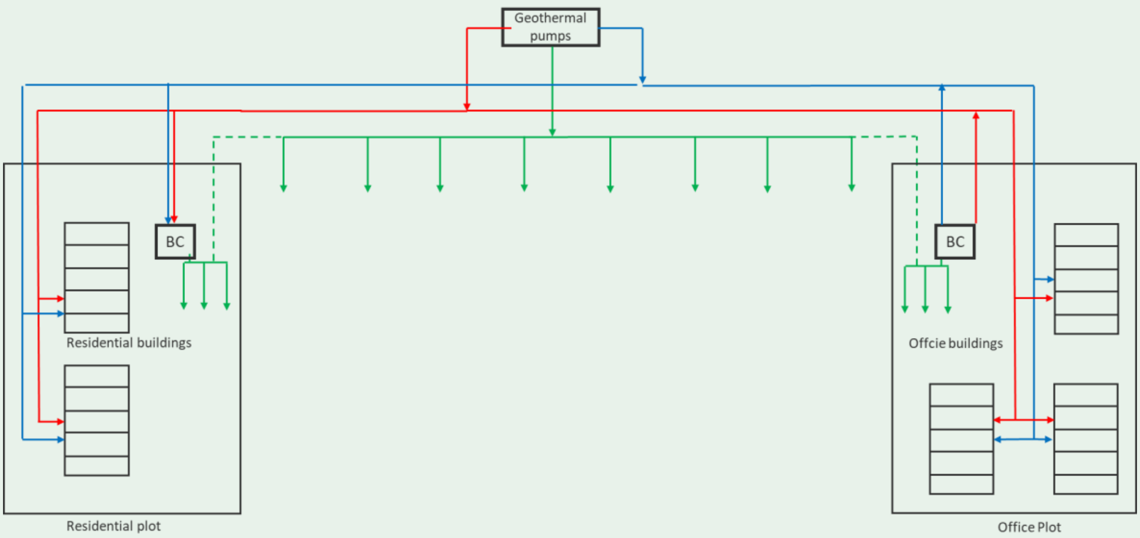
In the following sub-sections, the specific KPIs selected and applicable for each of the Living Labs are identified. Each of the sub-sections show the Main KPIs applicable to the LL (the ones related with the project impacts), the technical KPIs selected for the final validation of the performance of the individual innovations (the ones related with the technical innovations designed in WP3 "Smart Green Building Construction and Renovation" and WP4 "Energy monitoring and clean energy production") and the social ones (selected for the validation of the social innovations). In addition, for each Living Lab a potential monitoring period based on the currently available implementation plans is proposed.

4.1 Madrid Living Lab specific KPIs

Madrid Nuevo Norte (MNN) is the most important urban transformation project that Spain's capital will undergo and one of the largest urban regeneration projects in all of Europe, designed to improve the quality of life of its citizens, creating a more efficient, sustainable and prosperous Madrid.

The specific PROBONO LL is located in las Tablas Oeste area, the first of the four areas to be developed in Madrid Nuevo Norte. It includes the construction of a geothermal network connected to two buildings (a commercial building and a residential building). The two buildings connected to the geothermal network will be thermoactivated.





4.1.1 Madrid Living Lab Main KPIs

Figure 9, shows the Main KPIs (related with the Expected Impacts and technically defined in D6.1 "PROBONO Evaluation Framework") for Madrid LL. For each of the Main KPIs their related impact (From Impact 1 to 10) and the main phase affected during the PROBONO timeline (Highlighted in orange indicating construction or operational stages) are identified.

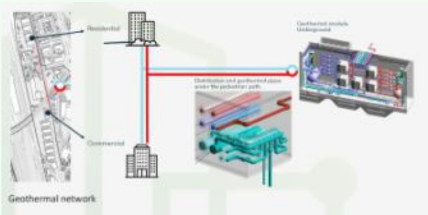
		IMPACT nº	IMPACT - stages					Madrid LL	
			Prod.	Cons.	Use	End	Bey.	Cons.	Use
KPI 1	Primary Energy Consumption	1							
KPI 2	Operational cost of energy	2							
KPI 3	Cost along the life cycle (LCC)								
KPI 4	Energy demand	3							
KPI 5	BER – Building Energy Rating								
KPI 6	Renewable energy production	4							
KPI 7	Self-consumption ratio								
KPI 8	Final energy								
KPI 9	CO2 emissions operational stage	5							
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7							
KPI 11	Embodied energy	6							
KPI 12	Air pollutants operational stage	7							
KPI 14	Shortened construction/retrofitting time	9							
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment								
KPI 16	Thermal comfort – Occupant perception	10							
KPI 17	IAQ Indoor Air Quality – Occupant perception								
KPI 18	Acoustic comfort – Occupant perception								
KPI 19	Dust quality – Occupant perception								
KPI 20	Visual comfort – Occupant perception								

Figure 9: PROBONO Main KPIs (Construction and Operational stages) vs Madrid Living Lab

4.1.2 Madrid Living Lab Technical Innovations KPIs

The following table shows the final list of technologies/innovations applicable to the Madrid Living Lab with the final KPIs selected.

Technologies / Innovations	Provider	Madrid LL project	KPI
Geothermal District Heating and Cooling network	IDOM	Las Tablas Oeste urbanization project	Global Seasonal Performance Factor (GSPF)

Technologies / Innovations	Provider	Madrid LL project	KPI
			
DHC simulation model	CARTIF	Geothermal network	DHC thermal demand supply
Demand and Response platform	TPF, STAM	Buildings and neighbourhood	Energy demand and production
2nd life batteries 	BEEPLANET	Geothermal network construction work	Energy saved thanks to the battery system
White steel slag for concrete and pavement	CELSA	Las Tablas Oeste urbanization project	Amount of reused material
Low carbon concrete & sustainable road pavement	ACC R&D	Las Tablas Oeste urbanization project	Amount of reused material
Integrated mobility infrastructure study	CIDAUT	Las Tablas Oeste urbanization project and office and residential buildings	Energy saved thanks to bidirectional charging system
Geothermal heat pumps 	ECOFOREST	Las Tablas Oeste urbanization project	Seasonal performance

Technologies / Innovations	Provider	Madrid LL project	KPI
Reclaimed asphalt	CELSA ACC I+D	Las Tablas Oeste urbanization project	Cost along the life cycle (LCC) - All phases GHG emissions along the life cycle (LCA) - All phases Embodied energy - Product stage (A1-A3), Construction stage (A4-A5)

Table 3: Madrid Living Lab list of selected innovations and related KPIs

4.1.3 Madrid Living Lab GBN Social KPIs

Table 4 shows the social KPIs applicable for Madrid LL.

Category	Subcategory	KPI	LL specification	Measure
Indoor Environmental Quality	**Thermal comfort**	Predicted Mean Vote - PMV	Simulation (if data of buildings available)	Percentage of dis/satisfaction
		Predicted Percentage Dissatisfied - PPD	Simulation (if data of buildings available)	
		Temperature - Tª	Simulation (if data of buildings available)	
		Relative Humidity - RH	Simulation (if data of buildings available)	
	Acoustic comfort	Sound Pressure Level	Acoustic emission satisfaction of District Heating and Cooling Network on Likert base	Noise rating >30% satisfied
Outdoor Environmental Quality	**Dust quality on work site**	Dust emission on work site	Reduction in number of complaints regarding dust on Likert base	>30% satisfied
	Visual comfort	Surface of public and green areas	Enjoy of public and green areas on Likert base	>30% satisfied
Social Performance	**Equity**	Access to services	Enjoy of pedestrian and bike network on Likert base	>30% satisfied
		Affordability of energy	Access to energy-efficient housing and transportation	BREEAM Survey
		Democratic legitimacy	Number of participatory activities. More than 10 in the last 5 years	Social Engagement report
		Living conditions	Mixed use in the urbanization	BREEAM Survey

Category	Subcategory	KPI	LL specification	Measure
	Community	Social cohesion	Social participation – Nº of participants in the activities of predesign	More than 11k
	People	Energy consciousness	Increase in citizens of Madrid City energy consciousness by 5%	CERNA assessment Spring 2024 and again in 2026
Public behaviour	**Company rewards**	Branding	No of CSR activities	More than 10 in the last 5 years
		Reputation	No of followers in LinkedIn	More than 10k followers
		Social responsibility	No of participative workshops	More than 10 in the last 5 years
		Marketing adv	Social Engagement program	Social Engagement report
	Market acceptance	Sustainability certificate	-	Min 1 sustainability certificate for Neighbourhood
		Behavioural barriers	Decrease in behavioural barriers (assessed through social norms, energy consciousness) by 5%	CERNA assessment Spring 2024 and again in 2026

Table 4: Madrid LL Social Key Performance Indicators

In the Madrid LL, Thermal comfort belonging to the section Indoor Environmental Quality, will be checked on the basis of a simulation of the building through software, which will deliver variables of Predicted Mean Vote, Predicted Percentage Dissatisfied, Temperature, Relative Humidity. Otherwise, Indoor air quality which implies measurement of CO_2 cannot be measured, because there are not building implemented for measuring it.

4.1.4 Madrid Living Lab monitoring periods

As shown in the figure below, District Heating and Cooling Network construction in the Madrid LL will be finalized by the end of 2026, therefore operational phase will begin in early 2027.

On the other hand, buildings' execution is going to start from 2026. It is worth to stress that buildings are not part of PROBONO scope, nevertheless they will affect the DHC Network operation.

Consequently, most of the KPIs can't be calculated under the PROBONO slot of time and a simulation will be done to help estimate the energy performance of the DHC Network.

It is important to highlight that the monitoring plan developed under PROBONO, will establish the requirements to be achieved by the DHC Network and buildings.

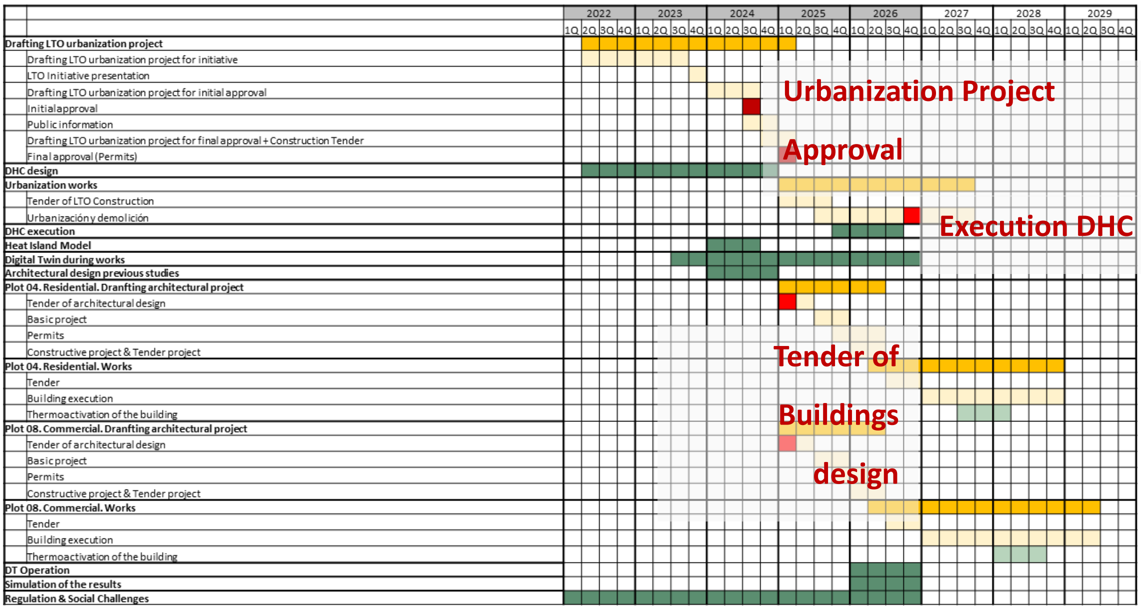


Figure 10: Madrid Living Lab Gantt chart representing the construction and operation phases

<u>District Network:</u>

Up to now technologies related to District Network have been selected and are being deployed, moreover the design has been duly finalized and submitted to the Municipality to get permits.

Construction of the District Network is envisaged to start on beginning of 2025.

As a consequence, on final part of 2026, E3 and E4 are likely to be implemented and monitoring system deployed.

<u>Buildings:</u>

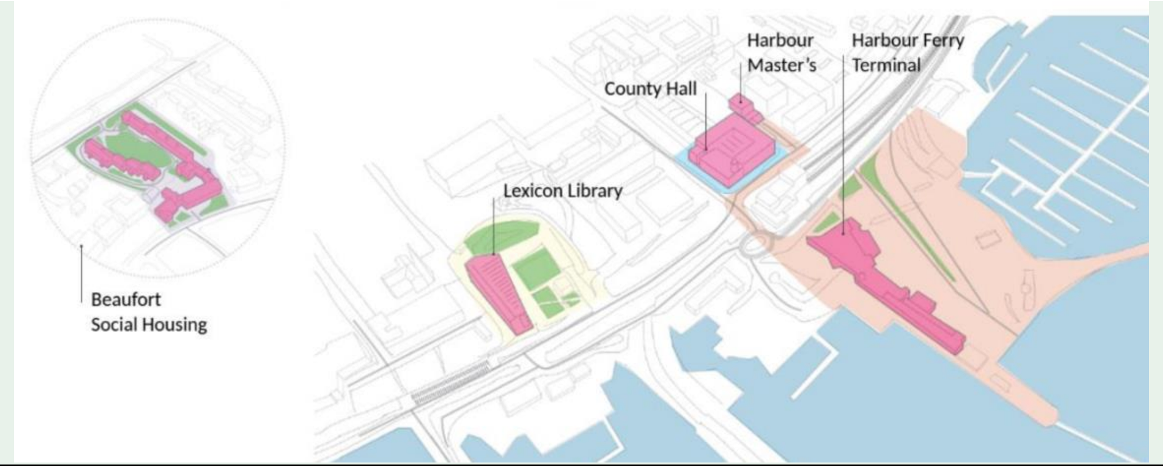
Buildings are not part of the PROBONO project, nevertheless they are mentioned since they belong to the same neighbourhood and are connected to the district network.

The innovative technologies are envisaged to be selected by the mid of 2024, and the design will be finalized by the end of 2024. Tendering process for construction will start on beginning of 2025.

4.2 Dublin Living Lab specific KPIs

Dublin LL is envisioned as a sustainable and cost effective, zero-carbon GBN, networking key municipal buildings and optimising prototypical housing retrofit for future, wider replication.

Country hall and Harbour ferry terminal are part of the Dublin Living Lab, and the Country Hall is the flagship building because will be the most of the technical innovations implemented.



4.2.1 Dublin Living Lab Main KPIs

Figure 11, shows the Main KPIs (related with the Expected Impacts and technically defined in D6.1 "PROBONO Evaluation Framework") for the Dublin LL. For each of the Main KPIs their related impact (From Impact 1 to 10 - grey cells) and the main phase affected during the PROBONO timeline (Highlighted in orange indicating construction or operational stages) are identified.

		IMPACT	IMPACT - stages					Dublin LL	
		nº	Prod.	Cons.	Use	End	Bey.	Cons.	Use
KPI 1	Primary Energy Consumption	1							
KPI 2	Operational cost of energy	2							
KPI 3	Cost along the life cycle (LCC)								
KPI 4	Energy demand	3							
KPI 5	BER – Building Energy Rating								
KPI 6	Renewable energy production	4							
KPI 7	Self-consumption ratio								
KPI 8	Final energy								
KPI 9	CO2 emissions operational stage	5							
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7							
KPI 11	Embodied energy	6							
KPI 12	Air pollutants operational stage	7							
KPI 14	Shortened construction/retrofitting time	9							
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment								
KPI 16	Thermal comfort – Occupant perception	10							
KPI 17	IAQ Indoor Air Quality – Occupant perception								
KPI 18	Acoustic comfort – Occupant perception								
KPI 19	Dust quality – Occupant perception								
KPI 20	Visual comfort – Occupant perception								

Figure 11: PROBONO Main KPIs (Construction and Operational stages) vs Dublin Living Lab

4.2.2 Dublin Living Lab Technical Innovations KPIs

The following table shows the final list of technologies/innovations applicable to the Dublin Living Lab with the final KPIs selected.

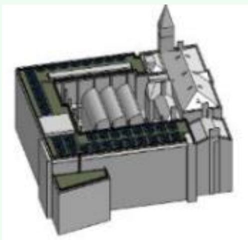
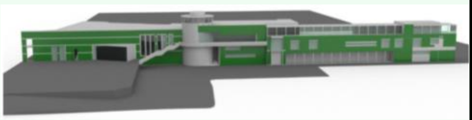
Technologies / Innovations	Provider	Location of implementation	KPI
Recycled Paper Insulation 	SOPREMA	Harbour Lodge Windows	Thermal Transmittance
2 Way EV Charging Infrastructure 	BOVLABS, CIDAUT	County Hall Basement Mobility Hub	Energy saved thanks to bidirectional charging system
Battery Bank	BEEPLANET	Country Hall Basement	Energy saved thanks to the battery system
Coloured BIPV Solar Panels  	Planning supported by FRHF, innovative coloured coating used, licensed by FRHF, produced by Megasol	County Hall Rooftop + Ferry Terminal	Production of solar electricity, increased solar production of coloured BIPV modules in comparison with standard products

Table 5: Dublin Living Lab list of selected innovations and related KPIs

4.2.3 Dublin Living Lab GBN Social KPIs

Table 6 shows the social KPIs applicable for Dublin LL.

Category	Subcategory	KPI	Measure
Indoor Environmental Quality	**Indoor air quality**	Carbon Dioxide (CO_2)	Ppm/Ventilation rate
	Thermal comfort	Predicted Mean Vote Predicted Percentage Dissatisfied Temperature Relative Humidity	Percentage of dis/satisfaction
	Acoustic comfort	Sound Pressure Level	Noise rating
	Dust quality	Biological allergens	NIOSH Survey
	Visual comfort	Illuminance Daylight factor	Light total Percentage of daylight in room
Social Performance	**Equity**	Access to services Affordability of energy Affordability of housing Democratic legitimacy Living conditions	GIS based assessment Income share spent on energy Share of housing cost overburden BREEAM Survey HQI Survey
	Community	Social cohesion	Scanlon Foundation survey
	People	Personal safety Energy consciousness	Eurostat metrics survey TPB Likert survey
Public Behaviour	**Company rewards**	Branding Reputation Social responsibility Marketing adv	Survey-based study Survey / metric availability Survey-based study Survey-based study
	Market acceptance	Percentage of green buildings Behavioural barriers	m^2 of certified green buildings Survey-based study

Table 6: Dublin LL Social Key Performance Indicators

4.2.4 Dublin Living Lab monitoring periods

The Gantt chart below for the Dublin LL outlines a detailed implementation plan for five technologies implemented: photovoltaic solar panels, battery bank, 2Way EV charging, green roof, and insulation. Each technology progresses through four phases: design, pre-construction, construction, and review. The design phases occur from October 2023 to February 2024, followed by pre-construction from March to June 2024. Construction takes place from July to October 2024, and finally, the review phase spans from January to April 2025. This staggered plan ensures organized and efficient project management.

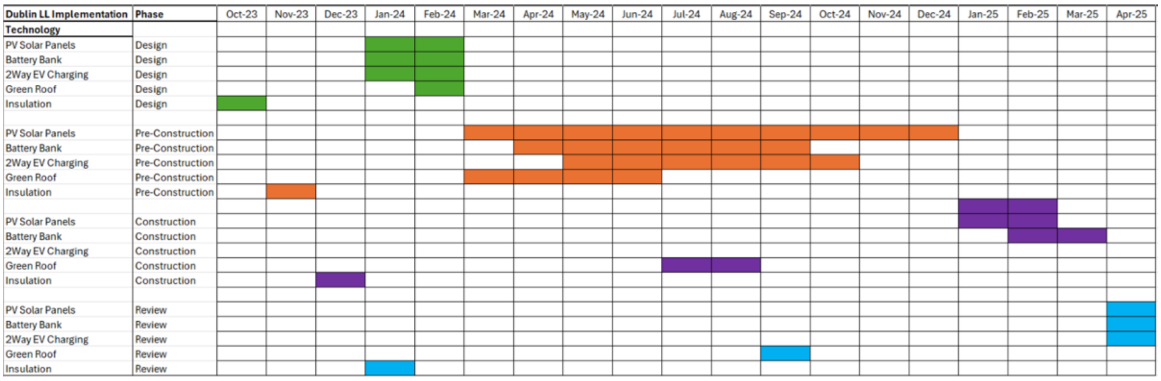
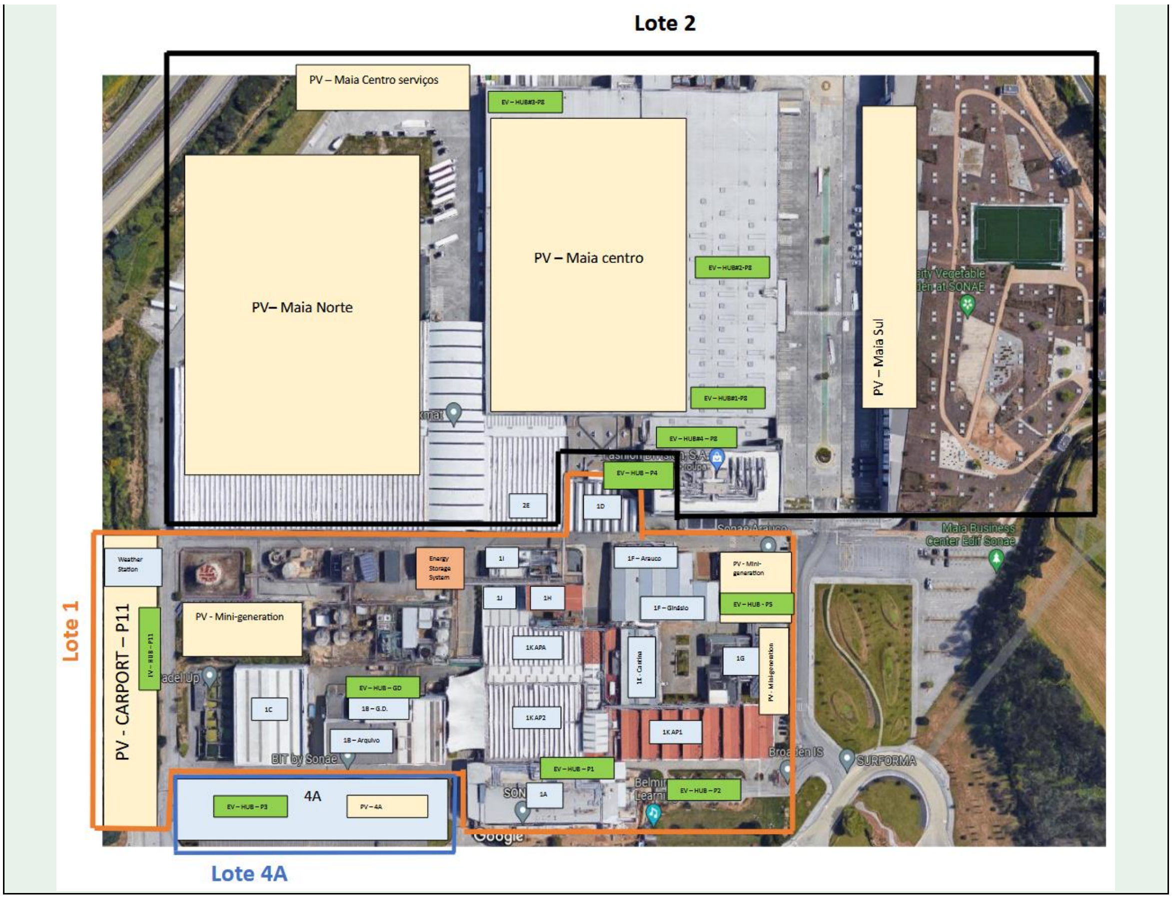


Figure 12: Dublin Living Lab Gantt chart representing the construction and operational phases.

4.3 Porto Living Lab specific KPIs

The Porto LL is the campus of the Sonae headquarters, one of the largest private companies in Portugal. It has a total area of more than 30.000 square meters with a working population of 2.000 employees. Most of the construction area is allocated to logistics (60%), a significant portion is dedicated to office spaces (30%) and a smaller but still notable part is designated for industrial and storage purposes (10%).

The main goal of the LL is to inspire a collective change and mobilize stakeholders by becoming a reference sustainable campus, raising awareness and promoting technical innovations that will have a positive impact in the environment.



4.3.1 Porto Living Lab Main KPIs

Figure 13, shows the Main KPIs (related with the Expected Impacts and technically defined in D6.1 "PROBONO Evaluation Framework") for Porto LL. For each of the Main KPIs their related impact (From Impact 1 to 10) and the main phase affected during the PROBONO timeline (Highlighted in orange indicating construction or operational stages) are identified.

		IMPACT nº	IMPACT - stages					Porto LL	
			Prod.	Cons.	Use	End	Bey.	Cons.	Use
KPI 1	Primary Energy Consumption	1							
KPI 2	Operational cost of energy	2							
KPI 3	Cost along the life cycle (LCC)								
KPI 4	Energy demand	3							
KPI 5	BER – Building Energy Rating								
KPI 6	Renewable energy production	4							
KPI 7	Self-consumption ratio								
KPI 8	Final energy								
KPI 9	CO2 emissions operational stage	5							
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7							
KPI 11	Embodied energy	6							
KPI 12	Air pollutants operational stage	7							
KPI 14	Shortened construction/retrofitting time	9							
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment								
KPI 16	Thermal comfort – Occupant perception	10							
KPI 17	IAQ Indoor Air Quality – Occupant perception								
KPI 18	Acoustic comfort – Occupant perception								
KPI 19	Dust quality – Occupant perception								
KPI 20	Visual comfort – Occupant perception								

Figure 13: PROBONO Main KPIs (Construction and Operational stages) vs Porto Living Lab

After reviewing the impacts and KPIs outlined in the Grant Agreement for the Porto Living Lab, it's been decided to reclassify the contribution of PCM technology from Expected Impact 6 to Expected Impact 1. This adjustment better aligns with the energy-saving outcomes of PCM technology. Consequently, Expected Impact 6 has been removed, while the contribution of PCM technology remains unchanged under Expected Impact 1.

Furthermore, Expected Impact 4 (High energy performance) has been added to the list to reflect the project's objectives. This impact will be achieved by implementing renewable energy sources and energy efficiency measures in the Porto Living Lab.

Due to the small-scale of the technological pilots being implemented in Porto LL, their contribution to the impacts and KPIs may not be perceptible at the Campus-wide scale. Currently, the Porto LL team is considering a method to assess scalability of the pilots to the Campus dimension to be able to measure the impacts of these technologies on a larger scale.

4.3.2 Porto Living Lab Technical Innovations KPIs

The following Table 7 shows the final list of technologies/innovations applicable to the Porto Living Lab with the final KPIs selected.

Additional technologies and their corresponding KPIs may be incorporated into the monitoring plan as they are confirmed.

Technologies / Innovations	Provider	Location	KPI
Phase Change Materials (PCM)	External provider	Local supermarket	Thermal storage capacity installed within the LL
Smart EV Hub	External provider	Logistics warehouse. floor –1 of the parking lot	CO_2 emissions per MWh of primary energy consumed in the GBN
2nd life batteries 	BEEPLANET	Smart Street area	Electrical storage capacity installed within the LL
Cool roof testing with Bi-facial PV	SOPREMA	Smart Street area	Electricity generation capacity installed
Vehicle to Grid (V2G)	External provider	Smart Street area	Energy saved thanks to bidirectional charging system. CO_2 emissions per MWh of primary energy consumed in the GBN
Solar to Vehicle (S2V)	External provider	Smart Street area	CO_2 emissions per MWh of primary energy consumed in the GBN

Table 7: Porto Living Lab list of selected innovations and related KPIs

4.3.3 Porto Living Lab GBN Social KPIs

Table 8 presents the social KPIs applicable to the Porto Living Lab. Only the Social Performance category will be included in the Social KPIs for the Porto LL

Category	Subcategory	KPI	LL specification
Social Performance	**Community People**	Number of users engaged in the vegetable garden Quantity of vegetables donated to charity Number of Campus Tours Featuring the Vegetable Garden	Attendance sheets. Weighing harvested vegetables. Attendance Record.

Table 8: Porto LL Social Key Performance Indicators

4.3.4 Porto Living Lab monitoring periods

Figure 14 presents the Porto LL Gantt chart, illustrating the implementation of initiatives, with the sequence and temporal localization of each phase of the process.

The construction phase of Porto LL is scheduled for completion in 2024.

Biodiversity initiatives were installed in 2022 and are currently operational, with continuous monitoring in place. However, these initiatives are not integrated into the LL monitoring system, which only compiles the technological component. Evolution is being tracked and reported in the WP2 "Social and behavioural innovations" reports.

Regarding the energy tech hub, for most of the technologies the design phase is ongoing, with preparatory works in progress. Once the construction phase, along with commissioning, is completed, the operational phase will begin. Each of the technologies will be integrated into the existing monitoring system during commissioning. As the technologies are installed, tracking of the results will start.

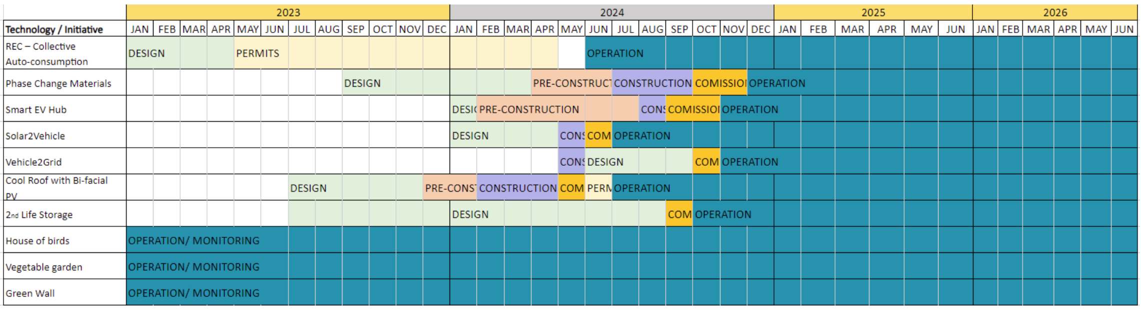


Figure 14: Porto Living Lab Gantt chart representing the construction and operational phases

4.4 Brussels Living Lab specific KPIs

Brussels LL is De l'Autre Côté de l'Ecole (ACE) school building, home to a Freinet pedagogy school. The LL will be renovating a large area, to bring it up into use for the educational needs of the school and in line with the latest environmental and regulatory requirements of the Green Deal. The areas to be renovated are minus 1, the ground floor, half of the 4th floor and the roof.

4.4.1 Brussels Living Lab Main KPIs

Figure 15, shows the Main KPIs (related with the Expected Impacts and technically defined in D6.1 "PROBONO Evaluation Framework") for Brussels LL. For each of the Main KPIs their related impact (From Impact 1 to 10) and the main phase affected during the PROBONO timeline

(Highlighted in orange indicating construction or operational stages) are identified. In this case the main KPIs applicable are only affecting the operational stage.

		IMPACT nº	IMPACT - stages					Brussels LL	
			Prod.	Cons.	Use	End	Bey.	Cons.	Use
KPI 1	Primary Energy Consumption	1							
KPI 2	Operational cost of energy	2							
KPI 3	Cost along the life cycle (LCC)								
KPI 4	Energy demand	3							
KPI 5	BER – Building Energy Rating								
KPI 6	Renewable energy production	4							
KPI 7	Self-consumption ratio								
KPI 8	Final energy								
KPI 9	CO2 emissions operational stage	5							
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7							
KPI 11	Embodied energy	6							
KPI 12	Air pollutants operational stage	7							
KPI 13	Replicability	8							
KPI 14	Shortened construction/retrofitting time	9							
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment								
KPI 16	Thermal comfort – Occupant perception	10							
KPI 17	IAQ Indoor Air Quality – Occupant perception								
KPI 18	Acoustic comfort – Occupant perception								
KPI 19	Dust quality – Occupant perception								
KPI 20	Visual comfort – Occupant perception								

Figure 15: PROBONO Main KPIs (Construction and Operational stages) vs Brussels Living Lab

4.4.2 Brussels Living Lab Technical Innovations KPIs

The following table shows the final list of technologies/innovations applicable to the specific Brussels Living Lab with the final KPIs selected.

Technologies / Innovations	Provider	Location	KPI
Green Roof 	SOPREMA	School building roof	Roof cooling efficiency of the outdoor environment [% or kWh/m².y] Roof energy cooling efficiency [% or kWh/m².y] Roof cooling efficiency for the indoor environment [% or °C.h]

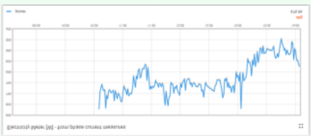
Technologies / Innovations	Provider	Location	KPI
Energy Monitoring System 	STAM, TPF	School building	Indoor air quality. Thermal comfort.

Table 7: Brussels Living Lab list of selected innovations and related KPIs

4.4.3 Brussels Living Lab GBN Social KPIs

Category	Subcategory	Key Performance Indicator	LL specification	Measure
Indoor Environmental quality	**Indoor air quality**	CO_2	CO_2 level of a classroom	ppm
	Thermal comfort	Temperature	Temperature of a classroom	°C
		Relative Humidity	humidity level of a classroom	%
Social Performance	**Community**	Social cohesion	Number of engagement activities	Yearly evaluation
	People	Personal safety	Attitude to travel by bike or by foot (cycling, walking) of (a) school users (b) neighborhood	(a) Yearly (b) 2024 & 2026 through CERNA assessment
			Nb of crashes and victims (a) Neighborhood (b) involving <18y) (b) Home-school trip	Yearly
			Road safety risk assessment	Baseline (2023), mid-term, final (2026)
			counts of bikes/e-steps in ACE parking or assimilated	Seasonal
			modal split of school users on period 2022-2027	Yearly
			Traffic counts (light, heavy, bikes, M2W)	Seasonal

Category	Subcategory	Key Performance Indicator	LL specification	Measure
			Average speed motorized vehicles	Seasonal
		Energy consciousness	5% increase in energy consciousness	CERNA assessment: Spring 2024 and again in 2026
Public behaviour	**Market acceptance**	Behavioural barriers	5% decrease in behavioural barriers	CERNA assessment: Spring 2024 and again in 2026

Table 9: Brussels LL Social Key Performance Indicators

4.4.4 Brussels Living Lab monitoring periods

As mentioned, ACE and a SOPREMA approved roofing contractor met in the first week of April and and right now, a detailed installation specification is not available. But as an indicative estimate of a construction plan, the following provides a realistic view from when ACE gives the approval to start. The amber cells in the Gantt in Figure 16 show where decision-making options are under consideration by ACE; the green cells are for implementation.

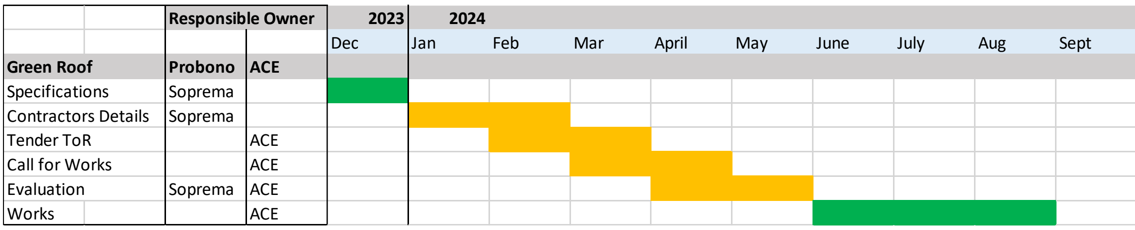
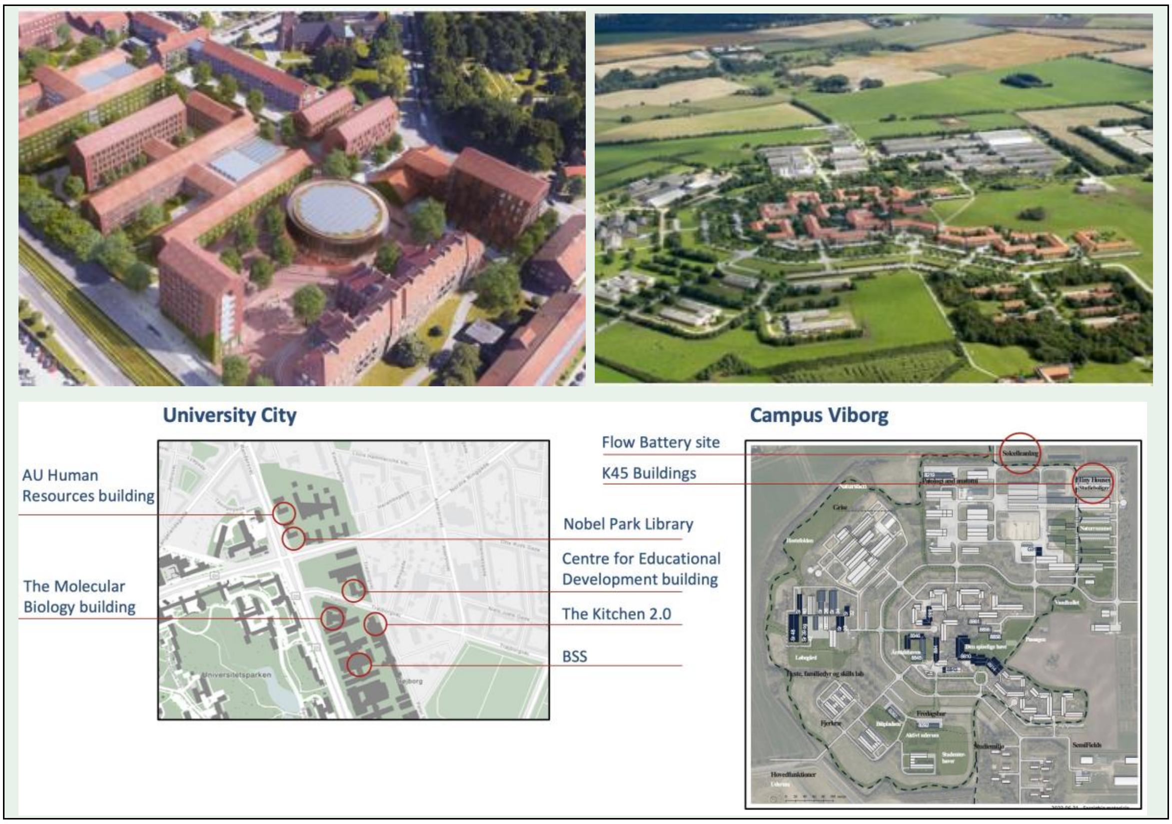


Figure 16: Brussels Living Lab Gantt chart representing the construction and operational phases

4.5 Aarhus Living Lab specific KPIs

Aarhus University is transforming into a modern, sustainable campus through the independent Campus 2.0 program (independent of Probono), aiming for gold grade in the DGNB green certification system.
The Aarhus LL, part of the Probono initiative, identifies high-impact opportunities within Campus 2.0 and pitches these concepts to AU (Aarhus University). Aarhus LL focuses on two sites: University City and Campus Viborg, with four main activities: installing flow batteries at Campus Viborg (VisBlue), renovating building K45 at Campus Viborg (COWI), conducting human-centred analysis in four buildings at University City, and renovating The Kitchen 2.0 (AU, ITA, IRTSX). These activities are detailed in the D7.18 "Aarhus LL Design and Progress Report (I)"



4.5.1 Aarhus Living Lab Main KPIs

Figure 17, shows the Main KPIs (related with the Expected Impacts and technically defined in D6.1 “PROBONO Evaluation Framework”) for the Aarhus LL. For each of the Main KPIs their related impact (From Impact 1 to 10) and the main phase affected during the PROBONO timeline (Highlighted in orange indicating construction or operational stages) are identified.

		IMPACT nº	IMPACT - stages					Aarhus LL	
			Prod.	Cons.	Use	End	Bey.	Cons.	Use
KPI 1	Primary Energy Consumption	1							
KPI 2	Operational cost of energy	2							
KPI 3	Cost along the life cycle (LCC)								
KPI 4	Energy demand	3							
KPI 5	BER – Building Energy Rating								
KPI 6	Renewable energy production	4							
KPI 7	Self-consumption ratio								
KPI 8	Final energy								
KPI 9	CO2 emissions operational stage	5							
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7							
KPI 11	Embodied energy	6							
KPI 12	Air pollutants operational stage	7							
KPI 13	Replicability	8							
KPI 14	Shortened construction/retrofitting time	9							
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment								
KPI 16	Thermal comfort – Occupant perception	10							
KPI 17	IAQ Indoor Air Quality – Occupant perception								
KPI 18	Acoustic comfort – Occupant perception								
KPI 19	Dust quality – Occupant perception								
KPI 20	Visual comfort – Occupant perception								

Figure 17: PROBONO Main KPIs (Construction and Operational stages) vs Aarhus Living Lab

Two activities in the Aarhus LL have been indefinitely halted due to a lack of acceptance by AU clients. Specifically, the use of biogen materials, wood fibre insulation, and potential solar panel technologies proposed by SOPREMA were declined due to performance concerns in the Danish climate and insurance coverage issues. Consequently, two original KPIs for assessing PROBONO impact have been removed:

- KPI 6. Renewable energy production.
- KPI 7. Self-consumption ratio.

These have been replaced with social value KPIs aligned with confirmed human-centred analysis activities:

- KPI 16. Thermal comfort.
- KPI 17. indoor air quality (IAQ).
- KPI 18 & KPI 20. Indoor environmental quality (IEQ) for both acoustic and visual comfort.

Many Aarhus LL activities focus on the design or pre-design phase of building lifecycles, such as the "upcycling" renovation of K45 (COWI) and The Kitchen 2.0 renovation. KPIs for these projects focus on design analysis, like predicted embedded carbon (measured as CO_2 equivalent), based on retaining existing building elements versus demolition and new construction. The monitoring plan will track these predictions throughout the design phase, using COWI's expertise, and compare them with actual construction outcomes if the construction occurs during the Probono project.

4.5.2 Aarhus Living Lab Technical Innovations KPIs

The final list of technologies/innovations applicable to the Aarhus Living Lab and their selected KPIs is shown in the Table 10. The human-centred analysis project focuses on capturing and digitalising social values in building projects using ProFormalise and ProBIM, and assessing environmental impacts with SEEDS. SEEDS, a decision support tool, evaluates social intents, design activities, and their environmental impacts. Input for SEEDS is collected via interviews and organized using the ProFormalise Social Value Capture Process. SEEDS and ProBIM integrate these assessments into the BIM model, enhancing visibility and tracking of social values throughout the building lifecycle.

Technologies / Innovations	Provider	Location	KPI
Flow Batteries[10] 	VISBLUE	Near solar panels (Campus Viborg)	AC kWh energy charge/discharge values, AC instantaneous values, historical values.
Human-centred analysis system: ProFormalise, SEEDS 	AU	Human resources building; Molecular Biology building; Nobel park library; Centre for Educational Development (all in University City)	Number of captured and digitalised social value design intentions Qualitative and quantitative environmental impact assessments of each design intention, and their aggregated impact
Repurposing existing buildings (Upcycling) 	COWI	K45 Buildings (Campus Viborg)	Embedded energy of the materials used (kg CO_2 eq): Calculate embedded GWP of supplied materials. Consider also resources and possible upcycle of any removed material (LCA perspective).

10 **Flow Batteries:** Data is collected through sensors directly connected to the flow batteries (as part of the unit, Inverters Victron Multiplus II), and accessed through a customer interface (Secomea Sitemanager Gateway), and an internet connection delivered normally by the customer's network.
This data, along with other measures (with support from VisBlue) will be used to assess: battery usage, battery lifetime (based on performance degradation measures) in comparison with estimates of lithium batteries, which were the original alternative planned to be used by AU (clients).

Technologies / Innovations	Provider	Location	KPI
Thermal comfort with Ventilation Assessment Tool, ProFormalise, ProBIM, MIC	ITA INNOVA, IRTSX, AU	The Kitchen 2.0 (University City)	Based on ITA CFD-based air quality simulations, followed by sensor readings on-site in the renovated building, social value KPIs will be assessed: Thermal Comfort Indoor Air Quality (IAQ) Indoor Environmental Quality (IEQ) - Acoustic Comfort Indoor Environmental Quality (IEQ) - Visual Comfort

Table 10: Aarhus Living Lab list of selected innovations and related KPIs

4.5.3 Aarhus Living Lab GBN Social KPIs

Table 11 presents the social KPIs for Aarhus LL, focusing on the Human Centred Analysis projects, The Kitchen 2.0, and the K45 renovation. KPIs from ProFormalise, ProBIM, and SEEDS are detailed, linking specific design intentions to social values. In the Kitchen 2.0 project, design decisions on ventilation aim to enhance human comfort, wellbeing, energy efficiency, and zero carbon emissions. The VisBlue battery balances electricity demand and storage, with KPIs centered on ROI, savings, and maintaining balance within the Green Campus Viborg network, reducing CO2 emissions. Collaboration with COWI on the Campus Viborg K45 project seeks to incorporate social KPIs, despite the AU facility team's current focus on CO2 and economic factors. This development aims to emphasize social qualities, fostering self-sustaining communities and enhancing comfort, safety, and inclusiveness.

Category	Subcategory	KPI	Measure
Indoor Environmental Quality	**Indoor air quality**	Carbon Dioxide (CO_2)	Ppm/Ventilation rate
	Thermal comfort	Temperature Relative Humidity	
	Acoustic comfort	Sound Pressure Level	Noise rating
	Visual comfort	Illuminance Daylight factor	Light total Percentage of daylight in room
Social Performance	**Equity**	Access to services Democratic legitimacy Living conditions	GIS based assessment BREEAM Survey HQI Survey

	Community	Social cohesion	Scanlon Foundation survey

Table 11: Aarhus LL Social Key Performance Indicators

4.5.4 Aarhus Living Lab monitoring periods

The monitoring periods in the Aarhus Living Lab are divided into three key activities: flow batteries, upcycling strategies, and human-centred analysis and started from August 2023 and will continue until November 2025.

Flow batteries

The contract for the purchase of flow batteries (2 units) was signed at the end of May 2024.

AU Facility Management has agreed with VisBlue on the delivery of the batteries in December 2024. Monitoring during the operation of the batteries will begin soon after they have been installed.

We will use the sensors that are integrated into the flow batteries for monitoring (data is collected via a web-based user interface developed by Visblue).

The monitoring period for the flow batteries is therefore currently planned to commence from March 2025 (or as soon as they are operational) until March 2026.

Upcycling strategies

Monitoring in the case of the upcycling strategies is with respect to the embodied carbon that is saved in the renovation of the K45 building on Campus Viborg, in comparison with the alternative strategy of demolition and reconstruction.

The monitoring period is divided into two phases:

- Embodied carbon predicted to be saved as per the design (planned for March-June 2025)
- Embodied carbon actually saved during the construction phase (planned for January 2026-June 2026)

Although progress in moving this case forward has been excellent, **there is currently significant uncertainty as to when, and if, the case will go ahead**, as it depends on whether the Campus Viborg directors can be convinced of the concept presented by COWI and Aarhus Living Lab members in Probono. The first pitch for renovating K45 building into accommodation (rather than demolishing and rebuilding) was presented to Campus Viborg project directors in May 2024, and was received very positively. The remaining stages are:

- More detailed pitch of the renovation concept to Campus Viborg project directors together with Viborg local authorities
- Confirmation by Campus Viborg directors to pursue renovation
- Detailed design by architects and engineering consultants (hired by Aarhus University, external to Probono)
- Construction phase
- Operation phase

Human centred analysis: ProFormalise social value capture process, and Revit Plugin tool

The attribute monitored is the degree to which as-designed social values can be identified, formalised, and communicated to design team members using the ProFormalise social value capture process and the Revit plugin tool, considering specific categories such as thermal comfort and acoustic comfort. Monitoring involves direct interaction with stakeholders through semi-structured interviews.

Validation activities with internal and external stakeholders have already been conducted to determine whether potential building users or design stakeholders perceive socially oriented design intents when introduced to the design choices.

Validation has been carried out twice: once as part of the bachelor course "Sustainability and Life Cycle Assessments" in the spring of 2024, and once during a webinar on social sustainability in the built environment. The workshop used Mentimeter, combining multiple-choice questions and open-ended questions.

Below is a table with the number and description of participants in the events:

Event	Responses per question	No. of participants	Date	Participants (type)
Bachelor course 2024	8-14	15	20th of March 2024	Bachelor students in the final semester of their bachelor program
Webinar 2024	47-72	116	13th of May 2024	Practitioners from the Danish construction industry and students from relevant education with between 0 and 45 years of industry experience.

Table 12: Aarhus Living Lab

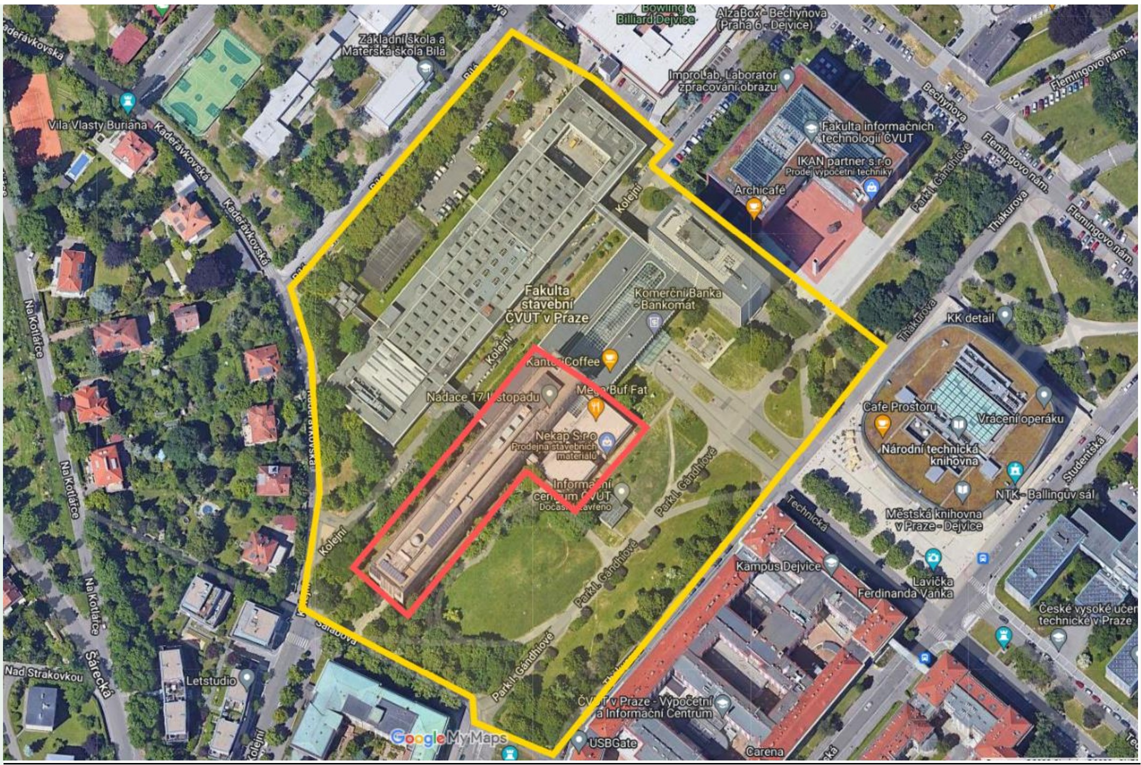
The workshop is planned to be repeated in the spring of 2025 with a new group of students. The workshop is also planned to be adapted to be held at the ICSA2025 conference. Thus, the monitoring period started from August 2023 and will continue until November 2025.

4.6 Prague Living Lab specific KPIs

The scope of the Prague LL is a deep renovation of an existing university building (Building B) which is part of a complex with several buildings of the Faculty of Civil Engineering at the Czech Technical University in Prague. Prague LL focuses on the design of an Energy positive building.

The expected outcomes through the PROBONO project will be description of all necessary interventions towards sustainable and energy positive revitalization and they will be verified by various calculations and simulations. The outcome will be included as proof of concept and recommendations and requirements into general contractor’s tender documentation.

PROBONO actions are focused on the planning and design stages of the renovation of Building B. The construction phase will not be part of the project timeline.



4.6.1 Prague Living Lab Main KPIs

Prague Living Lab is an exception for the PROBONO project as it is playing the role of replicator of the Aarhus Living Lab meaning that no impacts are described for it and therefore no associated Main KPIs are linked.

Although no specific impacts are expected to be achieved for Prague during the duration of the project, the Living Lab will try to estimate the values for some KPIs based on simulations considering the implementation of the PROBONO innovations in the near future but outside the PROBONO timeline.

4.6.2 Prague Living Lab Technical Innovations KPIs

In the following table the final list of technologies/innovations applicable to the specific Prague Living Lab with the final KPIs selected are shown. It is relevant to remark that the innovations selected will only achieve the design stage in order to be included in a tendering process but they will not be implemented during the project timeline.

Technologies / Innovations	Provider	Location	KPI
Building envelope: Light curtain façade equipped with PVs (ONLY DESIGN)	FRHF	Building B – CTU Faculty of Engineering	Production of solar electricity

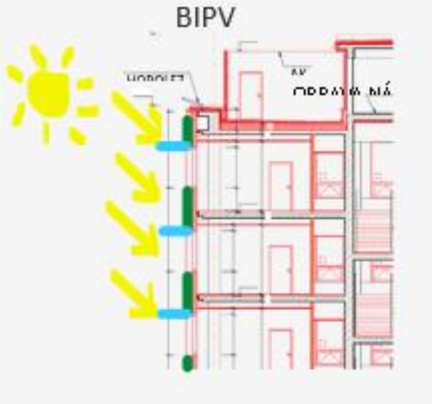
Technologies / Innovations	Provider	Location	KPI
		South-East facing façade	
Insulation and Green roof (ONLY DESIGN) 	SOPREMA ANERDGY	Building B – CTU Faculty of Engineering	· Thermal Transmittance · Roof cooling efficiency of the outdoor environment [% or kWh/m².y] · Roof energy cooling efficiency [% or kWh/m².y] · Roof cooling efficiency for the indoor environment [% or °C.h]

Table 13: Prague Living Lab list of selected innovations and related KPIs

4.6.3 Prague Living Lab GBN Social KPIs

Social KPIs are not applicable for Prague Living Lab.

4.6.4 Prague Living Lab monitoring periods

The overall time plan for tender and construction in Prague LL is unknown due to funding challenges. The expected starting of the tendering process is at mid of 2024, therefore PROBONO needs to provide recommendations and requirements for tender documentation before that deadline.

The overall Gantt chart shows particular activities and their time plan towards creation of recommendations and requirements to be included in the general contractor's documentation. For the sake of clarity, the Gannt is cut by December 2025 but the construction will continue until mid of 2027. The operational phases are completely out of the PROBONO timeline.

Prague LL acts as replicator of Aarhus and the project is only providing support for the planning and design phases. The revitalization of the building will be funded with own resources of the CTU. Selected technologies from the project will not be applied physically but only designed.

The main outcome of this deliverable for Prague LL will be a potential monitoring plan on the basis of the PROBONO Evaluation Framework. The monitoring plan will be prescribed in the tender documentation of the general contractor.

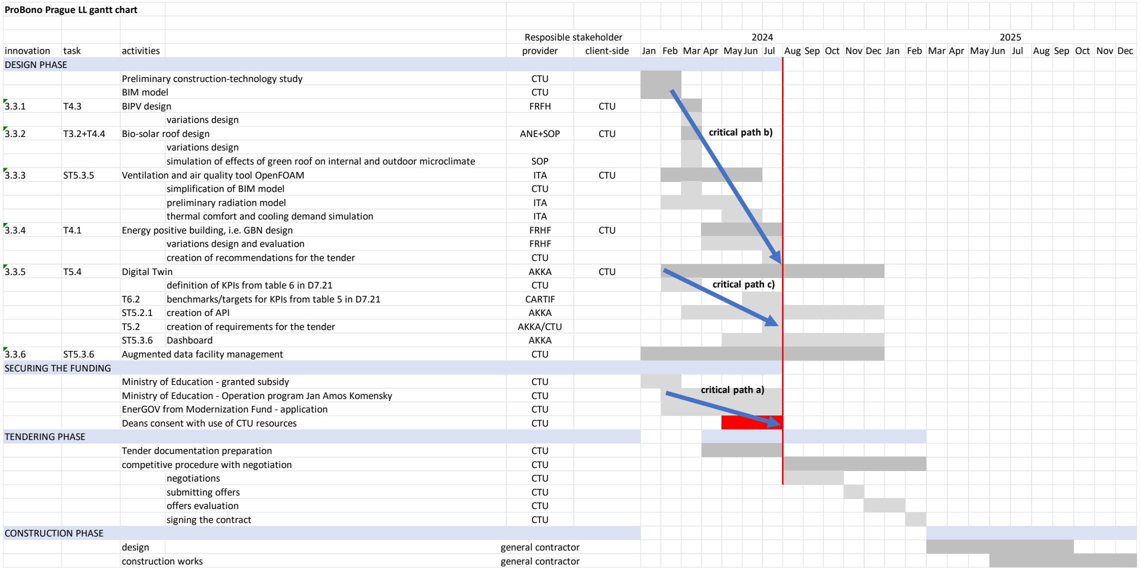


Figure 18: Prague Living Lab Gantt chart representing pre-construction phases

The KPIs selected for the Prague LL will be calculated through simulations that will be used to assess the potential effect of the innovations in the building. There will be a reference scenario (the current status of the building as it is right now) and some post-renovation scenarios based on the potential integration of the PROBONO innovations (BIPV and Green roof).

5 LLs construction monitoring plans

This section defines the specific construction monitoring plans for each of the Living Labs for the calculation of the specific KPIs (Main KPIs and technical innovation KPIs) identified in the previous Section 4 affected by the construction stage.

Figure 19, shows a summary table with all the Main KPIs linked to each of the PROBONO Impacts (From Expected Impact 1 to 10) and the specific Living Lab for the constructive stage (Highlighted in orange). Then, there is a specific subsection for each of the 6 Living Labs with their specific construction monitoring plan.

		IMPACT nº	IMPACT - stages					Madrid LL	Dublin LL	Porto LL	Aarhus LL
			Prod.	Cons.	Use	End	Bey.	Cons.	Cons.	Cons.	Cons.
KPI 1	Primary Energy Consumption	1									
KPI 2	Operational cost of energy	2									
KPI 3	Cost along the life cycle (LCC)										
KPI 4	Energy demand	3									
KPI 5	BER – Building Energy Rating										
KPI 6	Renewable energy production	4									
KPI 7	Self-consumption ratio										
KPI 8	Final energy										
KPI 9	CO2 emissions operational stage	5									
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7									
KPI 11	Embodied energy	6									
KPI 12	Air pollutants operational stage	7									
KPI 13	Replicability	8									
KPI 14	Shortened construction/retrofitting time	9									
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment										
KPI 16	Thermal comfort – Occupant perception	10									
KPI 17	IAQ Indoor Air Quality – Occupant perception										
KPI 18	Acoustic comfort – Occupant perception										
KPI 19	Dust quality – Occupant perception										
KPI 20	Visual comfort – Occupant perception										

Figure 19: PROBONO Main KPIs (Construction stage) vs Living Labs

5.1 Madrid Living Lab construction monitoring plan

Table 14, shows the list of Main KPIs affected by the construction stage for the Madrid Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Main KPI 3. Cost along the life cycle (LCC)	Invoices of innovations/materials	€	None	DHC Network	Bills/ Invoices	Once after	Yes
	Construction and deconstruction/demolition costs	€	None	DHC Network	Bills/ Invoices	Once after	Yes
	Construction project budget	€	None	DHC Network	Bills/ Invoices	Once after	Yes
Main KPI 10. GHG emissions along the life cycle (LCA)	Bill of materials	-	Other	DHC Network	Bills of materials	Once after	Yes
	Environmental Product Declarations (EPDs)	-	Other	DHC Network	Materials EPDs	Once before and after	Yes

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Main KPI 14. Shortened construction/retrofitting time	Construction progress related to plan	Days ahead	Other	DHC Network	Software	Once before and after	Yes
	Construction/retrofit phase duration	Days	Other	DHC Network	Software	Once after	Yes
	In-situ construction/retrofit duration for similar project.	Days	Other	DHC Network	Software	Once before and after	Yes
Main KPI 15. Shortened construction/retrofitting cost	Operational cost in construction/retrofit phase	€	Other	DHC Network	Software	Once after	Yes
	In-situ construction/retrofit cost for similar project. Baseline	€	Other	DHC Network	Software	Once before and after	Yes
Main KPI 18. IEQ – Acoustic comfort – Occupant perception	Perception of indoor noise by occupants.	Likert	Other	DHC Network	Survey	Once after	Yes

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
	Perception of outdoor noise by occupants	Likert	Other	DHC Network	Survey	Once after	Yes
Main KPI 19. EQ - Dust Quality -	Perception of dust levels by occupants or people involved during the construction process	Likert	Other	DHC Network	Survey	Once after	Yes
	Perception of allergens levels by occupants or people involved during the construction process	Likert	Other	DHC Network	Survey	Once after	Yes

Table 14: Monitoring needs for the Madrid LL Main KPIs affected by the construction stage

Main KPI 3 and Main KPI 10 are calculated for the Geothermal plant, so information will be collected during construction and indicators will be periodically assessed and adjusted.

KPI 14 and KPI 15 concern the timing, scheduling, and spatial planning of renovation activities on-site. The KPIs aim to capture the improvement after the utilisation of advanced Decision Support Systems (DSS) that utilise optimization algorithms to determine the optimal sequence of site activities. The optimised solution is implemented in a Digital Twin simulated environment and compared to a baseline that doesn't exploit the advanced DSS. For the quantification of the KPIs in a Digital Twin setting, information about the duration, space requirements and cost of each renovation task is required as well as the task dependencies for the completion of other tasks, through software tools.

Main KPI 18. IEQ – Acoustic comfort – Occupant perception and Main KPI 19. EQ - Dust Quality are to be calculated on a Likert base. Please see Table 4 of the present document.

Table 15, shows the final list of technologies selected for the Madrid Living lab that are affecting the construction stage. For each of the technologies the selected technical KPI for their final performance validation together with the list of variables needed for their computation are identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 13.

TECHNOLOGIES/INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	Location	Data Source	Frequency	Available
White steel slag for concrete and pavement	**CELSA**	**Amount of reused material**	White slag amount	tones	Other	CELSA Barcelona	Others	Other	Yes
			Black slag amount	tones	Other	CELSA Barcelona	Others	Yearly	Yes
Low carbon concrete & sustainable road pavement	**ACC I+D**	**Amount of reused material**	Global Warming Potential (GWP)	Kg CO_2-equivalents	LCA Software	-	Simulation	Other	Yes

Table 15: Monitoring needs for the Madrid LL Technical KPIs affected by the construction stage.

White and black steel slag will be incorporated to the concrete which is going to be used in the construction of geothermal station of the Heating and Cooling Network in the Madrid LL, so finally they have an impact on the CO2 emissions that will be calculated in the LCA of the project.

The amount of recycled material for the low carbon concrete mixes is as follows:

- Black slags: 100% of natural coarse aggregates and at least 20% of fine aggregates will be replaced by black slags.
- Recycled concrete aggregates: At least 20% of natural coarse aggregates will be replaced by recycled concrete aggregates.

Concerning the carbon footprint of the low carbon concrete, PROBONO estimates a saving of at least 20% of kg CO2 equivalent compared with the baseline calculation with ordinary Portland cement (CEM I/OPC) and natural aggregates without compromising their performance.

The amount of recycled material used in the asphalt mixes for the sustainable road pavement, is as follows:

- Reclaimed asphalt: 20% of the total asphalt mix
- Black slags: 100% of natural coarse aggregates can be replaced by black slags.
- Recycled concrete aggregates: 15% in asphalt mixtures or, preferably, 100% for subbases (unbound layers)
- In terms of environmental performance, a reduction between 5-10% of Kg CO2 equivalent it is estimated.

5.2 Dublin Living Lab construction monitoring plan

Table 16, shows the list of Main KPIs affected by the construction stage for the Dublin Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Main KPI 3. Cost along the life cycle (LCC)	Invoices of innovations/materials	€	Software	Digital Invoice (PDF)	Software	Once after	No
	Construction and deconstruction/demolition costs	€	Software	Digital Invoice (PDF)	Software	Once after	No
	Refurbishment costs	€	Software	Digital Invoice (PDF)	Software	Once after	No
	Construction project budget	€	Software	Digital Invoice (PDF)	Software	Once after	No
Main KPI 18. IEQ – Acoustic comfort – Occupant perception	Perception of indoor noise by occupants.	Likert	Software	Online	Survey	Once after	Yes
	Perception of outdoor noise by occupants	Likert	Software	Online	Survey	Once after	No
Main KPI 19. EQ - Dust Quality - Occupant perception	Perception of dust levels by occupants or people involved during the construction process	Likert	Software	Online	Survey	Once after	Yes

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Avail able
	Perception of allergens levels by occupants or people involved during the construction process	Likert	None	-	-	-	No

Table 16: Monitoring needs for the Dublin LL Main KPIs affected by the construction stage

Most of the required information for the Dublin LL KPIs will be retrieved from digital invoices to give indications of the costs of materials, construction etc. The architecture department within the County Council will also be able to provide a great deal of information regarding local context and projects, baselines and bill of quantities. After these are acquired, EPCs will be requested from manufacturers and used alongside the bills of quantities to create LCAs. This will likely require specialised software, as will the perception of noise and dust levels. The use of internal information wherever possible will serve to minimise monitoring costs. For Dublin LL there are no specific innovations affecting the construction stage.

5.3 Porto Living Lab construction monitoring plan

Table 17, shows the list of Main KPIs affected by the construction stage for the Porto Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Main KPI 3. Cost along the life cycle (LCC)	Invoices of innovations/materials	€	None	Lote 1, 2 and 4A	Simulation	Yearly	Yes
	Construction and deconstruction/demolition costs	€	None	Lote 1, 2 and 4A	Simulation	Yearly	Yes

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
	Construction project budget	€	None	Lote 1, 2 and 4A	Simulation	Yearly	Yes

Table 17: Monitoring needs for the Porto LL Main KPIs affected by the construction stage

Through KPI 3, the investments in PV solar installed in the campus will be quantified in lot 1, 2 and 4A. These investments on materials, project and construction will be calculated considering an estimated cost per kWp installed. Yearly status could be provided.

For Porto LL there are no specific innovations affecting the construction stage.

5.4 Brussels Living Lab construction monitoring plan

For the Brussels Living Lab there are no Main KPIs neither any innovation associated with the construction stage therefore there are no construction monitoring needs.

5.5 Aarhus Living Lab construction monitoring plan

Table 18, shows the list of Main KPIs affected by the construction stage for the Aarhus Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

In the case of the flow batteries provided by VisBlue (Aarhus LL Activity A1), it will be documented the actual cost of purchase, installation, and compare this with the lithium battery alternative that was originally planned by the AU “clients”. This will be assessed within a LCC framework, in addition to the operational phase assessment of the lifetime of the flow batteries, which is predicted to be longer than the lithium batteries (and thus realising improved lifecycle costs).

In the case of the K45 upcycling renovation project (Aarhus LL Activity A2 led by COWI) we are in the process of “pitching” a pre-design proposal to the AU “clients” for repurposing the K45 existing building (into student accommodation). The predicted CO_2 embedded energy in the materials is based on current early estimates from the pre-design. If the pitch is successful, then the renovation project will be taken up by architects hired by AU “clients” as ”part of the Campus 2.0 programme (i.e. external to Probono) where we intend to take a consultation role to provide expert input with respect to embedded energy of the preserved materials. If the design is then taken into construction within the Probono project duration, then the actual construction KPIs will be assessed in comparison to the predicted values.

<table>
<tr><th>Main KPI</th><th>Variable</th><th>Units</th><th>Equipment</th><th>Location</th><th>Data Source</th><th>Frequency</th><th>Available</th></tr>
<tr><td rowspan="4">Main KPI 3. Cost along the life cycle (LCC)</td><td>Invoices of innovations/materials</td><td>€</td><td>Other</td><td rowspan="7">Campus Viborg (K45 renovation project; VisBlue flow batteries)</td><td rowspan="7">AU facility management team (“client” side) will provide us (Aarhus LL within Probono) with the requested information.</td><td rowspan="7">3-6 months (we will be provided with relevant documentation when available)</td><td rowspan="7">On request</td></tr>
<tr><td>Construction and deconstruction/demolition costs</td><td>€</td><td>Other</td></tr>
<tr><td>Refurbishment costs</td><td>€</td><td>Other</td></tr>
<tr><td>Construction project budget</td><td>€</td><td>Other</td></tr>
<tr><td rowspan="3">Main KPI 11. Embodied energy</td><td>Information about local context (e.g., energy matrix)</td><td>-</td><td>None</td></tr>
<tr><td>Bill of materials</td><td>-</td><td>None</td></tr>
<tr><td>Environmental Product Declarations (EPDs)</td><td>-</td><td>None</td></tr>
</table>

Table 18: Monitoring needs for the Aarhus LL Main KPIs affected by the construction stage

Table 19, shows the final list of technologies selected for the Aarhus Living lab that are affecting the construction stage. For each of the technologies the selected technical KPI for their final performance validation together with the list of variables needed for their computation is identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 18.

COWI is using NovaDM (a decision support tool developed by AU) to explore the alternatives for renovating buildings in Campus Viborg, applying their expertise in LCA with the focus on gains from upcycling. Embedded energy of materials (kg CO2 eq) is based on calculating embedded GWP of supplied materials, resources and possible upcycle of any removed material from an LCA perspective. NovaDM is presented in more detail in D5.6 ("GBN Global Decision Support and Optimisation Platform (I)", submitted on M2), and the COWI K45 case is presented in more detail in D3.10 (“Building Materials – Upcycling (II)”, due M32).

TECHNOLOGIES /INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Upcycling	**COWI**	Embedded energy of the materials used. Consider also resources and possible upcycle of any removed material (LCA perspective).	Embodied carbon in existing materials on the building site*	$KgCO_2$	Software for identification of embodied energy (proprietary, COWI)	Drone mapping of selected buildings at Viborg Campus	Others	Once	No
			Potential for level of reuse- or recycling of the existing materials on building site.	Scale from A-D	Software for potential evaluation	Desk top	Others	Once	No
			Number of investigated renovation scenarios quantifying the CO_2 impact for the GBN	Number	Software NovaDM tool for renovation scenarios	Desk top	Others	Once	No
			Climate impact reduction potential of renovation scenarios	%		Desk top	Others	Once	No

Table 19: Monitoring needs for the Aarhus LL Technical KPIs affected by the construction stage

*Phase related is "Demolition" or "initial planning".

5.6 Prague Living Lab construction monitoring plan

Table 20 shows the list of Main KPIs affected by the construction stage for the Prague Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Data Source	Frequency	Available
Main KPI 3. Cost along the life cycle (LCC)	Invoices of innovations/materials	€	Bills/Invoices	Monthly	No
	Construction and deconstruction/demolition costs	€	Bills/Invoices	Monthly	No
	Refurbishment costs	€	Other	Once after	No
	Construction project budget	€	Other	Monthly	No
Main KPI 10. GHG emissions along the life cycle (LCA)	Environmental Product Declarations (EPDs)	-	EPD	Once after	No
Main KPI 11. Embodied energy	Environmental Product Declarations (EPDs)	-	EPD	Once after	No

Table 20: Monitoring needs for the Prague LL Main KPIs affected by the construction stage

For Prague LL there are no specific innovations affecting the construction stage.

6 LLs operational monitoring plans

This section defines the specific operational monitoring plans for each of the Living Labs for the calculation of the specific KPIs (Main KPIs and technical innovation KPIs) identified in the previous section 4 affected by the operational stage.

Figure 20, shows a summary table with all the Main KPIs linked to each of the PROBONO Impacts (Expected impacts from 1 to 10) and the specific Living Lab for the operational stage (Highlighted in orange). Then, there is a specific subsection for each of the Living Labs with their specific operational monitoring plan with exception of Prague explain in section 4.6.

		IMPACT nº	IMPACT - stages					Madrid LL	Dublin LL	Porto LL	Brussels LL	Aarhus LL
			Prod.	Cons.	Use	End	Bey.	Use	Use	Use	Use	Use
KPI 1	Primary Energy Consumption	1										
KPI 2	Operational cost of energy	2										
KPI 3	Cost along the life cycle (LCC)											
KPI 4	Energy demand	3										
KPI 5	BER – Building Energy Rating											
KPI 6	Renewable energy production	4										
KPI 7	Self-consumption ratio											
KPI 8	Final energy											
KPI 9	CO2 emissions operational stage	5										
KPI 10	GHG emissions along the life cycle (LCA)	5 & 7										
KPI 11	Embodied energy	6										
KPI 12	Air pollutants operational stage	7										
KPI 13	Replicability	8										
KPI 14	Shortened construction/retrofitting time	9										
KPI 15	Shortened construction/retrofitting cost 15.1 – manufacturing 15.2 – transportation 15.3 – stock keeping 15.4 – space costs/warehouse establishment											
KPI 16	Thermal comfort – Occupant perception	10										
KPI 17	IAQ Indoor Air Quality – Occupant perception											
KPI 18	Acoustic comfort – Occupant perception											
KPI 19	Dust quality – Occupant perception											
KPI 20	Visual comfort – Occupant perception											

Figure 20: PROBONO Main KPIs (Operational stage) vs Living Labs

6.1 Madrid Living Lab operational monitoring plan

Table 21, shows the list of Main KPIs affected by the operational stage for the Madrid Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Main KPI 1. Primary energy consumption	Electrical - Energy consumption	kWh	Software	-	Simulation	Yearly	Yes

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
	Thermal (fuel) - Energy consumption	kWh	None	-	Other		No
	Electrical - Energy exported	kWh	Software	-	Simulation	Yearly	Yes
Main KPI 2. Operational cost of energy	Option A - Energy Consumption	kWh	Software	-	Simulation	Yearly	Yes
Main KPI 4. Energy demand	Option A - Energy simulation model	kWh	Software	-	Simulation	Yearly	Yes
Main KPI 5. BER (Building Energy Rating)	Energy Performance of the building	A-G	None	-	Simulation	Hourly	Yes
Main KPI 6. Renewable energy production	Thermal - Geothermal	kWh	Software	In the public space	Simulation	Yearly	Yes
Main KPI 7. Self-consumption ratio	Renewable energy production - Electricity	kWh	Software	-	Simulation	Yearly	Yes
	Renewable energy production - Thermal	kWh	Software	-	Simulation	Yearly	Yes
	Energy consumption - Electricity	kWh	Software	-	Simulation	Yearly	Yes

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
	Energy consumption - Thermal	kWh	Software	-	Simulation	Yearly	No
Main KPI 8. Final energy consumption	Electricity - Energy consumption	kWh	Software	-	Simulation	Yearly	No
	Thermal (fuel) - Energy consumption	kWh	Software	-	Simulation	Yearly	No
Main KPI 9. CO_2 emissions operational stage	Final Energy consumption (KPI8)	kWh	Software	-	Simulation	Yearly	No
	Renewable production (KPI6)	kWh	Software	-	Simulation	Yearly	No
	Energy exported (Electrical & Thermal)	kWh	Software	-	Simulation	Yearly	No
Main KPI 12. Air pollutants operational stage	Fuel consumption by energy source	kWhfuel	Software	-	Simulation	Yearly	No
Main KPI 16. Thermal comfort – Occupant perception	Perception of the indoor temperature by occupants	ºC	Software	-	Simulation	Yearly	No
	Perception of the humidity by occupants	%HR	Software	-	Simulation	Yearly	No
Main KPI 18. IEQ – Acoustic comfort –	Perception of indoor noise by occupants.	Likert	Other	Geothermal Station	Survey	Once after	No

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Occupant perception	Perception of outdoor noise by occupants	Likert	Other	Geothermal Station	Survey	Once after	No
Main KPI 20. EQ – Visual comfort – Occupant (Neighbourhood) perception	Surface of public and green areas	Likert	Other	Geothermal Station	Other	Once after	No

Table 21: Monitoring needs for the Madrid LL Main KPIs affected by the operational stage

Due to the peculiarity of the Madrid LL, most of KPIs shown in the above table particularly from KPI 1 to KPI 8 will be calculated on the basis of a thermal and electricity simulation that will reproduce a virtual model of the DHC Network and the two buildings.

Moreover, it is worth to stress that:

- Acoustic Comfort concerns the District Heating and Cooling station. This will be measured on a Likert base.
- Dust Comfort will be measured in the outdoor during construction phase.
- Visual Comfort will be measured in the outdoor during operation phase. The positioning of the geothermal energy plant underground allows to gain m2 of public and green areas. The evaluation will be done through surveys/interviews collecting the perception of the neighbourhood measured on a Likert scale.

A remote monitoring system has been designed for the heating and cooling district network in the LL Madrid. This system will regulate the number of operating heat pumps to maintain the desired temperature in the distribution lines of the district network. Moreover, it will monitor:

- The all-nothing motorized valves openings in the heating exchangers.
- Geothermal hydraulic pumps are correctly working operation to achieve a proper returning temperature to condensers or evaporators.
- Distribution pumps to heating and cooling network district operation to provide water flow demanded by buildings.
- Design temperature values for the district network are:
    - Heat water network: impulsion temperature 50ºC – returning temperature 40ºC
    - Cool water network: impulsion temperature 5ºC – returning temperature 15ºC
- Primary circuits of heat pumps, will be doubled sized in order to halve the thermal difference (heat 50ºC - 45ºC; cool 5ºC - 10ºC), what will ensure the compatibility of soil and water temperature. Each heat pump is accompanied by a hydraulic pump for the condenser and another one for the evaporator. These have a variable flow and are monitored through the heat pump in order to keep the temperature difference controlled.

- Buffer tanks of 1000 l capacity are designed on the general heat water return pipes to the condenser and on the general cool water return pipes to the evaporators to ensure stability during low demand. Moreover, by passes are located to operate in case they are out of work due to maintenance.

In the District and Cooling network, a BEMS (Building Energy Management System) system will be implemented in order to control and distribute the flow of electric energy, thermal energy and information, in coordination with main devices such as multiple entry units and multiple exits, geothermal heat pumps, thermal storage, PV and fan coils, monitoring and controlling the whole system, the configuration and the working.

Different devices will support the monitoring activities, such as thermometers, manometers, with relative temperature and pressure probes in the entry and exit of heat pumps and interchanges, and on branches lines to buildings; water meters, energy meters on the branches from buildings and from the geothermal unit.

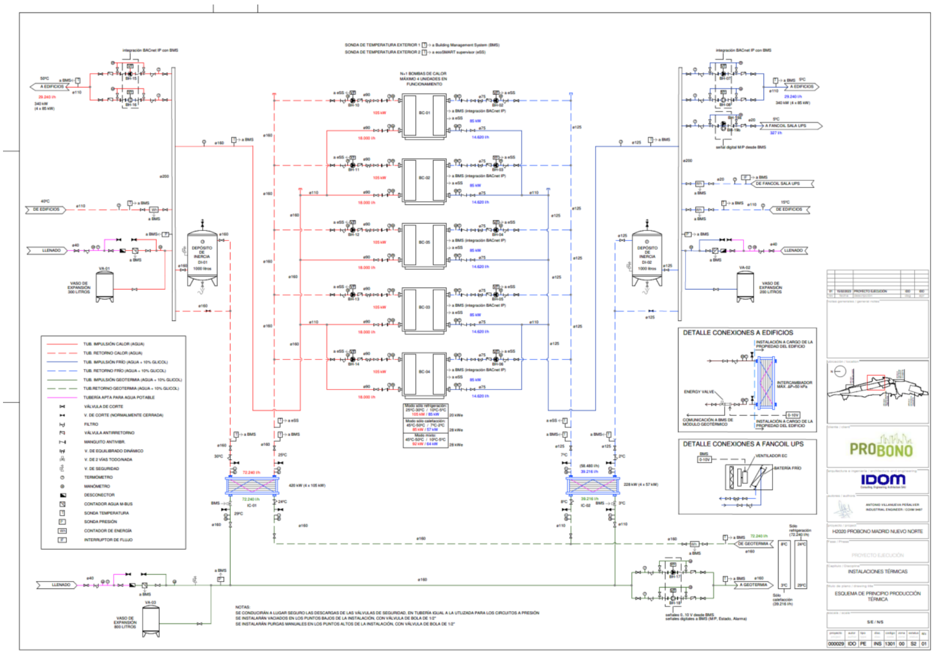


Figure 21:Madrid LL thermal system diagram

Table 22, shows the final list of technologies selected for the Madrid Living lab that are affecting the operational stage. For each of the technologies the selected technical KPI for their final performance validation with the selected list of variables needed for their computation are identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 21.

TECHNOLOGIES/INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Geothermal District Heating and Cooling network	**IDOM**	**Global Seasonal Performance Factor (GSPF)**	Electricity consumption / pumps	kWh	Software	1	Online	Meter	Monthly	No
			Cooling production	kWh	Software	1	Online	Meter	Monthly	No
			Heating production	kWh	Software	1	Online	Meter	Monthly	No
			RER (Renewable Energy Ratio)	-	Software	-	Online	Others	Monthly	No
			Heat recovery ratio	-	Software	-	Online	Others	Monthly	No
2nd Life batteries	**BEEP**	**Energy saved thanks to the battery system**	Battery utilization	%	Software	1	Online	Meter	Daily	Yes
			Battery capacity	kWh	Software	1	Online	Meter	Daily	Yes
			Injected Energy	kWh	Other	1	Online	Meter	Monthly	Yes

TECHNOLOGIES/INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Integrated mobility infrastructure study	**CIDAUT**	**Energy saved thanks to bidirectional charging system**	Energy that comes from the electric company	kWh	Software	-	Charging Station	Simulation	Monthly	No
			Energy from the EV that is fed into the grid	kWh	Software	-	Charging Station	Simulation	Monthly	No
			Electricity price over time	€/kWh	Statistics	-	-	Others	Monthly	Yes
Geothermal pumps	**ECOFOREST**	**Seasonal performance**	Electrical power / energy consumption	kW / kWh	Software	-	-	Simulation	Other*	Yes
			Heating/cooling power / energy output	kW / kWh	Software	-	-	Simulation	Other*	Yes
			Seasonal performance	-	Software	-	-	Simulation	Other*	Yes
			Instantaneous performance	-	Software	-	-	Simulation	Other**	Yes
			Others (see document "Guía Modbus-2023_EN_v02")	others	Other	-	-	Meter	Other	Yes

Table 22: Monitoring needs for the Madrid LL Technical KPIs affected by the operational stage

*Frequency: instantaneous, daily, monthly, yearly depending on where it is viewed: web portal or heat pump screen.

**Instantaneous at a certain moment.

BeePlanet utilizes data from its battery management system to monitor energy-related metrics. By tracking the current flowing into and out of the battery, as well as the battery voltage, the system can effectively assess the energy output of the battery (energy that might otherwise have been lost). This calculation enables the estimation of CO_2 savings. The energy storage capacity of the battery is also continuously monitored.

Ecoforest: One of the most representative parameters that can be measured on any Ecoforest heat pump system is the performance indicator known as SPF (Seasonal Performance Factor). This indicator measures the equipment energy production in relation to the energy consumed along a given periods (e.g., several months). The fact of taking into account the time variable is essential for obtaining a proper evaluation of the system performance as a whole. The SPF performance is defined by the different energy demands and links the thermal energy generated by the system to the consumed electricity, (thermal energy by electrical energy consumed). It combines both SCOP and SEER indicators, covering both heating and cooling efficiency.

While it is possible to observe these performances instantly through indicators such as COP, for heating and Domestic Hot Water production, and EER, for cooling production, it is much more representative to analyse them on a monthly or yearly basis (the latter option is also available on this monitoring system). This approach always allows for a more precise understanding of the real efficiency of each system (or cascaded systems).

IDOM: Within the PROBONO project framework, a detailed control system has been designed for the prototype District Heating and Cooling system in Madrid, comprised of a complex array of elements aimed at optimizing energy efficiency. At its core lies the geothermal module equipped with geothermal heat pumps, whose operation is monitored through temperature and flow probes. The cold and heat networks, each with its respective pumping systems, are integrated into the geothermal module, while the geothermal network, encompassing strategically placed geothermal boreholes, acts as a key element in thermal management. The control system relies on constant monitoring of the temperatures in both networks (hot and cold ones), establishing predetermined upper and lower limits. In proximity to these limits, the pumps adjust their performance to prevent exceeding them, ensuring efficient operation. In extreme situations where one of the networks fails to maintain the temperature within the established ranges, the system dissipates energy into the ground through the boreholes, guaranteeing precise control. Furthermore, the heat pumps, equipped with sensors at all their inputs and outputs, feature frequency inverters on the main compressors, providing fine-tuning capabilities to adapt to changing conditions and achieve maximum energy efficiency.

All these elements can also be controlled considering different time scenarios. The system can detect energy surpluses and adjust consumption accordingly, thanks to its integration with renewable energy production. Energy Demand Platform to be developed by TPF.

6.2 Dublin Living Lab operational monitoring plan

Table 23, shows the list of Main KPIs affected by the operational stage for the Dublin Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living

Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Main KPI 1. Primary energy consumption	Electrical – Energy consumption	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
	Thermal (fuel) – Energy consumption	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
	Electrical – Energy exported	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
	Thermal – Energy exported	kWh	None	-	N/A	N/A	N/A	N/A
Main KPI 2. Operational cost of energy	Option A – Energy Consumption	kWh	Wattmeter	1	Congnition world (API)	Software	Hourly	Yes
	Option A – Energy service maintenances cost	€	None	-	Building management services	Invoices	Monthly	No
	Option B - Electricity & fuel bills	€	Software	1	Energy Elephant	Software	Monthly	Yes
Main KPI 5. BER (Building Energy Rating)	Energy Performance of the building	A-G	Other	2	SEAI & Centrica	Energy performance Contract reports	Once	Yes
Main KPI 6. Renewable energy production	Electricity – PV	kWh	Software	1	Energy management system	Software	Monthly	No
	Electricity -Wind	kWh	None	N/A	-	-	-	-

Main KPI	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
	Thermal – Solar	kWh	None	N/A	N/A	N/A	N/A	N/A
	Thermal – Biomass	kWh	None	N/A	N/A	N/A	N/A	N/A
	Thermal – Geothermal	kWh	None	N/A	N/A	N/A	N/A	N/A
Main KPI 7. Self-consumption ratio	Renewable energy production – Electricity	kWh	Software	2	PV tool and Energy elephant	Software	Monthly	No
	Renewable energy production – Thermal	kWh	None	N/A	N/A	N/A	N/A	N/A
	Energy consumption – Electricity	kWh	None	N/A	N/A	N/A	N/A	N/A
	Energy consumption – Thermal	kWh	None	N/A	N/A	N/A	N/A	N/A
Main KPI 8. Final energy consumption	Electricity – Energy consumption	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
	Thermal (fuel) – Energy consumption	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
Main KPI 9. CO_2 emissions operational stage	Final Energy consumption (KPI8)	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
	Renewable production (KPI6)	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
	Energy exported (Electrical & Thermal)	kWh	Software	1	Energy Elephant	Software	Monthly	Yes
Main KPI 16. Thermal comfort – Occupant perception	Perception of the indoor temperature by occupants	Likert	Software	1	Online	Survey	Once after	Yes
	Perception of the air speed by occupants.	Likert	Software	1	Online	Survey	Once after	Yes

Main KPI	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
	Perception of the humidity by occupants	Likert	Software	1	Online	Survey	Once after	Yes
Main KPI 17. Indoor air quality (IAQ) – Occupant perception	Perception of the air quality by occupants.	Likert	Software	1	Online	Survey	Once after	Yes
	Perception of the ventilation quality by occupants.	Likert	Software	1	Online	Survey	Once after	-
Main KPI 18. IEQ – Acoustic comfort – Occupant perception	Perception of indoor noise by occupants.	Likert	Software	1	Online	Survey	Once after	Yes
	Perception of outdoor noise by occupants	Likert	Software	1	Online	Survey	Once after	-
Main KPI 20. IEQ – Visual comfort – Occupant perception	Perception of lighting levels	Likert	Software	1	Online	Survey	Once after	Yes
	Perception of artificial lighting quality	Likert	Software	1	Online	Survey	Once after	-
	Perception of natural lighting quality	Likert	Software	1	Online	Survey	Once after	-

Table 23: Monitoring needs for the Dublin LL Main KPIs affected by the operational stage

Table 22 shows the parameters that the LL will monitor during the project lifespan. Information regarding the performance of the planned interventions will primarily be recorded through the energy management system and invoices, with sensors such as meters already in place. Information pertaining to the performance of buildings will be captured through reports and datasets produced by Centrica, who are currently undertaking an energy performance contract with the County Council on their buildings. Surveys will also take place to ensure that all interventions preserve comfort and quality of life for the intended occupants of the buildings. Responses will be logged and uploaded to the digital twin.

Table 24, shows the final list of technologies selected for the Dublin Living lab that are affecting the operational stage. For each of the technologies the selected technical KPI for their final performance validation with the selected list of variables needed for their computation are identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 23.

TECHNOLOGIES/INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Recycled Paper Insulation	**SOPREMA**	**Thermal Transmittance**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
			TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
2-way EV Charging Infrastructure	**BOVLABS, CIDAUT**	**[WP4 - KPI 9] Energy saved thanks to bidirectional charging system**	Energy that comes from the electric company	kWh	Other	1	Charging Station	Bidirectional Meter	Daily	No
			Energy from the EV that is fed into the grid	kWh	Other	1	Charging Station	Bidirectional Meter	Daily	No
			Electricity price over time	€/kWh	Other			Statistics	Daily	No
Battery Bank	**BEEP**	**Energy saved thanks to the battery system**	Battery utilization	%	Software	1	Online	Meter	Daily	No
			Battery capacity	kWh	Software	1	Online	Meter	Daily	No
Coloured BIPV Solar Panels	**FRHF**	**Production of solar electricity, increased solar production of coloured BIPV modules in comparison**	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
			TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

TECHNOLOGIES/INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
		with standard products								

Table 24: Monitoring needs for the Dublin LL Technical KPIs affected by the operational stage

The Dublin LL aims to rely as much as possible on sensors and systems already in place. For this reason, the majority of KPIs will be derived from electricity meters and invoices. This data will also be fed into the planned digital twin to allow for more accessible and real-time monitoring. Additional sensors and software will be required. This involves an air quality kit, a microphone, LCA software and possibly survey software.

Data source	Content description	Availability
Electric Energy Meter	Monthly meter reading	yes
Gas Meter	Monthly meter reading	yes
Woodchip Meter	Monthly reading, woodchip weight	Yes
Gas and Energy Pricing	Monthly bills	yes
HVAC	Sensor readings	No, when sensors are installed
BMS	Temperature, set point, energy consumption	Not yet
Ambient Sensors	CO2, Humidity, Temperature Occupancy	Not yet
EV charging station	Current charging station status	no
EV vehicle	Vehicle data including location, current user and charge status and charge levels	no
Weather data on precise location and forecast	Sun radiation (sun position in time), clouds, temperature humidity, wind, precipitation	yes
Air quality	Google air quality Sensor attached at the outside of the building at various levels (height)	yes
Noise level	Sensor readings around and inside of the building at various locations	No, when sensors are installed
Lightning level	Sensor readings inside building	No, when sensors are installed
Windows state	Sensor readings inside building	No, when sensors are installed
Waste management report	Report on waste production	No, when procedure or sensors are established
Car park state	Current charge status and levels and parking location for each vehicle in the fleet	No, when sensors are installed

Table 25: Dublin LL data sources overview

6.3 Porto Living Lab operational monitoring plan

Table 26, shows the list of Main KPIs affected by the operational stage for the Porto Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location (see section 4.3) in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. the current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Main KPI 1. Primary energy consumption	Electrical - Energy consumption	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
	Electrical - Energy exported	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
Main KPI 6. Renewable energy production	Electricity - PV	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
Main KPI 7. Self-consumption ratio	Renewable energy production - Electricity	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
	Energy consumption - Electricity	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
Main KPI 8. Final energy consumption	Electricity - Energy consumption	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
Main KPI 9. CO2 emissions operational stage	Final Energy consumption (KPI8)	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
	Renewable production (KPI6)	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes
	Energy exported (Electrical & Thermal)	kWh	Other	Lote 1, 2 and 4A	Meters	Monthly	Yes

Main KPI	Variable	Units	Equipment	Location	Data Source	Frequency	Available
Main KPI 12. Air pollutants operational stage	Fuel consumption	kWh_{fuel}	Other	Lote 1, 2 and 4A	Bills/Invoices	Monthly	No

Table 26: Monitoring needs for the Porto LL Main KPIs affected by the operational stage

The provided dataset shows KPIs related to energy consumption, renewable energy production, and environmental impact (C02 emissions and air pollutants) at the specified locations, Lot 1, 2, and 4A. Each KPI features variables such as primary energy consumption, electrical energy exported, renewable energy production, and final energy consumption.

Table 27, shows the final list of technologies selected for the Porto Living lab that are affecting the operational stage. For each of the technologies the selected technical KPI for their final performance validation with the selected list of variables needed for their computation are identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 26.

TECHNOLOGIES /INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Phase Change Materials (PCM)	**External provider**	**Thermal storage capacity installed within the LL**	Thermal storage capacity	kJ/Kg	Other	-	Supermarket	Meter	Monthly	No
			Energy Consumption	KWh °C	Other	-	Supermarket	Meter	Monthly	No
			Discharge temperature	kWh °C	Other	-	Supermarket	Meter	Monthly	No
			Temperature setpoints	°C	Other	-	Supermarket	Meter	Monthly	No

TECHNOLOGIES /INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
			Working time ((compressors, condensers and evaporator fans))	h.	Other	-	Supermarket	Meter	Monthly	No
Smart EV Hub	**External provider**	**CO_2 emissions per MWh of primary energy consumed in the GBN**	Energy consumption	kWh	Other	-	Lot2	Meter	Monthly	No
			Station charger	-	Other	-	Lot2	Meter	Monthly	No
			Charge start datetime	datetime	Other	-	Lot2	Meter	Monthly	No
			Charge start datetime	datetime	Other	-	Lot2	Meter	Monthly	No
			fator de escala campus/piloto Transaction energy consumption	kWh	Other	-	Lot2	Meter	Monthly	No
2nd life batteries	**BEEPLANET**	**Electrical storage capacity installed within the LL**	Battery capacity	kWh	Other	-	Lot 1 and 4A	Meter	Monthly	No
			Battery utilization	%kWh	Other	-	Lot 1 and 4A	Meter	Monthly	No
Cool roof testing with Bi-facial PV	**SOPREMA**	**Electricity generation capacity**	PV Production in kWh.y - string n1	kWh	Other	-	Lot 1	Meter	Monthly	No

TECHNOLOGIES /INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
		installed	PV Production in kWh.y - string n2 - cool roof	kWh	Other	-	Lot 1	Meter	Monthly	No
			PV nominal power	kWp	Other	-	Lot 1	Meter	Monthly	No
Vehicle to Grid (V2G)	**External provider**	**Energy saved thanks to bidirectional charging system**	Total energy transferred	kWh	Other	-	Lot 1	Meter	Monthly	No
		CO2 emissions per MWh of primary energy consumed in the GBN	Energy efficiency of the bidirectional charging	%	Other	-	Lot 1	Meter	Monthly	No
Solar to Vehicle (S2V)	**External provider**	**CO_2 emissions per MWh of primary energy consumed in the GBN**	Total solar energy generated by the PV system	kWh	Other	-	Lot 1	Meter	Monthly	No
			Time taken to charge an electric vehicle using solar power	h	Other	-	Lot 1	Meter	Monthly	No

Table 27: Monitoring needs for the Porto LL Technical KPIs affected by the operational stage

Regarding PCM pilot, KPI 5 on thermal storage capacity will be calculated upon its installation in the supermarket. In terms of the electric mobility pilots, the main KPI to measure is KPI 12 about CO_2 emissions per MWh of primary energy consumed. V2G will also include KPI 9 to monitor the saved energy related to bidirectional charging. With the implementation of 2nd life batteries, the electrical storage capacity installed will be measured through KPI 4. And lastly, for the Bi-facial PV with the cool roof layer, KPI 1 will measure the capacity of electricity generation installed.

The current monitoring system is managed by Capwatt and Elergone and measures information about energy consumption, renewable energy production and variables regarding the use of electric vehicle chargers. Porto LL will use the monitoring systems already set up and make the necessary adaptations to accommodate the implementation of the technological pilots with integration of the monitoring equipment in the existing metering & control centre. The list of variables shown in Figure 23 will support the monitoring of the KPIs and impacts of the Porto LL and has already been shared and reported in detail in D6.1. The Campus is divided into three different areas lot 1, 2 and 4a with different CPEs connected to the energy grid (Figure 22). Capwatt monitors lot 1 and Elergone is responsible for the monitoring of lot 2. The monitoring of lot 4a is shared between the two entities, Capwatt is tasked with monitoring the photovoltaic panels, while Elergone oversees consumption.

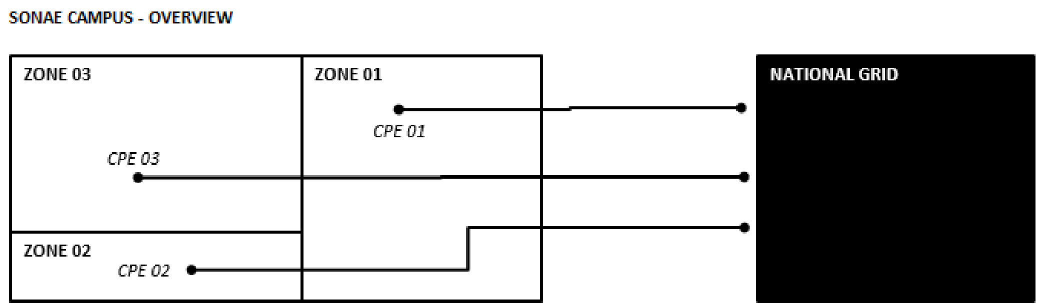


Figure 22: Simplified scheme of the monitoring system with the 3 existing CPEs (meters)

Figure 23 presents the list of variables intended to monitor the KPIs and impacts of the Porto LL.

Collected Data	
Installed Power	*MW*
Installed Power - Renewable	*MW*
Consumed Electricity	*MWh/month*
Produced Electricity - Renewable	*MWh/month*
Consumed Electricity - Renewable	*MWh/month*
Auto-consumption Electricity - Renewable	*MWh/month*
Storage Systems - Installed Power	*MW*
Storage Systems - Installed Capacity	*MWh*
Quantity of EV Charging Points	*(number)*
Total Power Installed of EV Charging Points	*MW*

Figure 23: List of variables that constitute the baseline and progress status for monitoring.

6.4 Brussels Living Lab operational monitoring plan

Table 28, shows the list of Main KPIs affected by the operational stage for the Brussels Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected is identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Main KPI 1. Primary energy consumption	Electrical - Energy consumption Total consumption, Connected to STAM's platform	kWh	Wattmeter	1	LVPB general input at -1 floor	Meters	Minute	Yes
	Electrical - Energy consumption Lighting consumption of classrooms 201 (6B) and 202 (4C)	kWh	Wattmeter	1	LVPB floor 2 South	Meters	Minute	No
	Electrical - Energy consumption Lighting consumption of classrooms 209 (2B) and 210 (3B)	kWh	Wattmeter	1	LVPB floor 2 North	Meters	Minute	No
	Thermal (fuel) - Energy consumption	kWh	Wattmeter	1	Boiler room "Poste" -1 floor	Meters	Hourly	Yes
	Thermal (fuel) - Energy consumption	kWh	Wattmeter	1	Boiler room "Main" +4 floor	Meters	Hourly	Yes
	Electrical - Energy exported - PV	kWh	Wattmeter	1	TBD (to be define)	Meters	Hourly	No

Main KPI	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Main KPI 4. Energy demand	Option A - Energy simulation model	kWh	Software TPF's platform developed for T4.2	1	TPF's intranet	Survey	Hourly	Yes
Main KPI 5. BER (Building Energy Rating)	Energy Performance of the building	A-G	Other	1	B+	Survey	-	Yes
Main KPI 8. Final energy consumption	Electrical - Energy consumption Total consumption, Connected to STAM's platform	kWh	Wattmeter	1	LVPB general input at -1 floor	Meters	Minute	Yes
	Thermal (fuel) - Energy consumption	kWh	Wattmeter	1	Boiler room "Poste" -1 floor	Meters	Hourly	Yes
	Thermal (fuel) - Energy consumption	kWh	Wattmeter	1	Boiler room "Main" +4 floor	Meters	Hourly	Yes
Main KPI 16. Thermal comfort – Occupant perception	Temperature of a classroom	°C	Other	4	Classrooms L201, 202, 209, 210	Meters	Hourly	No
Main KPI 16. Thermal comfort – Occupant perception	humidity level of a classroom	%	Other	4	Classrooms L201, 202, 209, 210	Meters	Hourly	No
Main KPI 17. Indoor air quality (IAQ) – Occupant perception	CO2 level of a classroom	ppm	Other	4	Classrooms L201, 202, 209, 210	Meters	Hourly	No

Table 28: Monitoring needs for the Brussels LL Main KPIs affected by the operational stage

Table 29, shows the final list of technologies selected for the Brussels Living lab that are affecting the operational stage. For each of the technologies the selected technical KPI for their final performance validation with the selected list of variables needed for their computation are identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 28.

TECHNOLOGIES /INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
Green Roof	**SOPREMA**	**Roof cooling efficiency of the outdoor environment [% or kWh/m².y]** **Roof energy cooling efficiency [% or kWh/m².y]** **Roof cooling efficiency for the indoor environment [% or °C.h]**	Weather data (temperature, radiation, relative humidity, etc.)	Latent Flux Kwh/y	No - Simulation	–	–	Local weather data	TBD	Actual or future weather database
			Energy consumption sub-metered on last floor	kWh	Energy meter	-	-	-	-	-
			Building envelope geometry and thermal&physical values of layers	W/(K.m)	Products data	-	-	TDS	_	Yes
			Measured indoor temperature in 1 or 2 rooms located directly under the roof.	°C	Thermometer	Mini one / room	rooms located directly under the roof	Sensors	hourly	Yes

TECHNOLOGIES /INNOVATIONS	Responsible partner	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available
		Grid water savings for irrigation [m^3/y of saved grid water]	Grid water consumption	Litre / m3	Flowmeter	1	Roof	sensor	continuous	No

Table 29: Monitoring needs for the Brussels LL Technical KPIs affected by the operational stage

Presently, data from the ACE sensors and monitoring for gas, electricity and IEQ are being sent to PROBONO project.

The installation of utility monitoring equipment in the ACE Brussels LL building for data driven decision making, and the deployment of sensors and monitoring systems, took place throughout late 2023 for both the gas and the electricity.

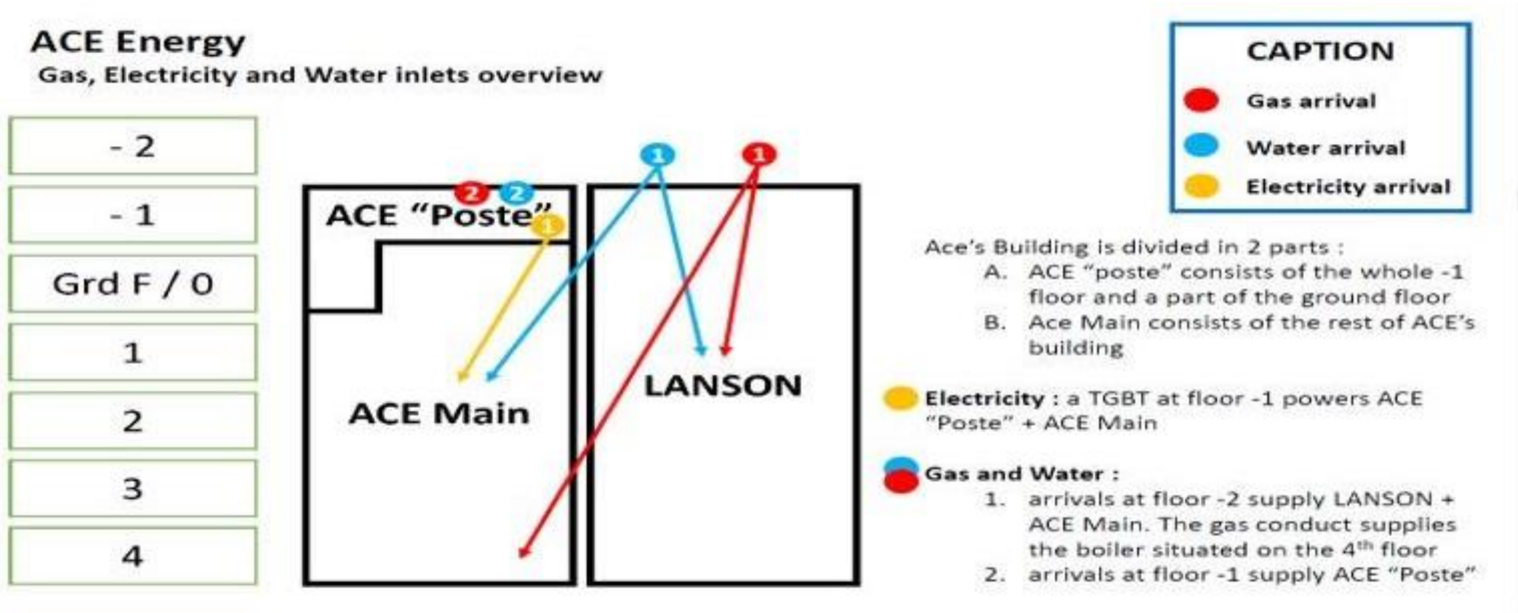


Figure 24*: Brussels LL – ACE Energy monitoring overview*

The sensors for IEQ are implemented in 2 classrooms with important sun exposure (rooms 6B and 4C) and 2 others to the rear of the building with less sun exposure (rooms 3B and 2B), so darker and colder.

- Classrooms 6B and 4C: South side of the building.
  - 1 Electrical meter for lighting of both classrooms.
  - 1 door, CO_2, humidity and temperature sensor in each room.
  - 4 windows sensors in each room.
- Classrooms 3B and 2B: North side of the building.
  - 1 Electrical meter for lighting of both classrooms.
  - 1 door, CO_2, humidity and temperature sensor in each room.

- 4 windows sensors in each room.

Type	Measuring	Installation	Commissioning DATA to STAM's Platform	Technical information	Comment
Electrical 3P meter	total consumption of the school	Done	Done to STAM Platform	ACREL ADW-300 3-phases electrical meter	Bought by TSRV and sent to TPF Installed by TPF Commissioned by TPF and STAM
Gas meter	Gas consumption of Main	Done	Done to TPF Platform	ITRON Delta Series + MBUS + Elvaco Gateway	Bought by STAM (TPF Supplier) and sent to TPF Installed by TPF Commissioned by TPF
Gas meter	Gas consumption of "Poste"	Done	Done to TPF Platform	ITRON Delta Series + MBUS + Elvaco Gateway	Bought by STAM (TPF Supplier) and sent to TPF Installed by TPF Commissioned by TPF Problem with the hardware, we ordered a new one.
Electrical 1P meter	Lighting consumption of the 2 classrooms	mar-24	mar-24	ACREL ADW-310	TPF and STAM bought the meters STATUS: Were installed beginning of March by TPF
Electrical 1P meter	Lighting consumption of the 2 classrooms	mar-24	mar-24	ACREL ADW-310	TPF and STAM bought the meters STATUS: Were installed beginning of March by TPF

Type	Measuring	Installation	Commissioning DATA to STAM's Platform	Technical information	Comment
Door open/close sensor (x4)	Classroom door opening/closing	mar-24	mar-24	Wifi modules homemade by TSRV	TSRV responsible for the hardware. STATUS : Were installed beginning of March by TPF
CO2, Humidity, temperature (x4)	Classrooms CO2, Humidity, temperature	mar-24	mar-24	Wifi modules homemade by TSRV (linked to door open/close sensors)	TSRV responsible for the hardware. STATUS : Were installed beginning of March by TPF
Window opening sensor (x20)	Classroom door opening/closing	mar-24	mar-24	Wifi modules homemade by TSRV	TSRV responsible for the hardware. STATUS : Were installed beginning of March by TPF

Table 30: Brussels LL data sources overview

6.5 Aarhus Living Lab operational monitoring plan

Table 31, shows the list of Main KPIs affected by the operational stage for the Aarhus Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected are identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

In the case of flow batteries in Campus Viborg, we intend to correlate the data collected on the batteries (energy stored, energy drawn) with energy prices on-grid to assess the financial benefit provided by the flow batteries. The batteries will be connected to solar panels, and thus excess energy stored is also a measure of environmental impact (i.e. the opportunity cost in comparison to generating energy through other non-renewable sources). Finally, we will consult VisBlue on measurements that provide information on battery lifetime (performance degradation) to assess life-cycle costs; it is predicted that the flow batteries will last longer than lithium batteries, resulting in lower life-cycle costs. This will also be assessed periodically during operation with data collected directly from the battery units.

Main KPI	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency
Main KPI 1. Primary energy consumption	Electrical - Energy consumption	kWh	Wattmeter	Unsure	Campus Viborg (all buildings on site); Aarhus Main Campus (all buildings on site)	Software	Daily
	Thermal (fuel) - Energy consumption	kWh	Wattmeter	Unsure			
	Electrical - Energy exported	kWh	Wattmeter	Unsure			
	Thermal - Energy exported	kWh	Wattmeter	Unsure			
Main KPI 2. Operational cost of energy	Option A - Energy Consumption	kWh	Wattmeter	Unsure	Campus Viborg (all buildings on site); Aarhus Main Campus (all buildings on site)	Software	Daily
	Option A - Energy service maintenances cost	€	None	Unsure			
	Option B - Electricity & fuel bills	€	Other	Unsure			

Main KPI	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency
Main KPI 4. Energy demand	Option A - Energy simulation model	kWh	None	Unsure	Campus Viborg (all buildings on site); Aarhus Main Campus (all buildings on site)	Software	Daily
	Option B - Useful energy provided by energy systems	kWh	Wattmeter	Unsure			
	Option C - Energy consumption considering systems performances	kWh	Wattmeter	Unsure			
Main KPI 5. BER (Building Energy Rating)	Energy Performance of the building	A-G	Software	Unsure	Campus Viborg (all buildings on site); Aarhus Main Campus (all buildings on site)	Software	Daily
Main KPI 8. Final energy consumption	Electricity - Energy consumption	kWh	Wattmeter	Unsure	Campus Viborg (all buildings on site); Aarhus Main Campus (all buildings on site)	Software	Daily
	Thermal (fuel) - Energy consumption	kWh	Wattmeter	Unsure			
Main KPI 9. CO_2 emissions operational stage	Final Energy consumption (KPI8)	kWh	Software		Campus Viborg (all buildings on site); Aarhus Main Campus (all buildings on site)	Software	Daily

Table 31: Monitoring needs for the Aarhus LL Main KPIs affected by the operational stage

Table 32, shows the final list of technologies selected for the Aarhus Living lab that are affecting the operational stage. For each of the technologies the selected technical KPI for their final performance validation with the selected list of variables needed for their computation is identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 31.

TECHNOLOGIES /INNOVATIONS	Provider	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Frequency	Available?
Flow Batteries	**VISBLUE**	**AC kWh energy charge/discharge values, AC instantaneous values, historical values.**	Sensing equipment installed with the batter monitors AC kWh energy charge/discharge values, AC instantaneously values, historical values (accessed through online customer interface). Equipment includes: a Secomea Sitemanager Gateway connected to the battery locally (Inverters Victron Multiplus II), and an internet connection delivered normally by the customer's network.	kWh	Wattmeter	1	Campus Viborg (batteries apply to energy storage for the entire site)	Daily	Yes
			Power consumption	kWh	Wattmeter	1	AU wide (including Campus Viborg)		Yes

Table 32: Monitoring needs for the Aarhus LL Technical KPIs affected by the operational stage

All monitoring equipment is already in place and running at the university (main campus), or we will be installed with the new construction (Campus Viborg). We have access to this data through PowerBI.

No additional monitoring equipment is needed to be purchased through the PROBONO project, as we will be exploiting the monitoring systems already set up by AU and which are already available to all AU employees.

KPIs 1, 4, 5, 8 that refer to energy consumption and demand will be monitored through AU's aggregated energy analysis that are available to all employees (accessed through PowerBI), with live data being updated at least daily. KPIs 2, 3, 11 that refer to energy cost, renewable energy production, and embedded CO_2 will be monitored through the CO_2 inventory reports that AU releases yearly.

VisBlue provides their own customer interface (Figure 25) which gets its data through the Secomea Sitemanager Gateway connected to the battery locally (Inverters Victron Multiplus II), and an internet connection delivered normally by the customer's network. The interface monitors AC kWh energy charge/discharge values, AC instantaneously values, historical values.

As presented in Section 3.5, the KPIs based on the human-centred analysis activity (Activity A3) using ProFormalise, ProBIM, and SEEDS refer to the number digitalised and analysed social value design intentions, and the correspondence with environmental impact as calculated through the SEEDS tool being developed by AU. These will associate social values with environmental impacts, which we currently expect to be assessed through KPI 1, KPI 2 and KPI 5.

The four case study buildings are already in operation, and we have interviewed architect Gustaf Lohm to elicit the as-designed social values in a series of formal interviews, documented in D1.2 GBN Analysis tools and decision support system and D5.6 GBN Global Decision Support and Optimization platform. Once the complete set of elicited design intentions is digitalised (due April 2024) and assessed with respect to socio-environmental performance with SEEDS (planned for December 2024), our ambition is incorporate these analyses into the embedded CO2 inventory that takes place across all AU buildings approximately annually. For this we will collaborate with AU Probono member Hans Sandersen, who leads the AU CO2 inventory activities, and is an expert in environmental sciences.

Figure 25*: Example screenshot of the VisBlue customer interface, accessed online.*

6.6 Prague Living Lab operational monitoring plan

Table 33, shows the list of Main KPIs affected by the operational stage for the Prague Living Lab. For each of the Main KPIs the list of variables needed for their computation, the units, the equipment that will be used to monitor the variable with the number of units needed, their specific location in the Living Lab, the specific data source and the potential frequency in which the data will be collected is identified. The current availability of the variable in the Living Lab with the idea to identify if any new monitoring equipment is needed to be added is also indicated.

Main KPI	Variable	Units	Equipment	Frequency	Available
Main KPI 1. Primary energy consumption	Electrical - Energy consumption	kWh	Software	Hourly	No
	Thermal (fuel) - Energy consumption	kWh	Software	Hourly	No
	Electrical - Energy exported	kWh	Software	Hourly	No
Main KPI 2. Operational cost of energy	Option A - Energy Consumption	kWh	Software	Hourly	No
	Option A - Energy service maintenances cost	€	Software	Yearly	No
	Option B - Electricity & fuel bills	€	Software	Hourly	No
Main KPI 4. Energy demand	Option A - Energy simulation model	kWh	Software	Hourly	No
	Option B - Useful energy provided by energy systems	kWh	Software	Hourly	No
	Option C - Energy consumption considering systems performances	kWh	Software	Hourly	No
Main KPI 5. BER (Building Energy Rating)	Energy Performance of the building	A-G	Software	Once before and after	Yes
Main KPI 6. Renewable energy production	Electricity – PV production	kWh	Software	Hourly	No

Main KPI	Variable	Units	Equipment	Frequency	Available
Main KPI 7. Self-consumption ratio	Renewable energy production - Electricity	kWh	Software	Hourly	No
	Energy consumption - Electricity	kWh	Software	Hourly	No
Main KPI 8. Final energy consumption	Electricity - Energy consumption	kWh	Software	Hourly	No
	Thermal (fuel) - Energy consumption	kWh	Software	Hourly	No
Main KPI 9. CO_2 emissions operational stage	Final Energy consumption (KPI8)	kWh	Software	Hourly	No
	Renewable production (KPI6)	kWh	Software	Hourly	No
Main KPI 16. Thermal comfort – Occupant perception	Perception of the indoor temperature by occupants	Likert	Survey	Yearly	No
	Perception of the air speed by occupants.	Likert	Survey	Yearly	No
	Perception of the humidity by occupants	Likert	Survey	Yearly	No
Main KPI 17. Indoor air quality (IAQ) – Occupant perception	Perception of the air quality by occupants.	Likert	Survey	Yearly	No
	Perception of the ventilation quality by occupants.	Likert	Survey	Yearly	No

Table 33: Monitoring needs for the Prague LL Main KPIs affected by the operational stage

Table 34, shows the final list of technologies selected for the Prague Living lab that are affecting the operational stage. For each of the technologies the selected technical KPI for their final performance validation with the selected list of variables needed for their computation is identified. The information collected for each of the variables is the same as the one presented before for the Main KPIs in Table 33.

TECHNOLOGIES/INNOVATIONS	Provider	KPI associated	Variable	Units	Equipment	No. of equipment	Location	Data Source	Frequency	Available?
Building envelope	**FRHF**	Production of solar electricity	Not Applicable (N.A.)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Green roof	**SOPREMA**	Thermal Transmittance Roof cooling efficiency of the outdoor environment [% or kWh/m².y] Roof energy cooling efficiency [% or kWh/m².y] Roof cooling efficiency for the indoor environment [% or °C.h]	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Table 34: Monitoring needs for the Prague LL Technical KPIs affected by the operational stage

At this moment only, measurements of electricity and heat for the whole complex of Faculty of Civil Engineering are available. It is not possible to know the real individual consumption of the building but only estimations.

The operational monitoring plan will not be deployed in the Prague LL during the project timeline but it will be considered in the tendering process. It is important to remark that the Prague Living Lab acts in the PROBONO project as a replicator of the Aarhus Living Lab. The KPIs will be calculated based on simulations considering the virtual implementation of the selected innovative solutions in the LL building.

7 Conclusions

D6.3 "LLs Monitoring program and associated execution plan" as outcome of T6.3 "Monitoring program definition and associated execution plan" collects all the relevant information about the monitoring plans that will be deployed in each of the PROBONO Living Labs (WP7 "Living Labs GBN Implementation") in order to collect and process all the necessary data (WP5) to comply with the requirements set in the PROBONO Evaluation Framework (D6.1) and therefore to be able to assess at the end of the project the effectiveness of the impacts achieved once the innovations have been implemented in the Living Labs.

The PROBONO Evaluation framework selected and defined 20 main KPIs to monitor and assess the impacts achieved in each of the Living Labs and several technical and social KPIs coming from the technical (WP3&WP4) and social (WP2) innovations. Although a preliminary list of technical and social KPIs was already included in D6.1 "PROBONO Evaluation Framework", the final selection and definition of the KPIs associated with the innovations is done in this report. The KPIs selected form the basis to define the specific monitoring requirements for each Living Lab.

The interlinks among WPs related with monitoring aspects is well represented in the following scheme:

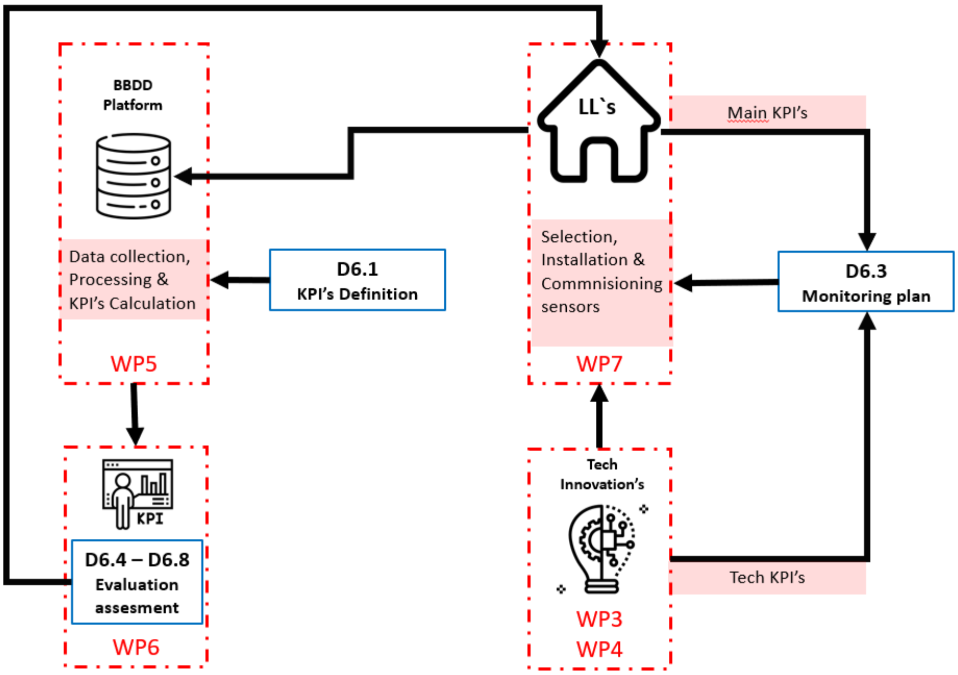


Figure 26: Interactions among WP5-WP6-WP7

The monitoring program is divided into two different main stages considering the PROBONO project scope. The construction period and the operational period and therefore specific monitoring plans are defined for each of these two stages for each Living Lab.

To define the specific plans for each Living Lab, monitoring templates were created and shared with the Living Labs and Technology providers in order to collect from them their specific requirements in terms of monitoring systems. It is important to remark that the plans are defined based on the current state of progress of the project and potentially some adaptations will be needed in the future and once the final implementations plans are completely defined.

In the case that adaptations are needed, these updates will be included in the next deliverables of WP6 “Monitoring and evaluation of the project’s Living Labs”.

In addition to this, this report includes the basis for the associated monitoring execution plans for each of the Living Labs by defining very detailed templates. In the next steps of the project these templates will be shared with the Living Labs to be completed and to define specific monitoring execution plans for each of them. The outputs of this LL specific execution monitoring plans will be reported under WP7 deliverables.

Madrid Living Lab is part of the Madrid Nuevo Norte urban regeneration project, focusing on creating a sustainable, efficient, and prosperous urban environment. Located in Las Tablas Oeste, it involves constructing a geothermal network connected to commercial and residential buildings, enhancing thermal activation. The project includes various innovative technologies such as geothermal district heating, demand and response platforms, second-life batteries, and low-carbon concrete. Key performance indicators (KPIs) cover energy consumption, GHG emissions, and social aspects like thermal comfort and acoustic quality. The operational phase will start in 2027, with continuous monitoring and assessment through simulations and real-time data to optimize energy efficiency and environmental impact.

Dublin Living Lab aims to create a sustainable, cost-effective, zero-carbon GBN network linking key municipal buildings and optimizing housing retrofits for future expansion. Key facilities include the County Hall, which serves as the flagship for implementing technical innovations, and the Harbour Ferry Terminal. The lab's primary Key Performance Indicators (KPIs) span construction and operational stages, covering technical innovations like recycled paper insulation, EV charging infrastructure, battery banks, and coloured BIPV solar panels. Social KPIs focus on indoor environmental quality, equity, community, and public behaviour. Monitoring involves detailed plans for capturing energy consumption, cost, thermal comfort, and CO_2 emissions through existing sensors and additional required equipment, with data feeding into a digital twin for real-time analysis. The structured implementation schedule ensures efficient project management, emphasizing the use of digital invoices and internal information to minimize costs.

Porto Living Lab, located at the Sonae headquarters campus in Portugal, spans over 30,000 square meters and serves 2,000 employees. It aims to foster sustainability and innovation by raising environmental awareness and implementing technical advancements. Key performance indicators (KPIs) have been redefined to align with energy-saving goals, including the addition of high energy performance through renewable sources and efficiency measures. Various technologies such as Phase Change Materials, Smart EV Hubs, 2nd life batteries, and bi-facial PV roofs are being monitored for their impact on energy storage, CO_2 emissions, and overall performance. The lab's monitoring system, managed by Capwatt and Elergone, tracks energy consumption and production, integrating new technologies into the existing infrastructure to evaluate scalability and impact on a larger scale. Social KPIs also measure community engagement through initiatives like the vegetable garden.

The Brussels Living Lab (LL) at De l’Autre Côté de l’Ecole (ACE) school, which follows the Freinet pedagogy, is undergoing renovations to align with environmental and regulatory standards of the Green Deal. Key Performance Indicators (KPIs) for this project focus on operational stages, covering areas like energy consumption, indoor air quality, and thermal comfort. Specific innovations include a green roof and an energy monitoring system. Social KPIs emphasize community engagement, personal safety, and energy consciousness. The project involves detailed monitoring plans for energy usage and environmental conditions, with various sensors and equipment installed to track these metrics continuously.

Aarhus University is transforming into a sustainable campus through the Campus 2.0 program, aiming for gold in the DGNB certification system. The Aarhus Living Lab (LL), part of the Probono initiative, focuses on high-impact projects at University City and Campus Viborg. Key activities include installing flow batteries, renovating buildings, and conducting human-centered analyses. The LL originally aimed to implement renewable energy production, but this was halted due to performance concerns and insurance issues, leading to a shift towards social value KPIs. Technologies and innovations like ProFormalise, ProBIM, and SEEDS are being used to capture social values and environmental impacts, which are integrated into the BIM model for enhanced monitoring and evaluation. The monitoring plan spans from 2023 to 2025, tracking energy consumption, cost, and CO2 emissions through various stages.

The Prague Living Lab (LL) is part of a renovation project for Building B at the Czech Technical University in Prague, aiming to transform it into an energy-positive structure. This project, under the PROBONO initiative, focuses on the design and planning stages, with construction occurring outside the project timeline. The project will develop necessary interventions and KPIs based on simulations to include in tender documentation. Prague LL will not physically implement innovations but will instead replicate and simulate impacts from the Aarhus Living Lab. The KPIs will help assess the potential effects of proposed technologies and innovations on energy efficiency and sustainability. Monitoring plans for these KPIs will be detailed in the tender documents, ensuring a comprehensive evaluation framework for future construction and operational phases.

As a next step, the monitoring plans here defined will be deployed in the Living Labs. The construction monitoring plan will be used as a basis to collect all the relevant data needed during the construction stage of the Living Labs to calculate the specific impacts and KPIs associated with the construction stage of the project. The operational monitoring plan will be deployed during the construction stage in order to have all the systems installed and commissioned before the operational monitoring period starts in order to be able to calculate, once the innovations are deployed, the specific impacts and KPIS associated with the operational stage of the project.

References

- *PROBONO D6.1. PROBONO Evaluation Framework.*
- *PROBONO D6.2. Baseline Evaluation.*
- *PROBONO D7.2 Overall LL Implementation Plan and Management (II)*
- *PROBONO D7.6 Dublin LL Design and Progress Report (I)*
- *PROBONO D7.9 Madrid LL Design and Progress Report (I)*
- *PROBONO D7.12 Porto LL Design and Progress Report (I)*
- *PROBONO D7.15 Brussels LL Design and Progress Report (I)*
- *PROBONO D7.18 Aarhus LL Design and Progress Report (I)*
- *PROBONO D7.21 Prague LL Design and Progress Report (I)*