PROBONO

Deliverable D6.1 – PROBONO Evaluation Framework

PROBONO - The Integrator-centric approach for realising innovative energy efficient buildings in connected sustainable green neighbourhoods - has received funding from the European Union's 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.

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The Integrator-centric approach for realising innovative energy efficient buildings in connected sustainable green neighbourhoods

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DEFINITIONS

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. 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, 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 mobility etc. Green neighbourhoods are the building blocks of Positive Energy Districts (PEDs) 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 Communities4 and Renewable Energy Communities5 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 co-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) 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) 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) considers all the costs incurred during the lifetime of the product, work, or service.

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Abbreviations and Acronyms

Acronym	Description
BER	Building Energy Rating
BIPV	Building Integrated Photovoltaic
EF	Emission Factor
EPD	Energy Product Declaration
GA	Grant Agreement
GB	Green Building
GBN	Green Building Neighbourhood
GHG	Green House Gas emissions
IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
IPMVP	International Performance Measurement and Verification Protocol
KPI	Key Performance Indicator
LC	Life Cycle
LCA	Life Cycle Assessment
LCC	Life Cycle Cost assessment
LL	Living Lab
M&V	Measurement and Verification
NZEB	Nearly Zero Energy Building
PEF	Primary Energy Factor
PV	Photovoltaic
RES	Renewable Energy System
s-LCA	Social Life Cycle Assessment
SDG	Sustainable Development Goals
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 Living Labs will provide both an experimentation and innovation environment and testbed for GBN innovative solutions. Although having a distinct scope, each Living Lab will follow a common process, starting with the GBN transition and strategic plan definition in WP1, the social innovations and stakeholders engagement activities in WP2 and the specification and selection of the maturing innovation technologies from WP3 and WP4, considering all the digitalization aspects in WP5 through the definition and deployment of the specific Digital Twins of each LL, going through the monitoring and evaluation in WP6, the implementation of all the actions in WP7 and ending with the dissemination, communication and replicability actions in WP8 and WP9.

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 Living Labs 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 Living Labs 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 KPIs, M&V plans and Life Cycle methodologies. T6.1.
- Baseline calculation for the Living Labs prior the implementation of the actions. T6.2.
- Monitoring program definition and associated execution plan for each Living Lab. T6.3.
- LLs impact assessment under operational and life cycle perspectives. T6.4.

D6.1 "PROBONO Evaluation Framework" is part of Task 6.1 whose objective is to define the Living Labs Evaluation Framework based on a set of KPIs, Measurement and Verification (M&V) plans and Life Cycle assessment methods (LCA, LCC and S-LCA) allowing to assess the effectiveness of the project actions and impact assessment of Green Building Neighbourhoods from different perspectives.

T6.1 is composed by different sub-tasks:

- Subtask 6.1.1 KPIs based Evaluation Framework covering Energy, Environmental, Economic and Social pillars. A technical definition is done for each KPI.
- Subtask 6.1.2 M&V Plans for energy savings assessment to reliably calculate energy savings associated with the operating phase of the buildings. The M&V plans are based on the International Performance Measurement and Verification Protocol (IMPVP).
- Subtask 6.1.3 Life Cycle assessment plans covering Environmental (LCA. Life Cycle Assessment), Economic (LCC. Life Cycle Cost) and Social (S-LCA. Social Life Cycle Assessment) perspectives. This subtask provides a holistic understanding of the impacts achieved through the GBNs taking into account all the life cycle phases.

This report (D6.1) formulates the findings of T6.1, and contains the complete evaluation framework including the KPIs, the M&V plans and the Life Cycle assessment plans.

This document defines the PROBONO Evaluation Framework and provides a common framework and guidelines for evaluating the impacts of the innovative solutions implemented in each of the Living Labs.

D6.1 should be seen by LLs as the main guidelines for deploying their specific impact assessment activities in the next phases of the project. D6.1 has been designed being flexible enough to be adapted to the specific context of each LL. Through the next phases of the project (Baseline, Monitoring and Impact assessment), and once the scope and LLs implementations plans are clearer, the Evaluation Framework will be tailor-made to the characteristics of each of them.

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 6.1 PROBONO Evaluation Framework	Define the Living Labs Evaluation Framework, identify of suitable KPIs, define measurement and verification (M&V) plans and Life Cycle assessment methods (LCA, LCC, s-LCA) which will allow assessing the effectiveness of the project actions and the impact assessment of GBNs from different perspectives.	Section 2, 3 and 4	The PROBONO Evaluation Framework is based on KPIs which allow to measure the progress of the PROBONO actions towards the achievement of the final impacts.
	KPIs based Evaluation Framework: The KPIs based Evaluation Framework is set covering Energy, Environmental, Economic and Social pillars. A technical definition is done for each KPI identifying all the variables and data requirements needed for their calculation in later stages as well as the identification of partners' responsibilities providing data.	Section 4.1	Main KPIs are defined in the Evaluation Framework as main mechanisms to validate the achievement of the PROBONO impacts. These main KPIs are categorized in 4 pillars and are technically defined in a high detail.
	Current existing initiatives and methodologies are considered for their selection and definition such as LEVEL(s) and alignments with the SDG are taken into account.	Section 2.2	PROBONO Evaluation Framework is completely aligned with the LEVEL(s) initiative and with the SDG goals.
	M&V plans for the energy savings assessment: Design and adapt a M&V plan for each of the LLs to reliably calculate the energy savings associated to the operating phase of the buildings. The M&V plan will be based on the IPMVP protocol.	Section 4.2.1	M&V plans are defined in PROBONO Evaluation Framework as supporting mechanisms to evaluate the energy savings achieved in the LLs in an accurate way.
	Life Cycle assessment plan. Define a Life Cycle assessment plan to cover Environmental (LCA), Economic (LCC) and Social (s-LCA) perspectives.	Section 4.2.2	Life Cycle plans covering the three perspectives, environmental, economic and social are defined in the PROBONO Evaluation Framework as supporting mechanism to evaluate the impacts and KPIs with a life cycle perspective.
DELIVERABLE			

GA Component Title	GA Component Outline	Respective Document Chapter(s)	Justification
TASK			
D6.1: PROBONO Evaluation Framework This report formulates the findings of T6.1, containing a complete evaluation framework including: KPIs based Evaluation Framework, M&V Plans & Life Cycle assessment Plan.			

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

1.2 Purpose and scope of the document

This document defines the PROBONO Evaluation Framework and provides a common framework and guidelines for evaluating the impacts of the innovative solutions implemented in each of the Living Labs.

D6.1 should be seen by LLs as the main guidelines for deploying their specific LLs impact assessment activities in the next phases of the project. D6.1 guidelines should be flexible enough to be adapted to the specific context of each LL.

Figure 1 shows the WP6 working flow. T6.1 establish the basis for the next activities within WP6.

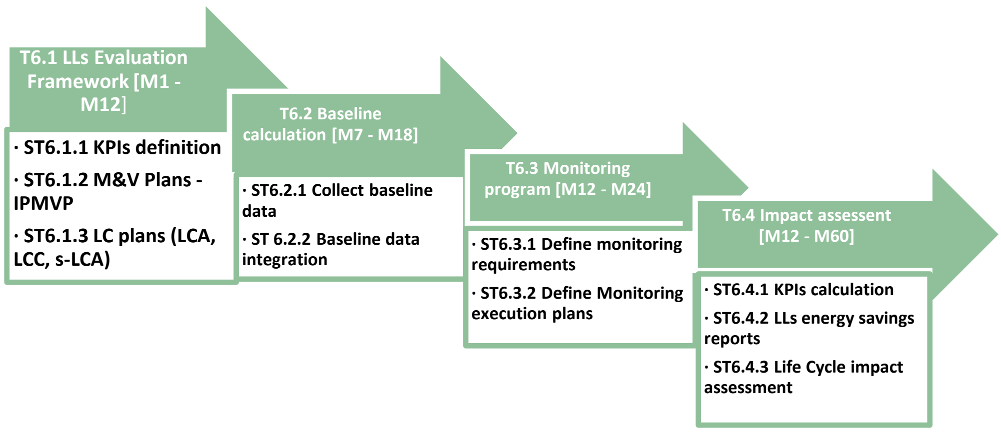

Figure 1: WP6 working flow

PROBONO Evaluation Framework receives inputs from different WPs in order to cover completely the assessment needs of the whole project. WP1 brings inputs to consider the GBN framework from a general point of view, WP2 to consider the social and behavioural innovations within the project, WP3 and WP4 for the consideration of the specific needs from technological innovations and WP8 and WP9 for the Dissemination/Communication and Exploitation aspects.

The main outputs from D6.1 will be to WP5 for the consideration of the variables needed from each of the Living Labs that need to be integrated in the Digital Platform, also to WP7 giving the monitoring requirements and needs from each of the Livings Labs to be deployed and commissioned, and to WP8 for Dissemination and Communication purposes.

1.3 Partners roles and responsibilities.

In the below table is shown the complete list of partners contributing to D6.1 and their specific role.

Partner	Role
CAR	WP6, T6.1 and D6.1 leader. Main contributor in the Impacts definition and Main KPIs definition. Main contributor in defining the M&V plans. Support in all the areas of the Evaluation Framework.
ACC ACC-R&D	Main contributor in the Impacts definition and Main KPIs definition. Main contributor in defining the LCA and LCC approach.
INLE	WP7 leader (Demonstration actions). Support in all related with the interactions with the Living Labs. Main contributor in the Impacts definition and Main KPIs definition.
FRHF	WP4 leader (Technological innovations). Support in all related with the interactions with the WP4 technical partners. Contributions to the Additional KPIs needed from WP1 and WP4.
SERCO	Contributions to the Additional KPIs needed from WP1. Specific contributions needed for the definition of the Evaluation Framework considering the LLs context (Brussels).
AU	Specific contributions needed for the definition of the Evaluation Framework considering the LLs context (Aarhus).
SIN	WP2 leader (Social innovations). Support in all related with the social aspects. Main contributor in the Impacts definition and Main KPIs definition. Main contributor in defining the s-LCA approach. Contributions to the Additional KPIs needed from WP2 and WP8.
UCD	Specific contributions needed for the definition of the Evaluation Framework considering the LLs context (Dublin).
VLTN	Main contributor in the Impacts definition and Main KPIs definition.
DCN	Specific contributions needed for the definition of the Evaluation Framework considering the LLs context (Madrid).
SONAE	Specific contributions needed for the definition of the Evaluation Framework considering the LLs context (Porto).
CTU	Specific contributions needed for the definition of the Evaluation Framework considering the LLs context (Prague).

Partner	Role
PNO	Contributions to the Additional KPIs needed from WP9.
TUC	WP3 leader (Technological innovations). Support in all related with the interactions with the WP3 technical partners. Contributions to the Additional KPIs needed from WP3.
CAPW	Specific contributions needed for the definition of the Evaluation Framework considering the LLs context (Porto).

Table 2: D6.1 partners main roles

1.4 Structure of the document

Deliverable D6.1 is structured in 6 different sections in addition to the Annex. Section 1 is covering the introduction, Section 2 defines the PROBONO Evaluation Framework and their links with the SDG and LEVEL(s) initiative, Section 3 presents the PROBONO expected impacts and their detail definition, Section 4 includes the technical definition of the Main KPIs that will be used to validate the achievement of the PROBONO impacts in addition to include the supporting methodologies and tools based on the M&V plans and the Life Cycle methods. The last two sections are for the conclusions and the references. At the end of the document is included an Annex including all the additional KPIs defined through the different PROBONO WPs in order to give the overall picture of the project.

2 PROBONO Evaluation Framework

2.1 General evaluation approach.

PROBONO Evaluation Framework should be seen by the Living Labs as the main guidelines for deploying their specific Living Labs impact assessment activities in the next phases of the project (Baseline data collection to define the reference scenario, Monitoring definition and impact assessment). These guidelines are developed being flexible enough to be adapted to the specific context of each of the six Living Labs.

PROBONO Evaluation Framework is composed by three different areas of assessment (KPIs, M&V plans and Life Cycle plans) although all of them are completely related.

- KPIs are the main evaluation assessment mechanisms within the PROBONO project, and are the ones used to be able to know if the project is progressing well and in the end if the project and the individual Living Labs have complied with their impacts. These KPIs are organized in four main pillars (Energy, Environment, Economy and Social).
- M&V plans (based on IPMVP) and Life cycle plans (covering LCA, LCC and s-LCA) are used in PROBONO as supporting tools for the deployment and calculation of several of the selected KPIs. All the KPIs in which in their definition need the application of any of the supporting tools to cover or well a life cycle perspective from an environmental, economic or social point of view, or on the other hand need an accurate energy savings measurement on the operational phase based on the IPMVP protocol.

In the following picture is well represented the composition of each of these assessment areas (KPIs, M&V plans and Life Cycle plans) and how at the end all of them are merged to form the PROBONO Evaluation Framework.

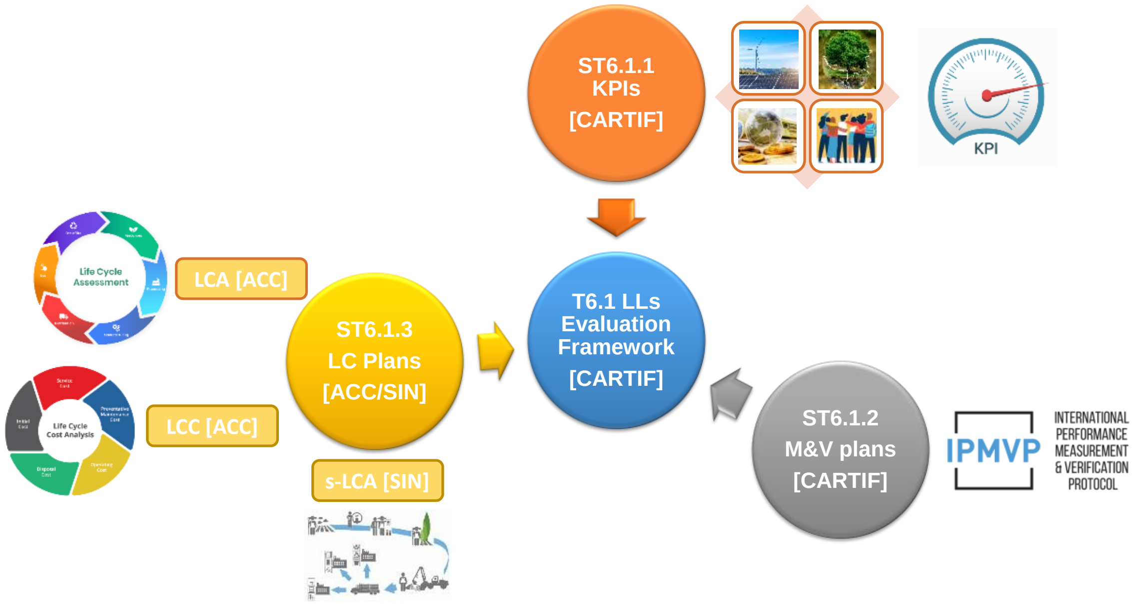

Figure 2: General view of the PROBONO Evaluation Framework

2.2 Links with SDG and Level(s)

PROBONO is completely aligned with the 2030 Agenda for Sustainable Development and it's Sustainable Development Goals (SDGs). PROBONO will support the progress towards the achievement of following SDGs over the next years through the innovations implemented in the Living Labs.

SDG	How PROBONO address the SDG
	**SDG1** by improving the energy efficiency of the buildings and therefore reducing the energy bills.
	**SDG2** by improving the Indoor Environmental Quality (Thermal comfort, Acoustic comfort, Indoor air quality and lighting comfort) of the buildings where the innovations will be implemented.

SDG	How PROBONO address the SDG
5 GENDER EQUALITY	**SDG5** by ensuring that all innovations (technological and social) are tested and developed equally across genders.
6 CLEAN WATER AND SANITATION	**SDG6** by improving the efficiency in the use of water by installing water meters and other related solutions.
7 AFFORDABLE AND CLEAN ENERGY	**SDG7** thanks to actions related with energy efficiency improvement and RES integration, reducing energy consumption and the greenhouse gas emissions.
8 DECENT WORK AND ECONOMIC GROWTH	**SDG8** by fostering investments and creating new jobs.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	**SDG9** by actions related with buildings resilient and sustainable infrastructure. PROBONO will research for finding solutions to social, economic and environmental challenges.
11 SUSTAINABLE CITIES AND COMMUNITIES	**SDG11** by deploying sustainable green neighbourhoods with access to basic services, energy, housing, transportation and green public spaces, while reducing resource use and environmental impact.
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	**SDG12** thanks to a sustainable production and consumption based on advance technological capacity, resource efficiency and reduced global waste.

SDG	How PROBONO address the SDG
	**SDG13** by increasing the use of RES systems and reducing the GHG emissions.
	**SDG15** by biodiversity innovations, protecting, restoring and promoting the conservation of ecosystems.

Table 3: PROBONO main support towards the SDGs compliance

In addition to the support from PROBONO to the compliance with the SDG, PROBONO is also very well aligned with the Level(s) methodology developed by the European Commission.

Level(s) is the first-ever European Commission framework for improving the sustainability of buildings. Level(s) has been designed to encourage users to think about the whole lifecycle of a building, providing a basis for quantifying, analysing and understanding the lifecycle. It goes beyond a building's service life and value by including elements that happened before and after this stage.

Level(s) owes its name to the fact that it proposed three different levels of accuracy for input data sources and data processing (related to the user's expertise), going from Level 1 (Conceptual design) corresponding to estimative and reference figures to Level 3 (As-built and in-use) corresponding to monitoring and values obtained from detailed assessment. In PROBONO the three levels are covered as Living Labs goes from conceptual design, going through the detailed design and construction until the commissioning, competition and occupation/use.

As can be seen from the previous description of Level(s), PROBONO is very well aligned with their principles and in the following table the links between Level(s) and PROBONO are shown.

Level(s) Macro objective	Indicator	PROBONO main impact associated
 Green house gas emissions along a building's life cycle	KPI 1.1. Use stage energy performance	PROBONO Impact 1 PROBONO Impact 3 PROBONO Impact 4
	KPI 1.2 Life cycle Global Warming Potential	PROBONO Impact 5 PROBONO Impact 6 PROBONO Impact 7

Level(s) Macro objective	Indicator	PROBONO main impact associated
 2 Resource efficient + circular material	KPI 2.2 Construction + demolition waste and materials KPI 2.3 Design for adaptability use KPI 2.4 Design for deconstruction, reuse + recycling	PROBONO Impact 5 PROBONO Impact 8 PROBONO Impact 9
 3 Efficient use of water resources	There is not any PROBONO Impact directly associated with Macro-Objective 3 but in PROBONO there will be actions related with the improvement in the use of water resources.	
 4 Healthy + comfortable spaces	KPI 4.1 Indoor air quality KPI 4.2 Time outside of thermal comfort range KPI 4.3 Lighting and visual comfort KPI 4.4 Acoustics and protection against noise	PROBONO Impact 7 PROBONO Impact 10
 5 Adaptation + Resilience	KPI 5.1 Protection of occupier health + thermal comfort	PROBONO Impact 10
 6 Optimised life cycle cost and value	KPI 6.1 Life cycle costs	PROBONO Impact 2

Table 4: PROBONO main alignments with LEVEL(s)

3 PROBONO expected Impacts and definition

3.1 PROBONO general expected impacts

All LLs have planned measures and innovations that are expected to collectively contribute to the impacts of the PROBONO project as described in Table 5. The General PROBONO expected impacts (as defined in GA impacts Section 2.1) should be achieved thanks to the aggregation of individual LLs specific impacts. The specific expected impacts from each of the LLs are defined in Section 3.2.

Impact Category	Unit	PROBONO Objective
I1. Primary energy savings	**%**	**35% reduction**

Impact Category	Unit	PROBONO Objective
Energy savings from resource efficiency improvements	GWh/y	>4GWh/year
Energy savings achieved through smart grid optimization	GWh/y	>3GWh/year
Energy efficiency of construction and retrofitting works	GWh/y	>1GWh/year
Energy savings from use of materials with lower environmental footprint	GWh/y	>0.6GWh/year
Energy savings from innovative insulation solutions	GWh/y	>2GWh/year
I2. Investments in sustainable energy	**€**	**-**
Investment in innovative solutions	€	>3 mill € invested in the next 5 years after the project end
Investment in renovation projects or new construction	€	>40 mill € invested in the next 5 years after the project end
Investment plans	€	>60 mill € invested in the next 5 years after the project end
I3. Demonstration sites that go beyond nearly-zero energy building performance	**-**	**-**
Reduced heating and cooling demand	%	>40%
Building Energy Rating (BER)	Energy Rating	A-rating
I4. High energy performance	**-**	**-**
Increase of Renewable energy generated on-site	%	>25%
Increase of Renewable energy covering LLs building energy demand vs other sources	%	>20%
Improved energy efficiency	%	35%-40%
I5. Reduction of GHG emissions for the total life-cycle	**tonCO_2-eq/year or %**	**>65%?**
GHG emissions reduction across the life cycle of the innovations	%	20%
GHG emissions reduction achieved across GB/GBN value chain	%	30%/35%
I6. Reduction of the embodied energy in buildings	**%**	**50%**
Reduction of embodied energy in buildings due to circular models	%	10-60%
Reduction of embodied energy in buildings due sustainable design	%	10-60%
I7. Reduction of air pollutants for the total life-cycle	**kg/year**	**-**
Decreased Sulphur dioxide	%	10% or < 20 μg/m^3
Decreased Nitrogen dioxide and oxides of nitrogen	%	5% or < 50 μg/m^3
Decreased PM10 and PM2,5	%	5% or < 12.5 μg/m^3 and 6 μg/m^3
Decreased Lead	%	5% or < 0.125 μg/m^3
Decreased Benzene	%	5% or < 0.8 μg/m^3
Decrease CO	%	5% or < 2.5 μg/m^3
I8. Potential for replicability	**-**	**-**
Number of follower GBN	nº	>6
Number of new GBs	nº	>20
I9. Shortened construction/retrofitting time and cost	**%**	**>30%**

Impact Category	Unit	PROBONO Objective
Shortened construction/retrofitting time required in-situ	% or days	>30%
Delays caused by supply chain complexity (materials/means not in place)	% or days	<1%
Shortened construction/retrofitting cost	%	>30%
I10. Improved indoor environmental quality (IEQ)	**%**	**>30%**
Reduction in number of complaints regarding air quality	%	>30%
Reduction in number of complaints regarding noise levels	%	>30%
Reduction in number of complaints regarding dust	%	>30%
Reduction of VOCs levels (PM2.5; CO; Radon; PAHs; Formaldehyde; etc.)	%	>30%

Table 5: General PROBONO expected impacts

3.2 Living Labs specific impacts

In addition to the general PROBONO impacts seen in previous section 3.1, each Living Lab (Madrid, Dublin, Porto, Aarhus and Brussels) have specific measures and innovations that are expected to contribute to the specific Living Labs impacts as shown in the following Tables.

It is also relevant to remark that although Prague Living Lab has not specific impacts associated, specific measures and innovations will also be implemented which will allow also Prague to contribute to different Impact Categories and to the global expected impacts.

The expected specific impacts achieved by each of the Living Labs through the implementation of the different innovations are the ones coming from the proposal phase. It is expected that some additional impact categories will be affected by the Living Labs once the implementation plan for each of the Living Labs will be clearer in the next phases of the project.

Madrid Living Lab specific impacts:

The expected Madrid LL impacts are summarized in Table 6 and comes directly from the GA Section 1.3.2.6.

Impact Category	Unit	LL Reference	LL Objective
I1. Primary energy savings	GWh/year	Flagship Building energy demand 8.8 GWh/year	Flagship building energy demand: 2.76 GWh/year Flagship building savings: 6.04 GWh/year
I2. Investments in sustainable energy	million €	-	Flagship building + network + thermal station 4.2 million €
I3. Demonstration sites that go beyond NZEB performance I4. High energy performance	-	Flagship Building specific heating and cooling demand: 140 kWh/m2/year	Flagship Building specific heating and cooling demand: 49 kWh/m2/year Flagship Building improvement: 65% At least nZEB status will be achieved for all buildings (commercial and residential).

Impact Category	Unit	LL Reference	LL Objective
			The aim is to achieve Energy Positive building status for residential building.
I5. Reduction of GHG emissions for the total life-cycle	tCO2-eq/year or %	Flagship building GHG emissions (cradle to cradle): 2,912.8 tCO2-eq/year	Flagship Building GHG emissions (cradle to cradle): 913.5 tCO2-eq/year Improvement: 69%
I6. Reduction of the embodied energy in buildings	GJ or %	Embodied energy in typical buildings: 1,000 GJ	Embodied energy in LL buildings: 500-900 GJ Improvement: 10-50% *depends on the % of components integrated
I7. Reduction of air pollutants for the total life-cycle	Not defined	-	Measurement will allow the measures definition and final improvement establishment
I9. Shortened construction/retrofitting time/cost	%	Construction/retrofitting typical time: high Construction/retrofitting typical cost: high	Improvement in time/cost expected: 40-50%
I10. Improved indoor environmental quality (IEQ) / Reduction of dust and noise during retrofitting	%	-	Improvement IEQ: 30-40% Improvement Dust and noise during retrofitting: 30%

Table 6: Madrid Living Lab expected impacts

Dublin Living Lab specific impacts:

The expected Dublin LL impacts are summarized in Table 7 and comes directly from the GA Section 1.3.2.5.

Impact Category	Unit	LL Reference	LL Objective
I1. Primary energy savings	GWh/year	Flagship Building energy demand 2 GWh/yr	Flagship Building energy demand 1.2 GWh/yr Flagship Building savings 0.8 GWh/yr
I2. Investments in sustainable energy	million €	-	40 million € invested
I3. Demonstration sites that go beyond NZEB performance	Not defined	Flagship Building specific heating and cooling demand: 128 kWh/m2/year Social housing F&G (BER): 380-450 kWh/m2/year	Flagship Building specific heating and cooling demand: 40-45 kWh/m2/year (nZEB standard for office building); Flagship building savings: 0.5 GWh/year Flagship building Improvement related to NZEB 40% Social housing A(BER) < 50 kWh/m2/year Social housing B2 (BER)<100 kWh/m2/year Social housing improvement related to NZEB 65%

Impact Category	Unit	LL Reference	LL Objective
			Retrofit buildings in Ireland need to achieve a BER of B2 to achieve nZEB status. The aim is to achieve nZEB status for all buildings. It is expected that the Lexicon Library will be energy positive. All the social housing units will achieve nZEB status with the potential to achieve the energy positive status.
I4. High energy performance	%	Flagship Building specific heating and cooling demand: 85-100 kWh/m2/year Onsite renewables: 45 kWh/m2/year Social housing specific heating and cooling demand: 120 kWh/m2/year	Flagship Building specific heating and cooling demand: 25 kWh/m2/year Flagship Building specific heating and cooling improvement: 58% Onsite renewables: 260 MWh Social housing specific heating and cooling demand: 50 kWh/m2/year Social housing specific heating improvement: 58%
I5. Reduction of GHG emissions for the total life-cycle	tCO2-eq/year or %	Flagship building GHG emissions (cradle to cradle): 420 tCO2-eq/year	Flagship Building GHG emissions (cradle to cradle): 167 tCO2-eq/year Improvement: 60%
I6. Reduction of the embodied energy in buildings	GJ or %	-	Improvement: 20% *The embodied energy of the building will not be reduced (already constructed), the embodied energy of the retrofit will be reduced.
I7. Reduction of air pollutants for the total life-cycle	Not defined	-	Air quality will be monitored in the flagship building and in the housing projects and inform about improvements.
I9. Shortened construction/retrofitting time/cost	%	-	Time/cost shortening period not specified so far. Optimization of the retrofit process will enable significant time and cost reductions.
I10. Improved indoor environmental quality (IEQ)	%	-	IAQ Improvement 30% Dust and noise issues will be reduced (Not quantified)

Table 7: Dublin Living Lab expected impacts

Porto Living Lab specific impacts:

The expected Porto LL impacts are summarized in Table 8 and comes directly from the GA Section 1.3.2.7.

Impact Category	Unit	LL Reference	LL Objective
I1 Primary energy savings	GWh/year	Energy demand 15.6 GWh/year	Energy demand 15.0 GWh/year: Savings: 0.6 GWh/year
I2. Investments in sustainable energy	million €	-	3 Million € invested
I3. Demonstration sites that goes beyond NZEB performance	-	-	Intended target to achieve nZEB or positive energy status
I5. Reduction of GHG emissions for the total life-cycle	tCO2-eq/year or %	GHG emissions (Cradle to cradle): 3ktCO2-eq/year (*not considering cogeneration)	Improvement: 30%
I6. Reduction of the embodied energy in buildings	GJ or %	-	Energy savings per year 986.4 MWh/year; Improvement 30%
I7. Reduction of air pollutants for the total life-cycle	-	-	The tech hub projects will have a future impact in the air pollutants

Table 8: Porto Living Lab expected impacts

Aarhus Living Lab specific impacts:

The expected Aarhus LL impacts are summarized in Table **9** and comes directly from the GA Section 1.3.2.9.

Impact Category	Unit	LL Reference	LL Objective
I1. Primary energy savings	GWh/year	Flagship building energy demand: 2GWh/year	Flagship Building energy demand: 1.2 GWh/year Savings: 0.8 GWh/year GBN projection: 3 GWh/year
I2. Investments in sustainable energy	million €	-	40 million € invested
I3. Demonstration sites that go beyond NZEB performance	-	Flagship building specific heating and cooling demand: 1.2 kWh/m2/year	Flagship building specific heating and cooling demand: 0.7 kWh/m2/year Savings flagship building: 0.5 GWh/year GBN projection improvement to nZEB 40%
I4. High energy performance	%	-	Achieve gold grade in the DGNB-DK certification system. Achieve Class 2 in the Danish voluntary energy regulation DGNB Gold corresponds to total performance index of 65% (aggregate across all major categories) and

Impact Category	Unit	LL Reference	LL Objective
			minimum 50% for each category. FB23 Danish energy regulations corresponds to no more than 12 kg CO2/m2/yr build bigger than 1,000m2 from 2023.
I6. Reduction of the embodied energy in buildings	GJ or %	-	As above.

Table 9: Aarhus Living Lab expected impacts

Brussels Living Lab specific impacts:

The expected Brussels LL impacts are summarized in Table 10 and comes directly from the GA Section 1.3.2.8.

Impact Category	Unit	LL Reference	LL Objective
I1. Primary energy savings	GWh/year	Energy demand: Gas consumption: 1.2 GWh/year (100% for heating purposes) Electricity consumption: 0.6 MWh/year (>50% lighting classrooms)	Savings: Flagship building: 0.65 GWh/year GBN projection: 3 GWh/year
I3. Demonstration sites that go beyond NZEB performance	-	Heating and cooling demand: 0.7 kWh/m2/year	Savings flagship building: 0.5 GWh/year Improvement related to NZEB: 40% *Intended target to achieve nZEB or positive energy status

Table 10: Brussels Living Lab expected impacts

Prague Living Lab specific impacts:

Although it was already mentioned before that Prague LL has not specific impacts form the proposal phase to be achieved, the main actions will be in line with the reduction of CO_2 emissions and energy consumption. Also, the Renewable energy production and the improvement of the healthy indoor comfort and biodiversity. This means that Prague Living Lab will contribute mainly to I1. Primary energy savings, I2. Investments in sustainable energy, I3. Demonstration sites that go beyond the NZEB performance, I4. High energy performance, I5. Reduction of GHG emissions for the total life-cycle and I10. Improved indoor environmental quality.

3.3 PROBONO impacts technical definition

This section presents the technical definition for each of the ten PROBONO expected impacts. The technical definition of each of the PROBONO Expected Impacts covers the following aspects:

- Unit in which the impact is assessed. It could be the case that the impact is related with different Main KPIs and therefore several units apply, in this case the reference unit should be the one of the Main KPIs.
- Pillar(s) in which the impact is included: Energy, Environmental, Economic or Social.
- Responsible partners for the technical definition and for the assessment of the impact.
- Detailed technical description of the impact.
- Main KPIs associated with the PROBONO impact. The Main KPIs will be the ones used to measure the progress towards the respective impact and to validate their achievement at the end of the project. Each PROBONO impact has at least one Main KPI associated with it. Main KPIs are listed and described in Section 4.
- Life Cycle Stages affected by the specific PROBONO impact. Specific information about the Life Cycle methods and concepts can be found in Section 4.2.2.
- Identification of Living Labs implementing innovations towards the achievement of the PROBONO impact (as indicated in the GA but it could be adapted in the next stages of the project once the implementations for each LL are clearer).
- Impact assessment associated deliverables. These are the reports in which the specific impact will be assessed depending on the life cycle stage affected.
- Influence of the technical innovations from WP3 and WP4 on each of the PROBONO impacts. It gives a first view of the expected qualitative impact based on technological partners' previous experience (High●; Medium●; Low●; None●). Here below the list of technological innovations and the code use in the tables below.

WP3 Technical Innovations "Construction and Renovation"	
Code	**Technical innovation**
a	**Insulation and green and cool roof solution**
a.1	Integrated thermal & acoustic insulation
a.2	Wood fibre insulation
a.3	Cool roof membranes and bi-facial PV panels
a.4	Evaporative green roof/walls
b	**Construction and lifecycle processes**
b.1	Modular construction
b.2	Climate change adaptation
b.3	Robots for construction inspection
b.4	Modular constructions workflow optimization
c	**Building materials / Upcycling**
c.1	Recycled plastics as raw materials
c.2	Materials applied to pavements

Table 11: WP3 Technical Innovations

WP4 Technical Innovations "Energy production, Storage and Distribution"	
Code	**Technical innovation**
a	**Climate neutral energy system**
a.1	Planning software for optimal energy system design
a.2	Planning guidelines
b	**GBN demand and response platform**
b.1	Energy system operation optimization platform
c	**Building Integrated Photovoltaics (BIPV)**
c.1	Coloured BIPV modules demonstrated
c.2	BIPV colour flexibility improved
d	**GB Positive Energy Package**
d.1	Innovative roof planning method
e	**Energy storage**
e.1	Flow batteries
e.2	Second Life Batteries
f	**Integrated Infrastructure Mobility**
f.1	V2G E-Mobility charging infrastructure with AI

Table 12: WP4 Technical Innovations

Expected Impact 1. Primary energy savings triggered by the project			
Unit	GWh/year or %	**Pillar**	Energy
Impact definition responsible	CARTIF	**Impact assessment responsible**	Living Labs
Detailed description			

The aim of the Expected Impact 1, is the calculation of the Primary energy savings in GWh/year or %, comparing the baseline (pre-intervention) and reporting (post-intervention) scenarios in each Living Lab. For the reduction of the Primary energy consumption the integration of renewable energy sources as well as the improvement of the building's energy performance through active and passive measures are very relevant.

The primary energy is the energy supplied to the building (from renewable and non-renewable sources) that has not been subjected to any conversion or transformation process. It is the energy contained in the fuels and other sources of energy and includes the energy necessary to generate the final energy consumed, including losses due to the extraction, processing, transformation, transportation to the building, etc. These losses are included in the primary energy factors, national or even regional conversion factors for calculating the primary energy consumptions from calculated or measured final energy consumption depending on the fuel and the fuel mix for generating electricity. In a life cycle approach, this is reported under Use stage (B).

To have a complete picture of the energy savings through the complete life cycle, Expected Impact 1 should be considered together with Expected Impact 6 "Reduction of the embodied energy in buildings". Within Expected Impact 6 are considered the Product and Construction Stage (A), the End

of Life (C) and the Beyond the Life Cycle Stage (D).

Having a holistic view of the entire life cycle of the building serves as a decision-making tool for designers and actors of the construction industry to make informed decisions and support the justification of choosing one product over another.

The Life Cycle Analysis methodology can be applied as an extra assessment for the indicators related to energy savings from resource efficiency improvements, construction and retrofitting works, and from the use of materials with lower environmental footprint. The calculation should include all life cycle stages of the building and its materials, from the embodied energy from the energy use in the stages of the production (A1-A5), the energy consumed in the operative stages (B1-B7), and the end-of-life stages (C1-C4, D). The entire calculation will allow a holistic view of the entire life cycle of the building serving as a decision-making tool for designers and actors of the construction industry to make informed decisions and support the justification of choosing one product over another.

When the overall balance is achieved, the LCA method allows the user to isolate specific phases of the life cycle or find possible "hot spots" of the energy use, depending on the objective and scope of the study.

Main KPIs associated with the Impact				
[Main KPI 1] Primary Energy Consumption				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	**Use (B1-B7)**	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Living Labs					
Dublin	**Madrid**	**Porto**	**Aarhus**	Prague	**Brussels**
Impact assessment associated deliverables			D6.6 and D6.7 Operation D6.8 Final Evaluation		

WP3 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2
High	High	High	High	None	None	Low	Low	Low	Low

WP4 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1
High	High	High	Medium	None	Low	Medium	Medium	Medium

Table 13: Expected Impact 1 definition

Expected Impact 2. Investments in sustainable energy triggered by the project			
Unit	€ or million €	Pillar	Economic
Impact definition responsible	ACC/CAR	Impact assessment responsible	Living Labs

Detailed description									
The aim of the Expected Impact 2, is the calculation of all the investments carried out in sustainable energy through all the Life Cycle stages of the project. Expected Impact 2 covers the following aspects: -Investment in public procurement of innovative solutions. -Investments in renovation projects or new construction defining the uptake of the solutions tested. -Master Plans & Investment Plans defining the uptake of the solutions tested. Two are the main blocks covering the assessment of this Impact: - Energy operational costs. Life Cycle Use stage (B6). With the idea to analyse the specific impact of the innovations in the LLs during the operational phase of the building. - Life Cycle Cost (LCC) Analysis covering all the Stages of the project (A, B, C and D) with the idea to analyse the complete picture of the investments during the whole life cycle process.									
Main KPIs associated with the Impact									
[Main KPI 2] Operational cost of energy [Main KPI 3] Cost along the life cycle (LCC)									
Life cycle stages									
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)					
Living Labs									
Dublin	Madrid	Porto	Aarhus	Prague	Brussels				
Impact assessment associated deliverables	D6.4 and D6.5 Construction D6.6 and D6.7 Operation D6.8 Final Evaluation D9.4 Exploitation, Replication and Sustainability								
WP3 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2
WP4 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1	

Table 14: Expected Impact 2 definition

Expected Impact 3. Demonstration sites that go beyond nearly-zero energy building performance			
Unit	Varies depending on the Main KPI	**Pillar**	Energy
Impact definition responsible	CARTIF	**Impact assessment responsible**	Living Labs
Detailed description			

The aim of the Expected Impact 3, is to demonstrate that LLs buildings go beyond the NZEB performance. According to the Directive 2010/31/EU(EPBD-Article 2(2) 'nearly zero-energy building' means "a building that has a very high energy performance, whereas this nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby". High energy performance means its energy consumption is very low. The concept of NZEB reflects the fact that renewable energy and energy efficiency measures work together.

Within PROBONO to demonstrate that LLs buildings go beyond the NZEB performance it is relevant to achieve a very high percentage of reduction in terms of energy demand for heating and cooling and a substantial improvement in terms of the Building Energy Rating of the LLs buildings. Expected Impact 3 should be considered together with Expected Impact 4 to have the complete picture of the Buildings' energy performance.

The exact definition of an NZEB in terms of primary energy use varies between Member States. However, in 2016 the Commission published possible benchmarks by climate zone for an NZEB performance (Source: European Commission 2016).

Climate zone	***Office buildings***			***Single family house***		
	Total primary energy (kWh/m²)	***On-site renewable energy contribution (kWh/m²)***	***"Net" primary energy (kWh/m²)***	***Total primary energy (kWh/m²)***	***On-site renewable energy contribution (kWh/m²)***	***"Net" primary energy (kWh/m²)***
Mediterranean	*80-90*	*60*	*20-30*	*50-65*	*50*	*0-15*
Oceanic	*85-100*	*45*	*40-55*	*50-65*	*35*	*15-30*
Continental	*85-100*	*45*	*40-55*	*50-70*	*30*	*20-40*
Nordic	*85-100*	*30*	*55-70*	*65-90*	*25*	*40-65*

Main KPIs associated with the Impact

[Main KPI 4] Energy demand

[Main KPI 5] BER – Building Energy Rating

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	**Use (B1-B7)**	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Living Labs

Dublin	Madrid	Porto	Aarhus	Prague	Brussels
Impact assessment associated deliverables			D6.6 and D6.7 Operation D6.8 Final Evaluation		

WP3 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2

WP4 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1

Table 15: Expected Impact 3 definition

Expected Impact 4. High energy performance			
Unit	Depending on the Main KPI	**Pillar**	Energy
Impact definition responsible	CARTIF	**Impact assessment responsible**	Living Labs

Detailed description

The aim of the Expected Impact 4 is to measure the increase in terms of buildings energy performance through the integration of renewable energy sources in the LLs buildings and thanks to the improvements in terms of energy efficiency measures (passive and active) of the building. Expected Impact 4 analyse the following aspects of energy performance of the LLs:

- Increase in renewable energy generation on-site in % compared to baseline scenario.
- Degree of renewable energy covering LLs energy consumption.
- Energy consumption reduction compared to baseline scenario.

As was mentioned before, Expected Impact 3 and 4 should be considered together to have the complete picture of the Buildings' energy performance.

Main KPIs associated with the Impact

[Main KPI 6] Renewable energy production

[Main KPI 7] Self-consumption ratio

[Main KPI 8] Final energy

Life cycle stages

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Living Labs									
Dublin	Madrid	Porto	Aarhus	Prague	Brussels				
Impact assessment associated deliverables			D6.6 and D6.7 Operation D6.8 Final Evaluation						
WP3 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2
WP4 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1	

Table 16: Expected Impact 4 definition

Expected Impact 5. Reduction of GHG emissions for the total life-cycle			
Unit	tonCO_2-eq/year or %	Pillar	Environmental
Impact definition responsible	ACC R&D/CARTIF	Impact assessment responsible	Living Labs
Detailed description			

The aim of the Expected Impact 5, is the calculation of the reduction in terms of CO_2-eq emissions for the total life-cycle of the LLs comparing the baseline situation (pre-intervention) with the reporting situation (post intervention).

There are two main blocks in which to divide the CO_2-eq emissions reductions: the first one is related with Use Stage (B) of the LLs buildings (baseline VS reporting) and the second one is related with the rest of the stages of the LLs life cycle covering stages A, C and D (PROBONO VS conventional technologies/processes). For having the partial results of each block, it is necessary to perform the entire Life Cycle Analysis. With the global result of the entire life cycle of the building, is possible to isolate the specific stages to provide results for the different blocks: operational and the remaining phases.

- Operational CO_2 emissions (Operational Energy Stage B6): represents the CO_2-eq emissions of a building caused by the different areas of application (heating, cooling, DHW, electrical appliances, etc.). This block encompasses the CO_2 emissions caused by the energy supply (thermal and electrical) for operating the building. It is calculated in $kgCO_2eq/m^2{\cdot}year$. The CO_2 emissions reduction for this block could be achieved thanks to the integration of renewable energy sources, the use of less polluting fuels and more efficient systems. Life Cycle Use Stage (B).

- Embodied CO_2 emissions: when the operational energy use stage of the building is taken aside (B6), the building itself can be seen as a repository of embodied energy that was consumed for the production of all the materials and services used in its construction (stages A1-A5), as well as the repair, maintenance, renovation (stages B1-B5, B7) and eventual deconstruction and end-of-life management of a building or product (stages C1-C4, D). With the analysis of these stages of the life cycle, it is possible to measure the CO_2 emissions embedded in products and services used in the project, and later compare the CO_2 emissions embedded in the PROBONO innovation/processes with the CO_2 emissions embedded in conventional processes/innovations.

Moreover, if the end-of-life of the components of the building is known to be able to be reusable or recyclable, this contributes to reduce the negative impacts of the overall CO_2 balance.
Main KPIs associated with the Impact
[Main KPI 9] CO_2 emissions operational stage [Main KPI 10] GHG emissions along the life cycle (LCA)
Life cycle stages

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Living Labs					
Dublin	Madrid	Porto	Aarhus	Prague	Brussels

Impact assessment associated deliverables	D6.4 and D6.5 Construction D6.6 and D6.7 Operation D6.8 Final Evaluation

WP3 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2
High	High	High	Medium	High	None	Medium	High	Medium	Medium

WP4 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1
Medium	Medium	Medium	Medium	Medium	Low	Low	Low	Low

Table 17: Expected Impact 5 definition

Expected Impact 6. Reduction of the embodied energy in buildings			
Unit	%	**Pillar**	Energy
Impact definition responsible	ACC R&D	**Impact assessment responsible**	Living Labs
Detailed description			

The aim of Expected Impact 6, is the calculation of the degree of reduction in terms of amount of energy embodied in the materials/processes used in the buildings/GBN comparing the innovative solutions proposed by PROBONO with the conventional solutions in a Business as Usual approach.

Embodied energy describes the energy used in building materials flows and construction activities throughout the life-cycle of a building. This includes material extraction, transport, processing, manufacturing, construction, maintenance, repair, replacement, deconstruction, waste processing and disposal. The energy consumption for the operation of the building is excluded (Stage B6).

For these indicators, the life cycle stages to be considered are the production process (A1-A5),

maintenance, repair, replacement and refurbishment (B2-B5), and end-of-life stages (C1-C4, D). With this, we can achieve a holistic view of the materials used on the building, including their end-of-life management, which can have a positive impact in the embodied energy when the products are designed for reuse or recycling. To have the complete picture of the energy reduction for the whole life cycle this Expected Impact 6 should be considered together with Expected Impact 1 "Primary Energy Savings". Within Expected Impact 1 is considered the Use Stage (B6). Embodied energy can be reduced thanks to the use of recycled materials (recycling/reuse of demolition materials). Further reductions in embodied energy are feasible through sustainable design and construction strategies such as optimization of building form and design layout plans, design for flexibility and adaptability, low maintenance and service life extension and reduction of construction impacts.									
Main KPIs associated with the Impact									
[Main KPI 11] Embodied energy									
Life cycle stages									
Product stage (A1-A3)		Construction stage (A4-A5)		Use (B1-B7)		End of Life (C1-C4)		Beyond the Building Life Cycle (D)	
Living Labs									
Dublin	Madrid	Porto	Aarhus	Prague	Brussels				
Impact assessment associated deliverables					D6.4 and D6.5 Construction D6.8 Final Evaluation				
WP3 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2
WP4 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1	

Table 18: Expected Impact 6 definition

Expected Impact 7. Reduction of air pollutants for the total life-cycle			
Unit	kg/year	**Pillar**	Environmental
Impact definition responsible	ACC R&D/CAR	**Impact assessment responsible**	Living Labs
Detailed description			
The aim of Expected Impact 7, is the calculation of the reduction in terms of air pollutants for the			

total life-cycle. According to Level(s), the Energy Use indicator can provide useful insights on the building's total emissions of air pollutants to the ambient air. Whereas an overall reduction in primary energy consumption will generally have a positive effect on air quality, a fuel switch may also lead to an increase or reduction of emissions of specific ambient air pollutants. These metrics can be achieved through a Life Cycle Analysis. Reduction of air pollutants (NOx, PM, etc.) from LLs during the Use stage (B) can be achieved thanks to mainly: - The improvement of the energy efficiency. - The increase of Renewable Energy Systems. - The reduction of conventional fuels utilization. - Increase the use of electro or less pollutant vehicles (e.g. Hybrid).
Main KPIs associated with the Impact
[Main KPI 10] GHG emissions along the life cycle (LCA) [Main KPI 12] Air pollutants operational stage
Life cycle stages

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Living Labs					
Dublin	Madrid	Porto	Aarhus	Prague	Brussels
Impact assessment associated deliverables			D6.4 and D6.5 Construction D6.6 and D6.7 Operation D6.8 Final Evaluation		

WP3 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2
High	High	High	High	Medium	Low	Low	Low	Low	Low

WP4 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1
Medium	Medium	Medium	Medium	None	Low	Low	Low	High

Table 19: Expected Impact 7 definition

Expected Impact 8. Potential for replicability using new or existing innovation clusters			
Unit	Nº	**Pillar**	Other
Impact definition	INLECOM/PNO	**Impact assessment**	Living Labs

responsible		responsible			
Detailed description					
The aim of the Expected Impact 8 is the demonstration of high potential for replicability and transferability of PROBONO innovations by EU Cities & Municipalities using new or existing innovation clusters incorporating the whole value chain. PROBONO will realize Impact 8 through the replicability actions designed in WP9.					
Main KPIs associated with the Impact					
[Main KPI 13] Replicability					
Life cycle stages					
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)	
Living Labs					
Dublin	Madrid	Porto	Aarhus	Prague	Brussels
Impact assessment associated deliverables			D6.8 Final Evaluation D7.5 Final performance assessment and replicability/transferability, LL certification. D9.4 Exploitation, Replication and Sustainability		

WP3 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2

WP4 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1

Table 20: Expected Impact 8 definition

Expected Impact 9. Shortened construction/retrofitting time and cost			
Unit	%	**Pillar**	Economic/Other
Impact definition responsible	VLTN	**Impact assessment responsible**	Living Labs
Detailed description			
The aim of Expected impact 9 is to measure the reduction in terms of the costs and time incurred in association to modular construction/retrofit by manufacturing, transportation, stock-keeping, and warehouse establishment while considering the influence of various site demand variation factors			

thanks to the PROBONO related innovations.									
Main KPIs associated with the Impact									
[Main KPI 14] Shortened construction/retrofitting time [Main KPI 15-1] Shortened construction/retrofitting cost – manufacturing [Main KPI 15-2] Shortened construction/retrofitting cost – transportation [Main KPI 15-3] Shortened construction/retrofitting cost – stock keeping [Main KPI 15-4] Shortened construction/retrofitting cost – space costs/warehouse establishment									
Life cycle stages									
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)					
Living Labs									
Dublin	Madrid	Porto	Aarhus	Prague	Brussels				
Impact assessment associated deliverables	D6.4 and D6.5 Construction D6.8 Final Evaluation								
WP3 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2
WP4 innovations expected influence (High●; Medium●; Low●; None●)									
a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1	

Table 21: Expected Impact 9 definition

Expected Impact 10. Improved indoor environmental quality (IEQ) and reduction of dust and noise			
Unit	%	**Pillar**	Social
Impact definition responsible	SIN/CARTIF	**Impact assessment responsible**	Living Labs
Detailed description			
The aim of the Expected Impact 10, is calculation of the reduction in terms of complaints (or increase of satisfaction) for the Indoor Environmental Quality (IEQ) aspects thanks to the implementation of the PROBONO innovations. Indoor Environmental Quality (IEQ) covers different aspects that will be analysed through the different stages of the project, such as: - Thermal comfort: Covering aspects such as Tª, Humidity and air-speed (Mainly affecting Life Cycle			

Use Stage B). - Indoor Air Quality (IAQ): Covering aspects such as the air quality and ventilation (Mainly affecting Life Cycle Use Stage B). - Acoustic comfort: Covering aspects such as indoor and outdoor noise (Mainly affecting Life Cycle Stages A and B). - Visual comfort: Covering aspects such as the Lighting levels, artificial and natural lighting (Mainly affecting Life Cycle Use Stage B). This impact also covers the calculation of the reduction in terms of complaints (or increase of satisfaction) regarding dust levels during the construction process (Life Cycle Stage A).
Main KPIs associated with the Impact
[Main KPI 16] Thermal comfort – Occupant perception [Main KPI 17] IAQ Indoor Air Quality – Occupant perception [Main KPI 18] Acoustic comfort – Occupant perception [Main KPI 19] Dust quality – Occupant perception [Main KPI 20] Visual comfort – Occupant perception

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Living Labs					
Dublin	Madrid	Porto	Aarhus	Prague	Brussels

Impact assessment associated deliverables	D6.4 and D6.5 Construction D6.6 and D6.7 Operation D6.8 Final Evaluation

WP3 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	a.3	a.4	b.1	b.2	b.3	b.4	c.1	c.2

WP4 innovations expected influence (High●; Medium●; Low●; None●)

a.1	a.2	b.1	c.1	c.2	d.1	e.1	e.2	f.1

Table 22: Expected Impact 10 definition

4 PROBONO KPIs based Impact assessment

As was previously mentioned in the PROBONO impacts description, all the PROBONO impacts have associated Main KPIs (at least 1 per Impact) allowing to measure progress towards the achievement of the project final objectives. Here in this section, the Main KPIs are technically described.

As can be seen in the description of each of the Main KPIs (Section 4.1), some of them, need the use of specific supporting methodologies or tools to be calculated. In the following section 4.2, the general fundamentals behind each of these supporting methods/tools together with their alignment with the PROBONO scope are described.

The technical definition of each of the Main KPIs covers the following aspects:

- Unit in which the Main KPI is calculated.
- Pillar in which the Main KPI is included: Energy, Environmental, Economic or Social.
- Responsible partners for their technical definition and for their calculation.
- Expected Impact to which the KPI is linked.
- Detailed technical description of the Main KPI.
- To define if baseline data is needed for the validation of the Main KPI and their associated Impact. Baseline data will be collected through T6.2 “Baseline”. It is also included a first estimation of the frequency in which the KPI will be calculated.
- The variables needed / data requirements for the Main KPI calculation. This will allow to identify the monitoring requirements for each Living Lab that will be defined in T6.3 “Monitoring” and implemented through WP7 activities in each LL.
- The assessment mechanism or formula for the Main KPI. Here it is indicated if for the calculation of the Main KPI any supporting method or tool is needed (IPMVP, LCA, LCC or s-LCA).
- Life Cycle Stages affected by the Main KPI.

In addition to this Main KPIs, and also as part of the general PROBONO Evaluation Framework, there are other more specific KPIs associated to each of the WPs. These additional KPIs coming from the specific needs of each of the WPs are also collected in this report and included in Annex I “Additional KPIs.

4.1 Main KPIs

Main KPI 1. Primary energy consumption			
Unit	kWh/year	Pillar	Energy
KPI definition responsible	CARTIF	KPI calculation responsible	Living Labs
Associated Expected Impact		Impact 1. Primary energy savings	
Detailed description			
The primary energy consumption is calculated from the final energy consumption of the different energy carriers (including renewable and non-renewable sources) and corresponding fuel-to-primary and electricity-to-primary conversion factors associated with each energy carrier. The primary energy factors may be based on national or regional weighted averages or a specific value for on-site production. Any given energy carrier may have a non-renewable factor and a renewable factor, or			

just one of the two. These factors may be greater than, equal to, or less than 1, although the combined total of non-renewable and renewable primary energy factors for a given energy carrier cannot be less than 1.

The primary energy includes the losses of the whole energy chain. These losses are included in the primary energy factors.

The primary energy is the energy found in nature (coal, oil, gas, etc.) which have to be converted (with subsequent losses) to useable forms of energy.

If energy is exported from the building, this should also be considered.

Baseline data needed	Yes	**Calculation frequency**	Monthly/Yearly

Variables needed / Data requirements

The variables needed for the calculation of the Primary energy consumption are the following:

· Energy consumption (kWh) in at least monthly basis for a complete year by type of energy source (Electricity, natural gas, etc.) – Main KPI8

· Renewable production (kWh) in at least monthly basis for a complete year by type of RES – Main KPI6

· Energy exported (kWh) to the grid or other locations in at least a monthly basis for a complete year.

· PEF (Primary Energy Factors) by energy source [kWh_{pe}/kWh_{fe}].

There are different ways to obtain the data from the Living Labs:

- On-site measurements - monitoring systems.
- Energy bills.
- Energy simulations (software).

Assessment mechanism / Formula

$$\text{Primary Energy Consumption [kWh]} = \sum FE_i * PEF_i - \sum E_{EXP} * PEF_{EXP}$$

International Performance Measurement and Verification Protocol (IPMVP)

- FE_i: Final energy consumption from the different energy carriers [kWh_{fe}].
- PEF_i: Primary Energy Factor of the different energy carriers [kWh_{pe}/kWh_{fe}].
- E_{EXP}: Energy exported [kWh_{EXP}]
- PEF_{EXP}: Primary Energy Factor of the energy exported [kWh_{pe}/kWh_{EXP}].

In the case of PROBONO the Primary energy savings (Impact 1) will be calculated in accurate way by applying the principles of the IPMVP (International Performance and Measurement and Verification Protocol). Information about this protocol and their applicability in PROBONO can be found in Section 4.2.

Life cycle stages

Product stage (A1-A3)	Construction stage (A4-A5)	**Use (B1-B7)**	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 23: Main KPI 1 definition

Main KPI 2. Operational cost of energy			
Unit	€/year	Pillar	Economic
KPI definition responsible	CARTIF	KPI calculation responsible	Living Labs
Associated Expected Impact		Impact 2. Investments in sustainable energy	
Detailed description			
The operational energy costs represent the total cost for the operation of the building spent on energy services (energy consumption, energy service maintenance, etc.) It includes all the costs arising from the use of energy sources (natural gas, electricity, oil, district heating, etc.). Operational energy costs can be reduced by improving the building's energy performance, integrating renewable energies and changing the fuel types. Operational costs are determined based on the final energy consumption, the fuel and electricity prices and other items. They can also been obtained directly from the energy bills. This specific KPI covers the Life cycle stage B6 (Operational use of the building).			
Baseline data needed	Yes	Calculation frequency	Monthly/Yearly
Variables needed / Data requirements			
The variables needed for the calculation of the Operational cost of energy are the following: Option A (by multiplying the energy consumption by the energy prices): · Energy consumption (kWh) in at least monthly basis for a complete year by type of energy source (Electricity, natural gas, biomass, etc.) – Main KPI8 · Energy prices (€/kWh) for the different energy sources. · Energy service maintenance costs and other items (€) Option B (directly from the energy bills): · Electricity and fuel bills (€)			
Assessment mechanism / Formula			
Operational cost of energy [€] = $C_{fuel} + C_{electricity} + C_{maintenance}$			
- C_{fuel}: Operational cost of the different fuels (natural gas, biomass, etc.) [€] - $C_{electricity}$: Operational cost of the electricity [€] - $C_{maintenance}$: Maintenance costs and other items [€]			
Life cycle stages			

Product stage (A1-A3)	Construction stage (A4-A5)	**Use (B1-B7)**	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 24: Main KPI 2 definition

<table>
<tr><th colspan="4">Main KPI 3. Cost along the life cycle (LCC)</th></tr>
<tr><td>Unit</td><td>€</td><td>Pillar</td><td>Economic</td></tr>
<tr><td>KPI definition responsible</td><td>ACC</td><td>KPI calculation responsible</td><td>Living Labs</td></tr>
<tr><td colspan="2">Associated Expected Impact</td><td colspan="2">Impact 2. Investments in sustainable energy</td></tr>
<tr><td colspan="4">Detailed description</td></tr>
<tr><td colspan="4">This indicator measures the total investment/costs in sustainable energy actions (product stage, process stage (A1-A5), Use stage (B2 Maintenance, B4 Replacement), End of life Stage (C2 Transport, Disposal C4)) incurred at each life cycle stage of a project (the operational part of the building B6 that is calculated through KPI 2 will be used as input for the LCC (Life Cycle Cost) calculation considering the variability of the prices (discount rate, future energy price) during the whole life cycle of the project).</td></tr>
<tr><td>Baseline data needed</td><td>No</td><td>Calculation frequency</td><td>Once, during the whole life cycle</td></tr>
<tr><td colspan="4">Variables needed / Data requirements</td></tr>
<tr><td colspan="4">The variables needed for the calculation of the Life Cycle Cost are the following:
- Invoices of innovations/materials [€]
- Construction and deconstruction/demolition costs [€]
- Refurbishment costs [€]
- Construction project budget (include material, cost, machinery cost, installation cost, etc.), Maintenance cost, Replacement cost and often, End of life stage focused on Transport cost and Disposal cost. [€]
- Operational cost of energy [€] – Main KPI2
The building life cycle phases generally included in the assessment are the cost for the initial investment related to construction, operation and maintenance and the end-of-life costs.</td></tr>
<tr><td colspan="4">Assessment mechanism / Formula</td></tr>
<tr><td colspan="4">LCC (Life Cycle cost Assessment)</td></tr>
<tr><td colspan="4">LCC - software tool and databases
LCC calculations can include a comparison between alternatives.
LCC methodology can be seen in Section 4.2.</td></tr>
<tr><td colspan="4">Life cycle stages</td></tr>
</table>

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 25: Main KPI 3 definition

<table>
<tr><th colspan="4">Main KPI 4. Energy demand</th></tr>
<tr><td>Unit</td><td>kWh/year</td><td>Pillar</td><td>Energy</td></tr>
<tr><td>KPI definition responsible</td><td>CARTIF</td><td>KPI calculation responsible</td><td>Living Labs</td></tr>
<tr><td colspan="2">Associated Expected Impact</td><td colspan="2">Impact 3. Demonstration sites that go beyond nearly-zero energy building performance</td></tr>
<tr><td colspan="4">Detailed description</td></tr>
<tr><td colspan="4">The energy demand of the building, is the total amount of energy the energy systems of the building need to provide to maintain its indoor environment in comfortable conditions, in this case the main areas are heating and cooling but it also worth considering other areas such as ventilation and lighting. Energy demand is usually differentiated by different energy uses (heating, cooling, lighting, etc.). It takes into account the energy lost and gained due to thermal transmission via opaque and transparent elements, the energy exchange due to ventilation and infiltration, the gains due to occupancy, lighting and electrical appliances as well as the required heating and cooling inputs.

Energy demand could be reduced through minimising the energy needs (i.e.: temperature set-points, ventilation rates, etc.) and also through the improvement of the passive elements of the building.

Energy demand is the amount of energy needed to maintain comfortable indoor conditions. Energy demand is normally measured in $kWh/m^2 \cdot year$.</td></tr>
<tr><td>Baseline data needed</td><td>Yes</td><td>Calculation frequency</td><td>Monthly/yearly</td></tr>
<tr><td colspan="4">Variables needed / Data requirements</td></tr>
<tr><td colspan="4">The variables needed for the calculation of the Energy demand are the following:

<u>Option A</u> (Through energy simulations):

· Complete building description for the definition of the energy simulation model, including all the active and passive elements.

· Weather data (temperature, radiation, relative humidity, etc.).

<u>Option B</u> (Measuring the useful energy provided by the energy systems):

· Energy demand (kWh) in at least monthly basis for a complete year by energy use (Heating, cooling, lighting, etc.).

<u>Option C</u> (From final energy consumption considering the energy systems performances):

· Energy consumption (kWh) in at least monthly basis for a complete year by type of energy source (Electricity, natural gas, etc.) – Main KPI8

· Energy systems performance to be able to convert energy consumption in energy demand. This is normally obtained through an energy audit.

There are different ways to obtain the data for the Living Labs:

• On-site measurements - monitoring systems (useful energy).
• Energy bills.
• Energy simulations (software).</td></tr>
<tr><td colspan="4">Assessment mechanism / Formula</td></tr>
</table>

Total energy demand [kWh] = ∑Energy demand i				
- Energy demand i [kWh] = Energy demand for the different energy uses within the building (heating, cooling, lighting, etc.).				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 26: Main KPI 4 definition

Main KPI 5. BER (Building Energy Rating)			
Unit	Energy Label	**Pillar**	Energy
KPI definition responsible	CARTIF	**KPI calculation responsible**	Living Labs
Associated Expected Impact		Impact 3. Demonstration sites that go beyond nearly-zero energy building performance	
Detailed description			
The Building Energy Rating is an energy label rating. This indicator represents the Energy Performance of the building on a scale from A to G, being A the higher energy efficiency level and G the lower energy efficiency level. The better the Building Energy Rating, the lower your energy bills, the less carbon (CO_2) emitted and the greater potential value of the property. A BER assessment and certificate may be compulsory to sell a building or shortly after its construction. Methods of calculation and legislations related to BER may be different from one country to another.			
Baseline data needed	Yes	**Calculation frequency**	Once before and after the renovation
Variables needed / Data requirements			
Complete description of the energy characteristics of the building: thermal envelope, energy systems, etc. - Building envelope: Walls, windows, roof, etc. - Energy systems: Heating, Cooling, Lighting, Ventilation, etc. - Any energy efficiency improvement or technology. All this information will be included in the energy labelling software or used in the methodology for their calculation. Normally this work is done by an energy certified assessor.			
Assessment mechanism / Formula			

Software for the building energy labelling Standard methodologies for BER assessment				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 27: Main KPI 5 definition

Main KPI 6. Renewable energy production			
Unit	kWh/year	**Pillar**	Energy
KPI definition responsible	CARTIF	**KPI calculation responsible**	Living Labs
Associated Expected Impact		Impact 4. High energy performance	
Detailed description			
This indicator measures the energy production from renewable sources. It is important to differentiate between type of energy production (electricity, heating, total) and type of technology (PV, solar, biomass, etc.). Renewable energy include both combustible (biomass and organic products) and non-combustible resources (solar, wind, etc.).			
Baseline data needed	Yes	**Calculation frequency**	Monthly/Yearly
Variables needed / Data requirements			
The variables needed for the calculation of the Renewable energy production are the following: · Renewable production in at least monthly basis for a complete year by type of Renewable Energy System (RES). There are different ways to obtain the data from the Living Labs: • On-site measurements - monitoring systems. • Energy simulations (software).			
Assessment mechanism / Formula			
Total Renewable Energy Production [kWh] = $\sum RES_{ei} + \sum RES_{thi}$			
- RES_{ei} [kWh] = Renewable electricity production produced by the different RES systems (PV, wind, etc.) - RES_{thi} [kWh] = Renewable thermal production produced by the different RES systems (Solar thermal, biomass, etc.)			
Life cycle stages			

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 28: Main KPI 6 definition

Main KPI 7. Self-consumption ratio			
Unit	%	Pillar	Energy
KPI definition responsible	CARTIF	KPI calculation responsible	Living Labs
Associated Expected Impact		Impact 4. High energy performance	
Detailed description			
This KPI quantifies the percentage of the total energy consumed covered by own generation through RES systems. The self-consumption ratio is the ratio between the renewable energy productions locally produced (on-site) and the total consumption of the building. The ratio can be between 0% and 100%, with 100% meaning that the complete energy consumption of the building is covered with Renewable systems. This KPI can be quantified totally but also individually for electricity and thermal purposes.			
Baseline data needed	Yes	Calculation frequency	Monthly/Yearly
Variables needed / Data requirements			
The variables needed for the calculation of the Self-consumption ratio are the following: · Renewable production in at least monthly basis for a complete year by type of RES [kWh] – Main KPI6 · Energy consumption [kWh] in at least monthly basis for a complete year. Electricity, natural gas, etc. – Main KPI8 There are different ways to obtain the data from the Living Labs: • On-site measurements - monitoring systems. • Energy simulations (software). • Energy bills.			
Assessment mechanism / Formula			
Self-consumption ratio $_{total}$ [%] = ∑Energy produced by RES $_{total}$ [kWh] / ∑ Energy consumption $_{total}$ [kWh] x 100			
- Energy produced by RES $_{total}$ [kWh] = Energy produced by all the RES systems locally - Energy consumption $_{total}$ [kWh] = Total energy consumption of the building			
Self-consumption ratio $_{electricity}$ [%] = ∑Energy produced by RES $_{electricity}$ [kWh] /			

∑ Energy consumption $_{electricity}$ [kWh] x 100				
- Energy produced by RES $_{electricity}$ [kWh] = Electricity produced by all the RES systems locally (PV, wind, etc.) - Energy consumption $_{electricity}$ [kWh] = Total electricity consumption of the building				
Self-consumption ratio $_{thermal}$ [%] = ∑Energy produced by RES $_{thermal}$ [kWh] / ∑ Energy consumption $_{thermal}$ [kWh] x 100				
- Energy produced by RES $_{thermal}$ [kWh] = Thermal energy produced by all the RES systems locally (solar thermal, biomass, etc.) - Energy consumption $_{thermal}$ [kWh] = Total thermal energy consumption of the building				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 29: Main KPI 7 definition

Main KPI 8. Final energy consumption			
Unit	kWh/year	**Pillar**	Energy
KPI definition responsible	CARTIF	**KPI calculation responsible**	Living Labs
Associated Expected Impact		Impact 4. High energy performance	
Detailed description			
The energy consumption is the energy necessary from the different energy sources (electricity, natural gas, biomass, etc.,) to meet the energy needs of the building (heating, cooling, DHW, lighting, etc.). The different energy sources could be in different units (kWh, m^3, kg, etc.) but all have to be converted through the conversion factors to kWh. The final energy is the energy actually consumed by the end-user. Final energy could be reduced by the installation of high performance energy systems and the introduction of renewable energy systems. Energy consumption is measured normally in kWh/m^2/year.			
Baseline data needed	Yes	**Calculation frequency**	Monthly/Yearly
Variables needed / Data requirements			
The variables needed for the calculation of the Final energy consumption are the following: · Energy consumption (kWh) in at least monthly basis for a complete year by type of energy source (Electricity, natural gas, etc.). There are different ways to obtain the data from the Living Labs:			

• On-site measurements - monitoring systems. • Energy bills. • Energy simulations (software).				
Assessment mechanism / Formula				
Final Energy consumption total [kWh] = $\sum FE_i$				
- FE_i: Final energy consumption from the different energy carriers (electricity, natural gas, biomass, etc.) [kWh].				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 30: Main KPI 8 definition

Main KPI 9. CO_2 emissions operational stage			
Unit	$kgCO_2eq$/year	**Pillar**	Environmental
KPI definition responsible	CARTIF	**KPI calculation responsible**	Living Labs
Associated Expected Impact		Impact 5. Reduction of GHG emissions for the total life-cycle	
Detailed description			
This indicator represents the CO_2 emissions of a building caused by the different areas of application (heating, cooling, electrical appliances, etc.). This KPI encompasses the CO_2 emissions caused by the energy supply (thermal and electrical) for operating the building. CO_2 emissions are calculated from the final energy consumption of both fuel and electricity and the corresponding conversion emission factors of each country. This KPI covers the Life Cycle stage B6 (Operational energy use).			
Baseline data needed	Yes	**Calculation frequency**	Monthly/Yearly
Variables needed / Data requirements			
The variables needed for the calculation of the CO_2 emissions at operational stage are the following: · Energy consumption (kWh) in at least monthly basis for a complete year by type of energy source (Electricity, natural gas, etc.) – Main KPI8 · Renewable production (kWh) in at least monthly basis for a complete year by type of RES – Main KPI6 · Energy exported (kWh) to the grid or other locations in at least a monthly basis for a complete year. · EF (Emission Factors) by type energy source [$kgCO_2$/kWh].			

There are different ways to obtain the data from the Living Labs: • On-site measurements - monitoring systems. • Energy bills. • Energy simulations (software).
Assessment mechanism / Formula
CO_2 emissions [$kgCO_2$] = $\sum FE_i * EF_i - \sum E_{EXP} * EF_{EXP}$ International Performance Measurement and Verification Protocol (IPMVP)
- FE_i: Final energy consumption from the different energy carriers [kWh_{fe}]. - EF_i: Emission Factor of the different energy carriers [$kgCO_2/kWh$]. - E_{EXP}: Energy exported [kWh_{EXP}] - EF_{EXP}: Emission Factor of the energy exported [$kgCO_2/kWh_{EXP}$]. In the case of PROBONO the CO_2 emission savings in the operational stage of the building will be calculated in accurate way by applying the principles of the IPMVP (International Performance and Measurement and Verification Protocol). Information about this protocol and their applicability in PROBONO can be found in Section 4.2.
Life cycle stages

Product stage (A1-A3)	Construction stage (A4-A5)	**Use (B1-B7)**	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 31: Main KPI 9 definition

Main KPI 10. GHG emissions along the life cycle (LCA)			
Unit	$kgCO_2eq$	**Pillar**	Environmental
KPI definition responsible	ACC-R&D	**KPI calculation responsible**	Living Labs
Associated Expected Impact		Impact 5. Reduction of GHG emissions for the total life-cycle Impact 7. Reduction of air pollutants for the total life-cycle	
Detailed description			
This indicator aims to quantify the GHG emissions of a building material/product at different stages along the life cycle (not including the operational part of the building). It therefore measures the building's contribution to emissions that contribute towards the earth's global warming, and the associated effects on climate change. This is sometimes referred to as a carbon footprint assessment or whole life carbon measurement. The indicator is measured according to the Global Warming Potential (GWP) of the greenhouse gases emitted. The unit of measurement is kg CO_2 equivalents per m^2 useful internal floor area for a			

reference study period of 50 years. Within the LCA assessment there are several impact categories (Climate change, Stratospheric ozone depletion, Human toxicity, Particulate matter formation, Ionising radiation, Photochemical ozone formation, Acidification, Eutrophication, Eco-toxicity, Land use, Water use and Resource use) and for the specific Impact 7 "Reduction of air pollutants for the total life-cycle" the one that is more related is the Particulate Matter Formation. Therefore LCA assessment will be also used as part of the validation of Impact 7 to cover the Life cycle perspective.			
Baseline data needed	Yes	**Calculation frequency**	Once, during the whole life cycle
Variables needed / Data requirements			
The variables needed for the calculation of the Life Cycle Analysis are the following: - Building description (location, climate zone, type of use...). - Bill of materials. - Environmental Product Declarations (EPDs).			
Assessment mechanism / Formula			
LCA (Life Cycle Analysis assessment)			
LCA - software tools and databases LCA calculations can include a comparison between alternatives. LCA methodology can be seen in Section 4.2.			
Life cycle stages			

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 32: Main KPI 10 definition

Main KPI 11. Embodied energy			
Unit	· Mega-joules (MJ) or Gigajoules (GJ) per unit weight (kg or tonne) or area (m^2) · %	**Pillar**	Environmental
KPI definition responsible	ACC-R&D	**KPI calculation responsible**	Living Labs
Associated Expected Impact		Impact 6. Reduction of the embodied energy in buildings	
Detailed description			

The second major component of the energy consumed by the building is the embodied energy (after the use stage consumption). The embodied energy is the total of non-renewable energy required for the extraction, processing, manufacturing, and delivery of a certain building or material. The need to understand and consider the embodied energy becomes more important as measures to reduce operational energy are taken. For so-called net-zero buildings, most of the impacts will be embodied, as systems are designed to cover net operational needs with on-site power generation. An LCA that includes the materials manufacturing and construction phase of the projects is the primary means of computing the embodied energy in a building. This indicator focusses on the non-renewable fraction of energy consumption (derived from fossil fuels), since it is the one that produces CO_2, contributing to greenhouse gas emissions. Thus, embodied energy is considered an indicator of the overall environmental impact of building materials and systems. The calculation of embodied energy is often performed within a lifecycle assessment (LCA) framework (ISO 14040:2006). Embodied energy in the context of LCA could represent energy consumption, greenhouse gas emissions and depletion of non-renewable fossil fuel sources.

Baseline data needed	Yes	**Calculation frequency**	Only once during the Life Cycle A stage

Variables needed / Data requirements
The variables needed for the calculation of the Embodied energy are the following: - Information about local context (e.g., energy matrix). - Bill of materials (inventory lists). - Environmental Product Declarations (EPDs).
Assessment mechanism / Formula
Embodied energy = ∑ all energy embedded in products and processes used in constructing a building - ∑ renewable energy embedded in products and processes used in constructing a building / per kg or m^2 LCA (Life Cycle Analysis assessment)
LCA - software tools and databases
Life cycle stages

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 33: Main KPI 11 definition

Main KPI 12. Air pollutants operational stage			
Unit	kg/year	**Pillar**	Environmental

KPI definition responsible	CARTIF/ACC R&D	KPI calculation responsible	Living Labs
Associated Expected Impact		Impact 7. Reduction of air pollutants for the total life-cycle	

Detailed description

This KPI measures the Air pollutants emitted to the environment from the operational stage of the buildings.

The energy use indicator can provide useful insights on the building's total emissions of air pollutants to the ambient air. Whereas an overall reduction in primary energy consumption will generally have a positive effect on air quality, a fuel switch may also lead to an increase or reduction of emissions of specific ambient air pollutants.

Reduction of air pollutants (NOx, PM, etc.) from buildings during the Use stage (B6) can be achieved thanks to:

- The improvement of the energy efficiency, the increase of RES and the reduction of conventional fuels utilization.

- Increase the use of Electro Vehicles.

NOx emissions can be derived from energy use. The level of NOx emissions varies depending mainly on the energy generation technology and type of fuel. It would be convenient to use an average ratio for the specific combustion process and fuel.

PM emissions can be calculated from the final energy consumption by using conversion ratios. WELL standards set limits of 15 μg/m^3 and 50 μg/m^3 for PM2.5 and PM10 respectively.

The air pollutants during the operational stage of the building can be calculated from the final energy consumption of the different fuels and the corresponding pollutants-to-final energy conversion factors.

Baseline data needed	Yes	Calculation frequency	Monthly/Yearly

Variables needed / Data requirements

The variables needed for the calculation of the air pollutants in the operational stage are the following:

· Fuel consumption [kWh_{fueli}] in at least monthly basis for a complete year by type of energy source (gasoil, natural gas, biomass, etc.).

· Pollutants-to-final energy conversion factors (PCF) [$kg_{pollutanti}/kWh_{fueli}$]

There are different ways to obtain the data from the Living Labs:

- On-site measurements - monitoring systems.
- Energy bills.
- Energy simulations (software).

Assessment mechanism / Formula

$$\text{Air pollutants}_{total}\ [kg] = \sum FE_i * PCF_i$$

- FE_i: Final energy consumption from the different fuel carriers [kWh].
- PCF_i: Pollutant conversion factor for fuels [kg/kWh].

This should be calculated per pollutant (NOx, PM, etc.) emitted per each of the fuels.				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 34: Main KPI 12 definition

Main KPI 13. Replicability			
Unit	nº	**Pillar**	Other
KPI definition responsible	PNO	**KPI calculation responsible**	Living Labs
Associated Expected Impact		Impact 8. Potential for replicability	
Detailed description			
This KPI measures the number of EU Cities & Municipalities acting as followers or pledging to replicate the GBN innovations by the end of the project. New GBNs Innovation Clusters: included in implementation/replicability local plans. Local Innovation Clusters and Followers: Replicating lessons learnt from the LLs. Receiving LL results and knowledge as well as technology and know-how linked to developed and implemented interventions.			
Baseline data needed	No	**Calculation frequency**	Once at the end of the project
Variables needed / Data requirements			
Number of EU Cities & Municipalities with potential of replicating the PROBONO innovations.			
Assessment mechanism / Formula			
Replicability actions designed in WP9			

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 35: Main KPI 13 definition

<table>
<tr><th colspan="4">Main KPI 14. Shortened construction/retrofitting time</th></tr>
<tr><td>Unit</td><td>%</td><td>Pillar</td><td>Other</td></tr>
<tr><td>KPI definition responsible</td><td>VLNT</td><td>KPI calculation responsible</td><td>Living Labs</td></tr>
<tr><td colspan="2">Associated Expected Impact</td><td colspan="2">Impact 9. Shortened construction/retrofitting time and cost</td></tr>
<tr><td colspan="4">Detailed description</td></tr>
<tr><td colspan="4">This KPI quantifies the reduction in terms of time incurred in association to modular construction/retrofit by manufacturing, transportation, stock-keeping, and warehouse establishment while considering the influence of various site demand variation factors.

By utilizing modular construction and optimization, the construction (or retrofit) is managed as a supply chain, and requires materials and equipment’s flow and queuing aspects to be considered in the planning phase, and implemented during the construction phase. The adoption of supply chain optimization techniques, typically remove slack and inefficiencies from the supply chain, however some slack might be useful for addressing unexpected delays due to weather or other externalities. Therefore, the construction planning optimization should account for delays in a stochastic manner.

This KPI can be sub-divided in the following:
- Resilience of construction plan [days (ahead of schedule)]
- Resilience of construction plan [days (average days ahead of schedule so far)]</td></tr>
<tr><td>Baseline data needed</td><td>Yes</td><td>Calculation frequency</td><td>Once during the construction stage</td></tr>
<tr><td colspan="4">Variables needed / Data requirements</td></tr>
<tr><td colspan="4">The variables needed for the calculation of the Shortened construction/retrofitting time are the following:
- Construction progress with related to plan (days ahead) (Captured daily or against specific milestones during construction phase).
- Construction/ retrofit phase duration (days).
- In-situ construction/retrofit duration for similar project (days). Baseline.</td></tr>
<tr><td colspan="4">Assessment mechanism / Formula</td></tr>
<tr><td colspan="4">Shortened time [%] = Construction or retrofit duration in PROBONO [days] / Construction or retrofit duration for similar projects [days]</td></tr>
<tr><td colspan="4">Life cycle stages</td></tr>
</table>

Product stage (A1-A3)	**Construction stage (A4-A5)**	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 36: Main KPI 14 definition

<table>
<tr><th colspan="4">Main KPI 15. Shortened construction/retrofitting cost</th></tr>
<tr><td>Unit</td><td>%</td><td>Pillar</td><td>Economic</td></tr>
<tr><td>KPI definition responsible</td><td>VLTN</td><td>KPI calculation responsible</td><td>Living Labs</td></tr>
<tr><td colspan="2">Associated Expected Impact</td><td colspan="2">Impact 9. Shortened construction/retrofitting time and cost</td></tr>
<tr><td colspan="4">Detailed description</td></tr>
<tr><td colspan="4">The indicator captures the costs incurred in association to modular construction/ retrofit by manufacturing, transportation, stock-keeping, and warehouse establishment while considering the influence of various site demand variation factors.

By utilizing modular construction and optimization, the construction (or retrofit) is managed as a supply chain, and requires materials and equipment's flow and queuing aspects to be considered in the planning phase, and implemented during the construction phase. The adoption of supply chain optimization techniques, typically remove slack and inefficiencies from the supply chain, however some slack might be useful for addressing unexpected delays due to weather or other externalities. Therefore, the construction planning optimization should account for delays in a stochastic manner.

This KPI can be sub-divided in the following:

· Shortened construction/retrofitting cost – manufacturing [%]

· Shortened construction/retrofitting cost – transportation [%]

· Shortened construction/retrofitting cost – stock keeping [%]

· Shortened construction/retrofitting cost –space costs/warehouse establishment [%]</td></tr>
<tr><td>Baseline data needed</td><td>Yes</td><td>Calculation frequency</td><td>Once during the construction stage</td></tr>
<tr><td colspan="4">Variables needed / Data requirements</td></tr>
<tr><td colspan="4">The variables needed for the calculation of the Shortened construction/retrofitting cost are the following:
- Operational costs in construction/ retrofit phase (€).
- Construction total cost if in-situ for similar project (€). Baseline.</td></tr>
<tr><td colspan="4">Assessment mechanism / Formula</td></tr>
<tr><td colspan="4">Shortened cost [%] = Construction or retrofit cost in PROBONO [€] / Construction or retrofit duration for similar projects [€]</td></tr>
<tr><td colspan="4">Life cycle stages</td></tr>
</table>

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 37: Main KPI 15 definition

<table>
<tr><th colspan="5">Main KPI 16. Thermal comfort – Occupant perception</th></tr>
<tr><td>Unit</td><td>% - Likert</td><td>Pillar</td><td colspan="2">Social</td></tr>
<tr><td>KPI definition responsible</td><td>SIN/CARTIF</td><td>KPI calculation responsible</td><td colspan="2">Living Labs</td></tr>
<tr><td colspan="2">Associated Expected Impact</td><td colspan="3">Impact 10. Improved indoor environmental quality (IAQ)</td></tr>
<tr><th colspan="5">Detailed description</th></tr>
<tr><td colspan="5">This KPI measures the perception of the occupants (owners, occupiers, tenant and employees) in LLs buildings feeling that the thermal comfort conditions have improved because of the project innovations.
Thermal comfort is defined as subjective satisfaction with the thermal environment (ISO 7730).
For thermal comfort the reference temperature could be in the range of 18ºC to 27ºC.</td></tr>
<tr><td>Baseline data needed</td><td>Yes</td><td>Calculation frequency</td><td colspan="2">Once before and after the renovation</td></tr>
<tr><th colspan="5">Variables needed / Data requirements</th></tr>
<tr><td colspan="5">In the case of PROBONO, thermal comfort will be measured in a qualitative way. The evaluation will be done through surveys/interviews collecting the perception of the occupants in the following aspects based on a Liker scale:
- Perception of the indoor temperature by occupants.
- Perception of the air speed by occupants.
- Perception of the humidity by occupants.</td></tr>
<tr><th colspan="5">Assessment mechanism / Formula</th></tr>
<tr><td colspan="5">Thermal comfort satisfaction [%] = Average Likert by occupants / Total Likert scale
s-LCA (Social Life Cycle assessment)</td></tr>
<tr><td colspan="5">- Surveys (Likert scale to different aspects).
- Interviews before and after the implementation of the project.
- Social monitoring tools.
- s-LCA methodology can be seen in Section 4.2.</td></tr>
<tr><th colspan="5">Life cycle stages</th></tr>
<tr><td>Product stage
(A1-A3)</td><td>Construction stage
(A4-A5)</td><td>Use
(B1-B7)</td><td>End of Life
(C1-C4)</td><td>Beyond the Building Life Cycle
(D)</td></tr>
</table>

Table 38: Main KPI 16 definition

Main KPI 17. Indoor air quality (IAQ) – Occupant perception				
Unit	% - Likert	Pillar	Social	
KPI definition responsible	SIN/CARTIF	KPI calculation responsible	Living Labs	
Associated Expected Impact		Impact 10. Improved indoor environmental quality (IAQ)		
Detailed description				
This KPI measures the perception of the occupants (owners, occupiers, tenant and employees) in LLs buildings feeling that the Indoor Air Quality (IAQ) conditions have improved because of the project innovations. IAQ depends on a variety of sources such as occupants, finishing materials, cleaning products, installed equipment, and activities carried out in the spaces. The presence of people guarantees the presence of CO_2 from breathing. CO_2 is a proxy for air quality and gives a good indication of the ventilation rate.				
Baseline data needed	Yes	Calculation frequency	Once before and after the renovation	
Variables needed / Data requirements				
In the case of PROBONO, Indoor Air Quality will be measured in a qualitative way. The evaluation will be done through surveys/interviews collecting the perception of the occupants in the following aspects based on a Likert scale: - Perception of the air quality by occupants. - Perception of the ventilation quality by occupants.				
Assessment mechanism / Formula				
IAQ [%] = Average Likert by occupants / Total Likert scale s-LCA (Social Life Cycle assessment)				
- Surveys (Likert scale to different aspects). - Interviews before and after the implementation of the project. - Social monitoring tools. - s-LCA methodology can be seen in Section 4.2.				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	**Use (B1-B7)**	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 39: Main KPI17 definition

Main KPI 18. IEQ – Acoustic comfort – Occupant perception				
Unit	% - Likert		Pillar	Social
KPI definition responsible	SIN/CARTIF		KPI calculation responsible	Living Labs
Associated Expected Impact			Impact 10. Improved indoor environmental quality (IAQ)	
Detailed description				
This KPI measures the perception of the occupants (owners, occupiers, tenant and employees) in LLs buildings feeling that the Acoustic comfort conditions have improved because of the project innovations. The objective is to provide an assessment of the acoustic comfort of a building before and after renovation. In the context of seeking to measure the acoustic performance of a building, the selected design solutions need to protect its users from both the acoustic climate outside and from unwanted noise generated inside the building, or coming from neighbouring buildings.				
Baseline data needed	Yes		Calculation frequency	Once before and after the renovation
Variables needed / Data requirements				
In the case of PROBONO, acoustic comfort will be measured in a qualitative way. The evaluation will be done through surveys/interviews collecting the perception of the occupants in the following aspects based on a Likert scale: - Perception of indoor noise by occupants. - Perception of outdoor noise by occupants.				
Assessment mechanism / Formula				
Acoustic comfort satisfaction [%] = Average Likert by occupants / Total Likert scale s-LCA (Social Life Cycle assessment)				
- Surveys (Likert scale to different aspects). - Interviews before and after the implementation of the project. - Social monitoring tools. - s-LCA methodology can be seen in Section 4.2.				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 40: Main KPI 18 definition

Main KPI 19. EQ – Dust quality – Occupant perception			
Unit	% - Likert	Pillar	Social
KPI definition responsible	SIN/CARTIF	KPI calculation responsible	Living Labs
Associated Expected Impact		Impact 10. Improved indoor environmental quality (IAQ)	
Detailed description			
This KPI measures the perception of the occupants (owners, occupiers, tenant and employees) in LLs buildings feeling that the dust quality conditions have improved because of the project innovations.			
Baseline data needed	Yes	Calculation frequency	Once before and after the renovation
Variables needed / Data requirements			
In the case of PROBONO, dust quality will be measured in a qualitative way. The evaluation will be done through surveys/interviews collecting the perception of the occupants in the following aspects by a Likert scale: - Perception of dust levels by occupants or people involved during the construction process. - Perception of allergens levels by occupants or people involved during the construction process.			
Assessment mechanism / Formula			
Dust quality [%] = Average Likert by occupants / Total Likert scale s-LCA (Social Life Cycle assessment)			
- Surveys (Likert scale to different aspects). - Interviews before and after the implementation of the project. - Social monitoring tools. - s-LCA methodology can be seen in Section 4.2.			
Life cycle stages			

Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 41: Main KPI 19 definition

Main KPI 20. IEQ – Visual comfort – Occupant perception			
Unit	% - Likert	Pillar	Social
KPI definition	SIN/CARTIF	KPI calculation	Living Labs

responsible		responsible	
Associated Expected Impact		Impact 10. Improved indoor environmental quality (IAQ)	
Detailed description			
This KPI measures the perception of the occupants (owners, occupiers, tenant and employees) in LLs buildings feeling that the visual comfort conditions have improved because of the project innovations. The objective is to provide an assessment of the visual comfort of a building before and after renovation. Subjective condition of visual well-being induced by Illuminance and daylight factors (EN12665).			
Baseline data needed	Yes	Calculation frequency	Once before and after the renovation
Variables needed / Data requirements			
In the case of PROBONO, visual comfort will be measured in a qualitative way. The evaluation will be done through surveys/interviews collecting the perception of the occupants in the following aspects by a Likert scale: - Lighting levels perception by occupants. - Artificial lighting by occupants. - Natural lighting by occupants.			
Assessment mechanism / Formula			
Visual comfort [%] = Average Likert by occupants / Total Likert scale s-LCA (Social Life Cycle assessment)			
- Surveys (Likert scale to different aspects). - Interviews before and after the implementation of the project. - Social monitoring tools. - s-LCA methodology can be seen in Section 4.2.			

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	**Use (B1-B7)**	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 42: Main KPI 20 definition

4.2 Impact assessment support Methodologies/Tools

In this specific subsection, the idea is to identify and define the supporting methodologies and tools (M&V plans based on IPMVP and Life Cycle plans) that will be used in PROBONO for the specific assessment of some Impacts and their associated Main KPIs in which in their definition applies a life cycle perspective from environmental, economic or social point of view, or need an accurate energy savings assessment based on the applicability of the IPMVP protocol.

- Section 4.2.1 M&V plans based on IPMVP protocol.
- Section 4.2.2 Life cycle methods covering Environmental (LCA), Economic (LCC) and Social (s-LCA) aspects.

4.2.1 M&V plans - IPMVP

4.2.1.1 Scope and objectives

The objective is to define the Measurement and Verification (M&V) plan to evaluate the energy savings achieved in the Living Labs after the implementation of the technical innovations based on the IPMVP (International Performance Measurement and Verification Protocol)[1].

IPMVP is a protocol developed by the Efficiency Valuation Organization (EVO). It is the most widely used and recognised M&V protocol worldwide and has been developed based on ESCo (Energy Service Company) contracts and it defines a common sense approach to Measurement and Verification (M&V). This protocol is perfectly able to help improve the credibility and attractiveness of energy efficiency retrofitting projects.

The International Performance Measurement and Verification Protocol (IPMVP) is a guidance document describing common practice in measuring, computing and reporting savings achieved by energy efficiency projects. The IPMVP presents a framework and four M&V options for transparently, reliably and consistently reporting a project's savings. When adhering to IPMVP's recommendations, these M&V activities can produce verifiable savings reports.

A Measurement and Verification plan of energy savings during the operation phase of the buildings is carried out consisting in selecting the IPMVP option most suitable for each Living Lab, definition of the baseline and reporting periods and conditions, energy savings calculation methodologies, among others.

The aim of this plan is the definition of the energy assessment plan that will be followed for each of the Living Labs at the time of reporting the energy savings.

This Measurement and Verification plan establishes the basis for the Measurement and Verification energy savings reports developed in D6.6 and D6.7 for each LL.

4.2.1.2 Assessment plan

Measurement and Verification (M&V) is the process of planning, measuring, collecting and analysing data to verify and report energy savings resulting from the implementation of an energy conservation measure.

Energy savings are, by definition, the absence of energy use and subsequently cannot be measured. However, we do measure energy use. M&V therefore represents the process of analysing measured energy use before and after a retrofit to determine savings. To make a consistent comparison, appropriate adjustments for change in conditions shall be made according to the IPMVP methodology.

[1] https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

The comparison of before and after energy use is made on a consistent basis, using the following general equation:

Savings = (Baseline Period energy use – Reporting Period energy use) +/- Adjustments

The "Adjustments" term in this general equation is used to re-state the energy use of the baseline and reporting periods under a common set of conditions.

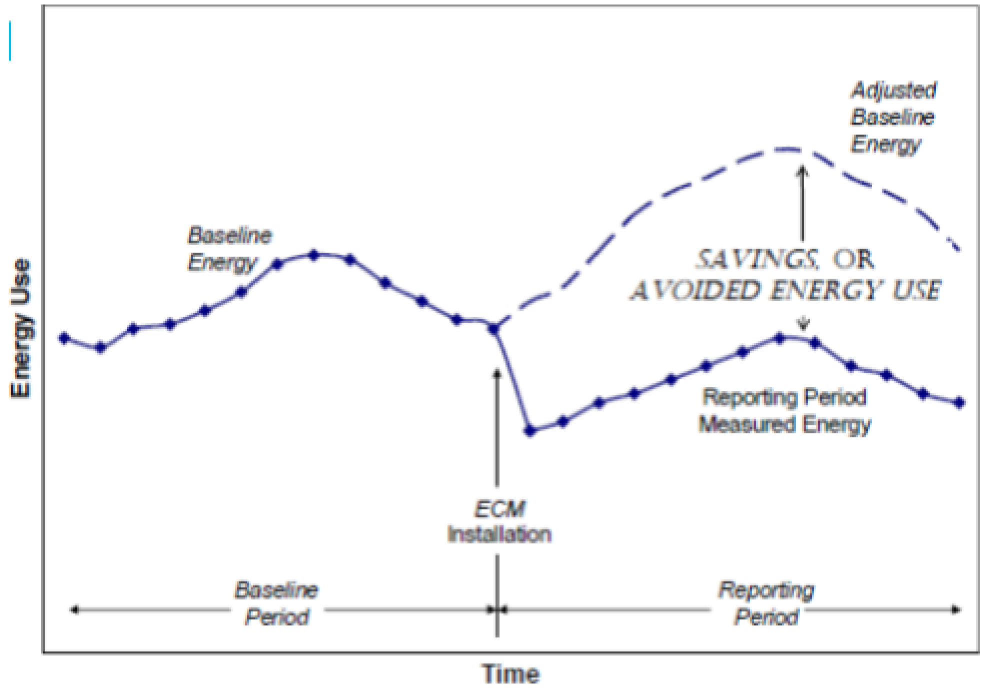

Figure 3: IPMVP monitoring periods (source: IPMVP Framework)

The baseline in an existing facility project is usually the performance of the facility or system prior to modification. This baseline physically exists and can be measured before changes are implemented. In new construction, the baseline is usually hypothetical and defined based on code, regulation, common practice or documented performance of similar facilities. In either case, the baseline model must be capable of accommodating changes in operating parameters and conditions so "adjustments" can be made.

IPMVP provides four Options for determining savings (A, B, C and D). The choice among the options involves many considerations including the location of the measurement boundary.

Option A	**Retrofit Isolation: Key Performance Measurement** **Savings determination:** - Savings are determined by measuring the performance parameters that will have the higher influence on the savings calculation. - Savings are calculated by combining measured values with estimates. **Measurement:** - Measurement frequency ranges from short-term to continuous depending on

	- the expected variations in the measured parameter and the length of the reporting period. - Measurements of the same parameter must occur in the baseline and reporting periods. **Considerations:** - Any remaining parameters are estimated, using historical data, manufacturer's specifications or engineering judgment.
Option B	**Retrofit Isolation: All Parameter Measurement** **Savings determination:** - Savings are determined by measuring energy use and all variables affecting energy use within the measurement boundary. **Measurement:** - Measurement frequency ranges from short-term to continuous depending on the expected variations in the savings and the length of the reporting period. **Considerations:** - Option B provides greater certainty of savings versus Option A.
Option C	**Whole Facility: Continuous measurements of entire facility's energy use** **Savings determination:** - Savings are determined by measuring energy use at the whole facility or sub-facility level. - Actual cost savings can also be determined. - Option C is for ECMs where expected savings are high compared to site energy use, and where measurement periods are long. **Measurement:** - Continuous measurements of the entire facility's energy use are taken throughout the reporting period. - This option typically makes use of existing utility meters and/or energy invoices and the combined effect of all ECMs is determined. - An energy model using techniques such as regression is developed spanning the baseline period, which is adjusted for the post-retrofit period. **Considerations:** - The primary challenges of Option C are to identify and incorporate all routine and non-routine adjustments, as well as ensuring that all the savings are

	large enough (10% or more) when compared to the site's energy use.
Option D	**Calibrate Simulation: savings are determined through simulations** **Savings determination:** - Savings are determined through simulation of the energy use at the whole facility or sub-facility level. **Measurement:** - Simulations routines are demonstrated to accurately model actual energy performance measured at the facility. - Computer simulation software is used to predict energy use once detailed information is entered. - ECMs can be evaluated as a group, or individually, where multiple simulations are run. - The simulations need to be calibrated against actual energy use. **Considerations:** - Option D is useful where baseline data does not exist or is unavailable. - The primary challenges are to develop an accurate simulation and to calibrate it against measured energy data. - Specific software modelling skills and careful documentation is required.

Table 43: IPMVP options (source: IPMVP Framework)

The selection of an IMPVP Option is a decision that is made by the designer of the M&V program for each project, based on the full set of project conditions, analysis, budgets and professional judgment.

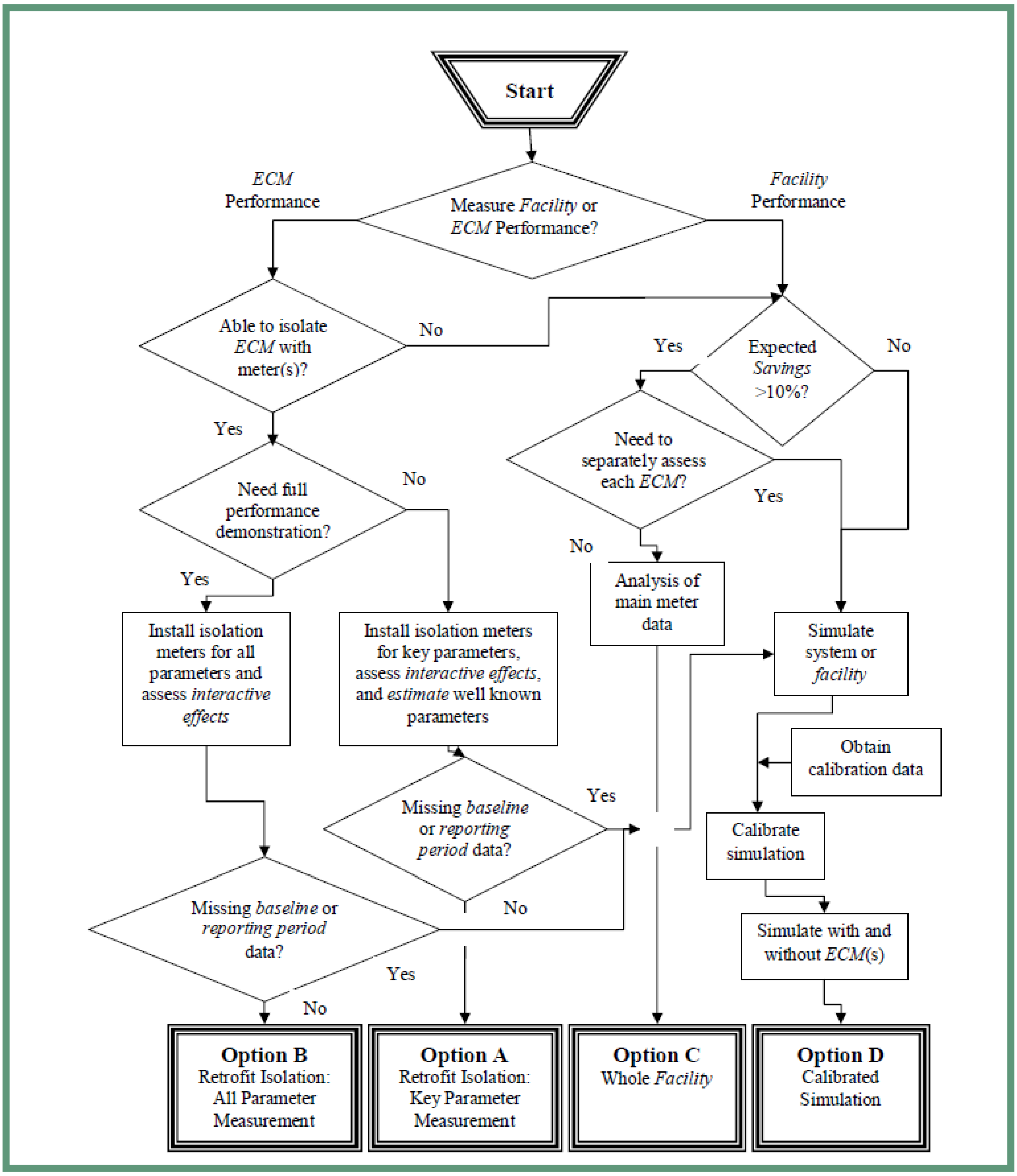

Figure 4: Option selection process (source: IPMVP Framework)

M&V is not just a collection of tasks conducted to help a project meet IPMVP requirements. Properly integrated, each M&V task serves to enhance and improve facility operation and maintenance savings.

A complete M&V Plan should include discussion of the following 13 topics:

Nº	Topic	Description
1	ECM Intent	Describe the ECM (Energy Conservation Measure), its intended result, and the operational verification procedures that will be used to verify successful implementation of each ECM.

Nº	Topic	Description
		A range of operational verification methods can be applied, selection of a given approach depends on the ECM's characteristics. - Visual inspection: ECM will perform as anticipated when properly installed; direct measurement of ECM performance is not possible. - Sample spot measurements: Achieved ECM performance can vary from published data. - Short-term performance testing: ECM performance may vary depending on actual load, controls, and/or interoperability of components. - Data trending and control logic review: ECM performance may vary depending on actual load and controls. The system can be monitored through independent meters.
2	**Selected IPMVP Option and Measurement Boundary**	Specify which IPMVP Option, is used to determine savings (A, B, C or D). This identification should include the date of publication or the version number and volume number of the IPMVP edition followed. - Option A Retrofit Isolation: Key parameter measurement. - Option B Retrofit Isolation: All parameter measurement. - Option C Whole facility. Measurement energy use at the whole facility or sub-facility level. - Option D Calibrated Simulation with energy modelling software. Savings are determined through simulation of the energy use. Identify the measurement boundary of the savings determination (Entire facility or simply a portion of it). Any energy effect that occurs beyond the notional measurement boundary is named interactive effect. Describe the nature of any interactive effect beyond the measurement boundary together with their possible effects. Find a way to estimate the interactive effects or justify why they are ignored.
3	**Baseline period**	Document the facility's baseline conditions and energy data within the measurement boundary. The baseline period should be established to represent a full operating cycle. Whole-building energy use can be significantly affected by weather conditions. Typically a whole year of baseline data is needed to define a full operating cycle. The baseline documentation should include: - Identification of the baseline period. - Baseline energy consumption. - Independent variable data coinciding with the energy data. Parameters which are expected to change regularly and have a measurable impact on the energy used of a system or facility. - Static factors coinciding with the energy data.
4	**Reporting period**	The reporting period should encompass at least one normal operating cycle of the equipment or facility in order to fully characterize the savings effectiveness in all normal operating modes. The length of any reporting period should be determined with due

Nº	Topic	Description
		consideration of the life of the ECM and the likelihood of degradation of originally achieved savings over time.
5	Basis for Adjustment	Declare the set of conditions to which all energy measurements will be adjusted. The conditions may be those of the reporting period (avoided energy) or some other set of fixed conditions (normalized savings). When reported savings are under reporting period conditions, baseline-period energy needs to be adjusted to reporting-period conditions. Two types of adjustments are possible: - Routine adjustments: for any energy factor expected to change routinely during the reporting period. A variety of techniques can be used to define the adjustment methodology. Valid mathematical techniques must be used to derive the adjustment method for each M&V Plan. - Non-Routine adjustments: for those energy factors which are not usually expected to change. These static factors must be monitored for change throughout the reporting period.
6	Analysis Procedure	Specify the exact data analysis procedures, algorithms and assumptions to be used in each savings report. For each mathematical model used, report all of its terms and the range of independent variables over which it is valid.
7	Energy Prices	Specify the energy prices that will be used to value the economic savings.
8	Meter Specifications	Specify metering points and period if metering is not continuous. Energy quantities can be measured by one or more of the following techniques: - Utility or fuel supplier invoices, or reading utility meters. - Special meters isolating an ECM or portion of a facility. Measurements may be periodic for short intervals, or continuous throughout the baseline or reporting periods. - Measurement of proven proxies for energy use. - Computer simulation that is calibrated to some actual performance data for the system or facility being modelled.
9	Monitoring Responsibilities	Assign responsibilities for reporting and recording the energy data, independent variables and static factors within the measurement boundary during the reporting period.
10	Expected Accuracy	Evaluate the expected accuracy associated with the measurement, data capture, sampling and data analysis. Some are the characteristics within a M&V process which should be carefully reviewed to manage accuracy or uncertainties. - <u>Instrumentation</u>: measurement equipment errors are due to calibration, inexact measurement or improper meter selection installation or operation. It is determined by the manufacturer's specifications according to the installation guidelines. - <u>Data gathering</u>: data gaps and inconsistencies.

Nº	Topic	Description
		- <u>Modelling</u>: the inability to find mathematical form that fully account for all variations in the real energy use. Modelling errors can be owing to inappropriate functional form, inclusion of irrelevant variables, or exclusion of relevant variables. - <u>Sampling</u>: use of a sample of the full population of items or events to represent the entire population introduces error as a result of the variation in values within the population, or biased sampling. - <u>Interactive effects</u> (beyond the measurement boundary) which are not fully included in the M&V methodology.
11	**Budget**	Define the budget and resources required for the savings determination, both initial setup costs and ongoing costs throughout the reporting period.
12	**Report Format**	Specify how results will be reported and documented. A sample of each report should be included. Complete M&V reports should include at least: - Observed data of the reporting period (measurement period, energy data, and independent variables). - Description and justification for any corrections made to observed data. - Energy price. - Any baseline non-routine adjustment performed. - Computed savings in energy and monetary units.
13	**Quality Assurance**	Specify quality-assurance procedures that will be used for savings reports and any interim steps in preparing the reports.

Table 44: M&V Plan contents

Depending upon the circumstances of each project, some additional specific topics should also be discussed in a complete M&V Plan.

For Option A:

Justification of estimates	Report the values to be used for all estimated values.
Periodic Inspections	Define the periodic inspections that will be performed in the reporting period to verify that equipment is still in place and operating as assumed when determining the estimated values.

Table 45: Additional info to the M&V plan for Option A

For Option D

Software Name	Report the name and version number of the simulation software to be used.
Input/Output Data	Provide a paper and electronic copy of the input files, output files, and

	weather files used for the simulation.
Measured Data	Note which input parameters were measured and which were estimated. Describe the process of obtaining any measured data.
Calibration	Report the energy and operating data used for calibration. Report the accuracy with which the simulation results match the calibration energy data.

Table 46: Additional info to the M&V plan for Option D

Each M&V plan follows a common structure, but must adapt independently to Living Lab. Therefore, a customized plan should be performed for each Living Lab.

The following Measurement and Verification (M&V) plan have as main objective to serve as base document for the Measurement and Verification energy savings (T6.4) derived from the implementation of the PROBONO energy efficiency solutions. The M&V plan document in detail how the estimation of the energy savings will be developed in T6.4.

In the following points can be seen a generic M&V plan applicable to any of the PROBONO Living Labs. In T6.4 this generic M&V will be adapted to the specific peculiarities of each Living Lab; also, the estimation of the energy savings will be determined in T6.4.

4.2.1.2.1 ECM Intent

The ECMs (Energy Conservation Measures) affecting the energy behaviour of the buildings which will be implemented in the PROBONO project are described in this section. Here are included the general description of the solutions, the technical specification for each of them, will be included in the specific deliverables developed within WP3 and WP4 activities for each of the innovations.

The ECMs can be divided into passive and active solutions. The aim of passive solutions is to reduce the energy demand, while the active solutions focus on generating energy in a more efficient and sustainable way.

In the case of the passive solutions the commissioning of the ECM will consist on a simple final supervision, while in the case of the active solutions it will be necessary to configure all the systems and do different test in order to assure the optimal performance of the facility.

Table 47, shows the general list of the PROBONO innovations related with energy efficiency aspects. Table 47: Generic PROBONO ECMs

show the innovative ECMs currently considered by each of the Living Labs in PROBONO.

Generic PROBONO ECMs
WP3 technical innovations "Construction and Renovation"
1. Insulation and green and cool roof solution 1.1. Integrated thermal & acoustic insulation 1.2. Wood fibre insulation 1.3. Cool roof membranes and bi-facial PV panels 1.4. Evaporative green roofs/walls
WP4 technical innovations "Energy production, Storage and Distribution"
2. Building Integrated Photovoltaics (BIPV)

2.1. Coloured BIPV modules demonstrated 2.2. BIPV colour flexibility improved 3. Energy storage 3.1. Flow batteries 3.2. Second Life Batteries 4. Integrated Infrastructure Mobility 4.1. V2G E-Mobility charging infrastructure with AI

Table 47: Generic PROBONO ECMs

DUBLIN LL	
Building	**Interventions**
County Hall	200kWp coloured façade BIPV
	Microgrid Battery and connection links
	Vapour permeable insulation / PIR (Polysterene foam) insulation
	Electric vehicle charging infrastructure
Ferry terminal	Microgrid Connection links
Lexicon Library	Microgrid battery and connection links
	Smart lighting retrofit
Social Housing	Microgrid connectivity (for 10 social housing units)

Table 48: Dublin LL ECMs

MADRID LL	
Building	**Interventions**
Whole LL	Geothermal network PVP storage
Commercial building	Thermo-activation of commercial and residential buildings connected to the geothermal network
Residential building	

Table 49: Madrid LL ECMs

PORTO LL	
Building/system	**Interventions**
Energy Tech Hub	Solar 2 Vehicle: to provide PV energy directly to an electrical vehicle.
	Vehicle to Grid: use electric vehicles as a means of energy storage and to reinject electricity back into the grid.
	BIPV incorporation in the Energy Tech-hub.
	2nd life batteries.
	Green Hydrogen production: a small electrolyser producing green Hydrogen.
	Solar Heat for Industrial Processes (SHIP): this package will use solar energy in Industrial processes, in the medium temperature range.
	Phase Change Materials (PCM).
	SMART EV HUB: The campus has a vast number of parking lots, many dedicated to collaborators meaning that many EVs are parked for many hours, creating a challenge to charge all of them during the available time slot and an opportunity for improved charging management.
	Cool roof technology for Bi-Facial PV production
Whole Campus	Social innovations & biodiversity initiatives

Table 50: Porto LL ECMs

AARHUS LL	
Building	**Interventions**
The Kitchen BSS Building	“Virtual Sensors” deployed into the as-designed BIM models for the integration of ventilation simulators during design and operation
	Electricity: Advanced electricity storage with Flow-Batteries
	Insulation (PIR Polysterene foam) insulation panels
	Electric vehicle charging infrastructure

Table 51: Aarhus LL ECMs

BRUSSELS LL	
Building	**Interventions**
De l’Autre Côté de l’Ecole (ACE)	Presence detectors for lighting (on/off)
	Replace traditional lighting with LED
	Roof solutions: • New Wood Fibber insulation. Treated with bio-based additives against fungi propagation. • Partially bio-based roofing membranes with root repellent additive. Smart & monitored irrigated green roof with the best plants cocktail for evapotranspiration.
	Prefabricated Concrete in the planned staircase construction.
	Charging/battery solution: Upon the outcome of the roof analysis, and possible solar panel solutions, linked storage and charging options on individual or neighbourhood scale are to be further assessed and developed.

Table 52: Brussels LL ECMs

PRAGUE LL	
Building	**Interventions**
Dejvice - CTU Campus. Faculty of Civil Engineering building B	Innovative insulation products and study of the integration of innovative roof planning concepts in the design.
	BIPV in the new suspended façade, quality triple-glazing and external roller blinds.
	Pro-cognitive LED lighting.
	Heat and humidity exchangers for ventilation with Nano-technology filtration considering epidemiology risks.
	Automation of building systems based on occupancy and IEQ sensors: • A control centre with a demand response platform will be integrated. The demand response platform (predictive operation system) will be based on prediction of PV’s production, energy consumption and instant capacity of the energy storage. • Smart mobility will be represented by e-cars and e-bikes chargers. An agrivoltaics living lab will contribute to electricity production from building integrated photovoltaics and to the education of visitors as teachers and students.

Table 53: Prague LL ECMs

4.2.1.2.2 Selected IPMVP Option and Measurement Boundary

“IPMVP Core Concepts EVO 10000 – 1:2022” will be followed, as it is the last version at this moment.

Following the selection process defined within the IPMVP protocol to select the option more suitable for each specific case, as the savings will be determined at building level, the more suitable options for the M&V of the energy savings in the LL's buildings within the PROBONO project are Option C "Whole facility" and Option D "Calibrated Simulation".

Option C "Whole facility"

Savings are determined by measuring energy use at the whole facility. Continuous measurements of the entire facility's energy use are taken throughout the baseline and reporting periods.

The analysis of whole facility meter data is done by using techniques from simple comparison to regression analysis.

The selection of this option is mainly due to the existence of baseline data of the specific building.

Red line is the path followed during the decision process in order to take the option C as the most appropriate for the application of the IPMVP.

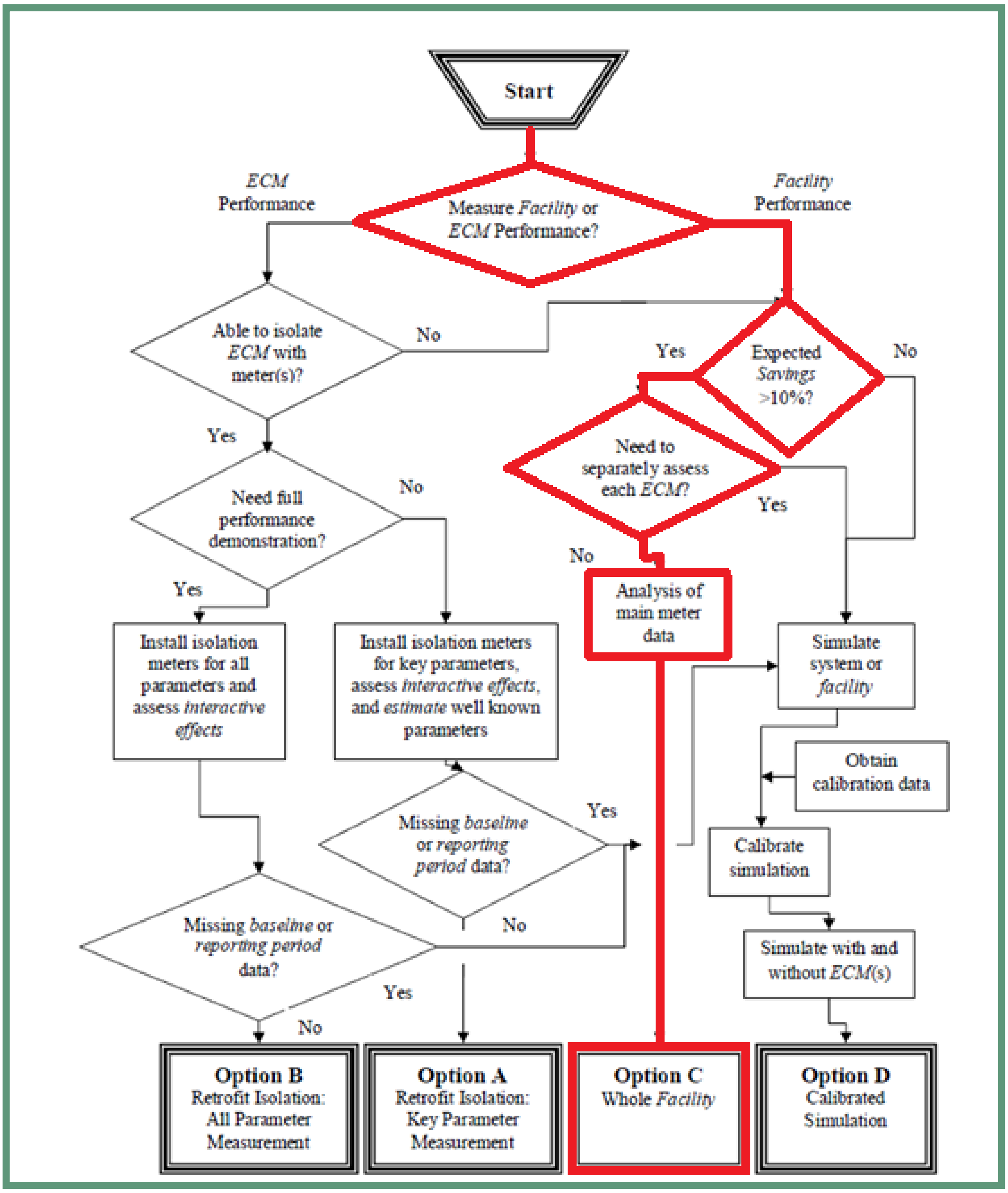

Figure 5: Option C selection process (source: IPMVP framework)

Option D "Calibrated Simulation"

Savings are determined through calibrated simulation of the energy use of the whole facility. Simulations routines are demonstrated to adequately model actual energy performance measured in a facility, but it usually requires high skills in simulation models.

Energy use simulation calibrated with hourly or monthly utility billing data and/or endues metering.

Option D may be used to assess the performance of all ECMs in a facility as in Option C, however, Option D allows also to estimate the savings attributable to each ECM within a multiple ECM project as is the case of PROBONO project.

The selection of this option is mainly due to the non-existence of baseline data of the specific building. In this case, it would be needed to work with energy simulation models to simulate the energy behaviour of the building prior to the implementation of the PROBONO solutions.

Red line is the path followed during the decision process in order to take the option D as the most appropriate for the application of the IPMVP.

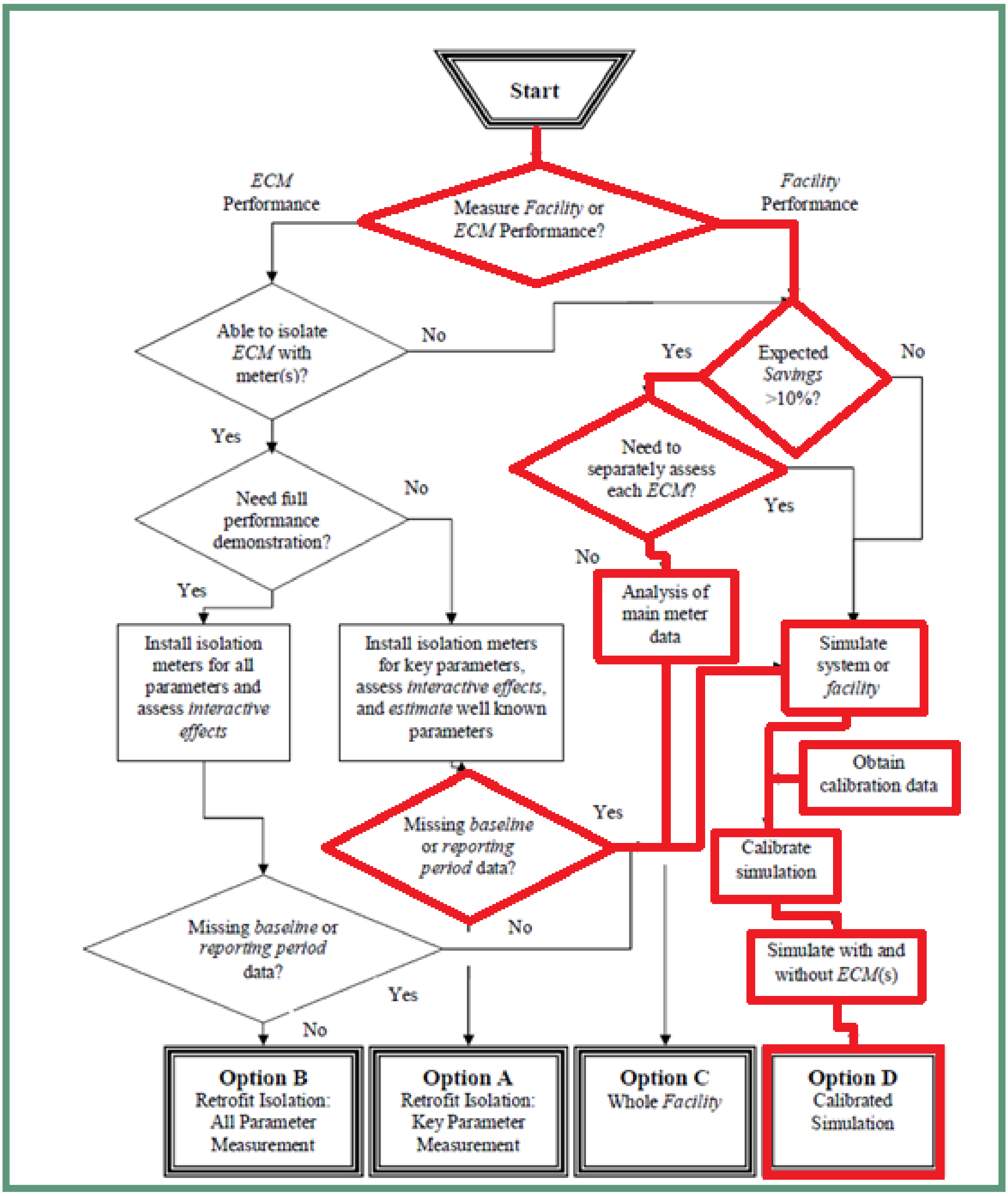

Figure 6: Option D selection process (source: IPMVP framework)

<table>
<tr><th>PROBONO LL</th><th>M&V option proposed based on IPMVP protocol</th><th>Comments</th></tr>
<tr><td>Madrid LL</td><td>D (Calibrated simulations)</td><td>No baseline data available as it a new neighbourhood</td></tr>
<tr><td>Dublin LL</td><td>C (Whole facilities)</td><td rowspan="2">Baseline data currently available</td></tr>
<tr><td>Brussels LL</td><td>C (Whole facilities)</td></tr>
<tr><td>Porto LL</td><td>C (Whole facilities)?</td><td rowspan="3">In progress of obtaining baseline data
It seems baseline data will be available for defining the reference model</td></tr>
<tr><td>Prague LL</td><td>C (Whole facilities)?</td></tr>
<tr><td>Aarhus LL</td><td>C (Whole facilities)?</td></tr>
</table>

Table 54: M&V option selection for PROBONO LLs

4.2.1.2.3 Measurement boundary

The measurement boundaries for the savings determination of PROBONO buildings are established at building level. In this way the meters measuring the supply of energy to the building can be used to assess the performance and savings. As the measurement boundary covers the complete building, all the possible interactive effects are included within it.

It is also important to remark that although the scope of the PROBONO M&V plan is to define the energy savings assessment plan for the whole building, evaluations of the performance achieved with the isolated PROBONO solutions (PV system, CHP system, thermal insulation, etc.) are also important to show not only the effect of the PROBONO interventions as a whole if not also to analyze the effect of each of the energy interventions in an isolated way. To analyze the isolated effect of individual ECMs, Options A "Retrofit Isolation: Key Parameter Measurement" and B "Retrofit Isolation: All Parameter Measurement" are the most recommended, although Option D can be also used for this purpose. In this case, a measurement boundary should be drawn around the PROBONO solutions. All these aspects will be analyzed in detail in D6.6 and D6.7 in which all the energy savings will be calculated.

4.2.1.2.4 Baseline Period

The baseline period, is the period considered before the starting of the interventions and should cover a full operating cycle of the building. Typically, a whole year of baseline data is needed to define a full operating cycle. In PROBONO project, the baseline period will be the period immediately before the buildings' retrofitting.

Option C "Whole facility"

For buildings based on Option C, it is necessary to collect the information from the baseline period for the energy consumption data and the independent variables coinciding within the same period. Whole-building energy use is usually affected by the weather conditions, but other variables can also affect significantly the energy consumption and could be considered.

Option D "Calibrated Simulation"

For buildings following Option D as it was described before, the baseline energy consumption data does not exist and it will be generated with the support of a calibrated energy simulated model.

Information of the baseline situation of the buildings including information about the static factors can be found in D7.1 "Overall LL Implementation Plan and Management" and will be improved in D6.2 "Baseline Evaluation" and D7.2 "Overall LL Implementation Plan and Management (II)".

DUBIN LL	Year 2022				Year 2023				Year 2024				Year 2025				Year 2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
BASELINE PERIOD																				
IMPLEMENTATION PERIOD																				
REPORTING PERIOD																				

MADRID LL	Year 2022				Year 2023				Year 2024				Year 2025				Year 2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
BASELINE PERIOD	NO BASELINE																			
IMPLEMENTATION PERIOD																				
REPORTING PERIOD																				

PORTO LL	Year 2022				Year 2023				Year 2024				Year 2025				Year 2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
BASELINE PERIOD																				
IMPLEMENTATION PERIOD																				
REPORTING PERIOD																				

AARHUS LL	Year 2022				Year 2023				Year 2024				Year 2025				Year 2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
BASELINE PERIOD																				
IMPLEMENTATION PERIOD																				
REPORTING PERIOD																				

BRUSSELS LL	Year 2022				Year 2023				Year 2024				Year 2025				Year 2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
BASELINE PERIOD																				
IMPLEMENTATION PERIOD																				
REPORTING PERIOD																				

PRAGUE LL	Year 2022				Year 2023				Year 2024				Year 2025				Year 2026			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
BASELINE PERIOD																				
IMPLEMENTATION PERIOD																				
REPORTING PERIOD																				

Table 55: Baseline, Implementation & Reporting Period for each Living Lab

4.2.1.2.5 Reporting Period

Reporting period is the period considered after the finalization of the PROBONO interventions and should cover at least one normal operating cycle of the building in order to fully characterize the savings effectiveness in all normal operating modes.

Once the ECMs have been implemented and embedded into normal operations, the reporting period data will need to be measured and collected in accordance with the process and task timelines specified in the M&V plan.

In general reporting period data will provide the input required to adjust the energy model and calculate the predicted energy consumption during the reporting period which will then be compared to the actual energy consumption to determine the estimated savings.

4.2.1.2.6 Basis for Adjustment

The adjustments terms should be computed from identifiable physical facts about the energy governing characteristics of the building within the measurement boundary.

The energy consumption of the building is not constant, it depends on independent variables. Therefore, the energy model must reflect the influence that different factors have on the energy consumption. In order to adapt to those factors, energy consumption must be adjusted reflecting the routine and non-routine adjustments.

Two types of adjustments are possible:

- Routine adjustments: Any energy-governing factor, expected to change routinely during the reporting period such as weather. It is important that the adjustment is as simple as possible, but always keeping in mind the reliability of the model. Valid mathematical techniques must be used to derive the adjustment method for each M&V plan.
- Non-routine adjustments: Those energy-governing factors which are not usually expected to change during the reporting period, such as: the facility size, the design and operation of installed equipment, the type of occupants, etc. These static factors must be monitored for changes throughout the reporting period.

The adjustment terms in the equation are used to express both pieces of measured energy data (baseline and reporting) under the same set of conditions. The mechanism of the adjustments depends upon whether savings are to be reported on the basis of the conditions of the reporting period (avoided energy), or normalized to some other fixed set of conditions.

The energy consumption during the reporting period can be compared to the adjusted baseline energy, in order to obtain the expected energy savings by using the following equations based on each specific IMPVP option.

Option C "Whole facility"

- Reporting period conditions → *Equation 1b)* Avoided Energy Use (or Savings) = Adjusted-Baseline Energy – Reporting-Period Energy +/- Non-Routine Adjustments of baseline energy to reporting-period conditions.
- Normalized to a fix set of conditions → *Equation 1c)* Normalized Savings = (Baseline Energy +/- Routine Adjustments to fixed conditions +/- Non-Routine Adjustments to fixed conditions) - (Reporting Period Energy +/- Routine Adjustments to fixed conditions +/- Non-Routine Adjustments to fixed conditions).

Option D "Calibrated Simulation"

- Reporting with calibrated model → *Equation 1f)* Savings = Baseline energy from the calibrated model [hypothetical or without ECMs] – Reporting-period energy from the calibrated model [with ECMs].
- Reporting with calibrated data → *Equation 1g)* Savings = Baseline energy from the calibrated model [hypothetical or without ECMs] – Actual calibration-period energy +/- Calibration error in the corresponding calibration reading.

4.2.1.2.7 Analysis Procedure

This section specifies the data analysis procedures, algorithms and assumptions to be used in the savings report. Depending on the IPMVP option followed for each Living Lab, a specific analysis procedure will be followed.

Option C "Whole facility"

Mathematical modelling is used in Option C to find a mathematical relationship between dependent and independent variables. The dependent variable, in this case the energy, is modelled as being governed by one or more independent variable(s). This type of modelling is called regression analysis, in which the model attempts to explain the variation in energy that results from variations in the individual independent variables such as weather conditions, occupancy, etc. The model quantifies the causation. Models can also include a different set of regression parameters for each range of conditions, such as summer or winter periods. The independent variables should be measured and recorded at the same time as the energy data.

The most common models are linear regressions in the form of:

$$Y = b_0 + b_1X_1 + b_2X_2 + ... + e$$

Where:

- Y is the dependent variable (energy).
- X_i represents the independent variables such as weather, occupancy, etc.
- b_i represents the coefficients for each independent variable and one fixe coefficient b_0 unrelated with the independent variables.
- e represents the residual errors that remain unexplained after accounting for the impact of the various independent variables.

The data used for the calculation of the mathematical model using regression analysis, should have the same structure in all periods, following the same time schedule.

In order to evaluate how well a particular regression model explains the relationship between energy use and independent variables, at least these three statistical terms should be considered:

- R^2: Coefficient of determination. Shows how well a regression model explains the variations observed in the dependent variable.
- SE: Standard Error. This term is used in estimating precision of a sample mean.
- T-statistic: To determine whether an estimate has statistical significance.

Statistic	IPMVP recommended value
R2 (Coefficient of determination)	>0.75
CV (Coefficient of variation)	<0.2
Bias	<0.005%
t-statistic (independent variables)	P<0.05

The mathematical models will be defined and included in D6.2

The savings will be determined by subtracting the measured actual usage from the adjusted baseline.

Savings = (Adjusted Baseline Energy – Reporting period energy)

Where

Adjusted Baseline Energy = Baseline Energy ± Routine Adjustments ± Non Routine Adjustments

The analysis procedure for the evaluation of the energy savings will be the following:

1. Check if there are any changes in the static factors between both periods.
2. Collect independent variables.
3. Introduce the independent variables in the validated mathematical model.
4. Determine the energy savings.

Option D "Calibrated Simulation"

The use of energy simulation models is always applicable if there is no measured data available or data is incomplete in any of the periods.

To use accurate simulations models it is needed to calibrate the energy simulation models.

ASHRAE guideline 14 is widely used to help calibration. The guideline clearly defines static indexes as threshold for calibrated model.

The error or inaccuracy of the energy simulation model is considered as the difference between simulated result and the actual energy data of the building.

The analysis procedure will be the following:

1. Define the resolution and target tolerances based on the following indicators from ASHRAE guideline 14:

   a) NMBE - Normalized Mean Bias Error.

$$NMBE = \frac{\sum_{i=1}^{n}(m_i - s_i)}{n \cdot \bar{m}} \cdot 100\ (\%)$$

m_i = measured value

s_i = simulated value

$\bar{m}$ = mean of measured values

n = number of measured data points

   b) CV (RMSE) – Coefficient of Variation of Root Mean Square Error.

$$\boldsymbol{CVRMSE} = \frac{\left[\frac{\sum_{i=1}^{n}(\mathbf{m}_i - \mathbf{s}_i)^2}{\boldsymbol{n}-\mathbf{1}}\right]^{1/2}}{\bar{\boldsymbol{m}}} \cdot \mathbf{100}\ (\%)$$

m_i = measured value

s_i = simulated value

$\bar{m}$ = mean of measured values

n = number of measured data points

2. Collect data from the reporting period for the model validation.
3. Run the simulation model.

4. Compare simulation model output with real data. Simulation outputs of the energy model should be coherent with the real data available.
5. Refine the model until an acceptable calibration is achieved. Significant deviations are investigated and addressed, and corrections and adjustments are applied to the model in order to achieve the calibration. After calibrating the model, the calculated energy use should correspond to the real data. The model can be considered calibrated if the tolerances defined at point 1) are met.
6. Estimate the baseline energy consumption with the calibrated model. To calculate the baseline, it is needed to use the calibrated model obtained in point 5) and remove the ECMs from the model in order to consider the baseline period conditions. The projected baseline period is determined by energy simulation under same climatic and operating conditions of the reporting period.
7. Determine savings. Compare baseline and reporting period results to determine the energy savings due to the PROBONO implementations.

4.2.1.2.8 Energy Prices

The energy prices provide information for the calculation of the economic savings from the energy assessment. The energy prices should be obtained from the energy supplier and contain all the elements (consumption charges, power factor, fuel price adjustments, taxes, etc.).

In PROBONO project, conditions of the reporting period will be used as the basis for reporting energy savings and therefore the energy price of the reporting period it will be used to compute avoided cost.

Cost should be determined by applying the same energy price in computing both periods baseline and reporting. If and ECM creates a change in fuel type or a change in price schedule between both periods, the energy prices for each period should be used, however both energy prices should be for the same time period (in this case reporting period).

The economic savings due to the energy interventions in the PROBONO project will be calculated based on the energy prices scheme of each Living-Lab location.

Energy source	Price
Energy source 1	XX €/kWh
Energy source 2	YY €/kWh

Table 56: Example of table for the energy prices collection

4.2.1.2.9 Meter Specifications

For the procedure of analysis and evaluation of the results, it is required a metering system. Thus, for achieving the objectives established by the M&V plan, a monitoring system will be design and installed. Meter specifications will be defined in detail in T6.3 “Monitoring program definition and associated execution plan” and all related information will be included in D6.3. The meters specifications will include:

- Meter type, model and characteristics.
- Accuracy and precision.
- Communication protocol.
- Commissioning procedure.

- Calibration procedure.
- Method for dealing with lost data and data transfer.

A table like the following will be defined for each demo-site specifying the measured parameters and their related meters.

Parameters	Meter specifications	
	Source	Frequency
Dependent variable (energy)	Energy bills Utility company counter Monitoring equipment	To be defined in T6.3 "Monitoring program definition and associated execution plan"
Independent variable 1	-	-
Independent variable 2	-	-
Independent variable ...	-	-

Table 57: Example of meter specification table

4.2.1.2.10 Monitoring Responsibilities

For carrying out a suitable monitoring process, a set of responsibilities and collaborative work among PROBONO partners is necessary. Ongoing and periodic inspections should be carried out.

A table like the following will be defined collecting the monitoring responsibilities to report and record the energy data, independent variables and static factors during the reporting period in each demo.

Monitoring variable	Responsible
Energy data	Living Lab responsible (bills) / PROBONO partners in charge of each innovation (monitoring equipment installed)
Independent variables	Living Lab responsible
Static factors	Living Lab responsible
ECMs correct operation	PROBONO partners in charge of each innovation
Energy savings reports	CARTIF/Living Labs responsible

Table 58: Monitoring responsibilities table

4.2.1.2.11 Expected Accuracy

Some are the characteristics within a M&V process which should be carefully reviewed to manage accuracy or uncertainties.

- Instrumentation: measurement equipment errors are due to calibration, inexact measurement or improper meter selection installation or operation. Is determined by the manufacturers' specifications according to the installation guidelines.
- Data gathering: data gaps and inconsistencies.
- Modelling: the inability to find mathematical form that fully account for all variations in the real energy use. Modelling errors can be owing to inappropriate functional form, inclusion of irrelevant variables, or exclusion of relevant variables.
- Sampling: use of a sample of the full population of items or events to represent the entire population introduces error as a result of the variation in values within the population, or biased sampling.
- Interactive effects (beyond the measurement boundary) which are not fully included in the M&V methodology.

Option C "Whole facility"

Uncertainty of the mathematical model is calculated by using the following equation:

$$u(\%) = \frac{t \cdot \sqrt{n \cdot SE_{y^2}}}{expected\ savings}$$

$t = \text{t} - \text{student statistic for a confidence level and degree of freedom}$

$SE_{y^2} = \text{standard error of the model}$

$\text{n} = \text{number of estimates made with the mathematical model to cover a period}$

Option D "Calibrated Simulation"

From ASHRAE Guideline 14 a model should have normalized mean bias error (NMBE) at 5% or lower and coefficient of variation of root mean square error (CVRMSE) of 15% or lower if actual monthly data is used. For hourly data calibration, those two indexes are 10% and 30%.

Monthly criteria (%)	**NMBE**	**±5**
	CV (RMSE)	**15**
Hourly criteria (%)	NMBE	±10
	CV (RMSE)	30

Calibration criteria based on ASHRAE Guideline 14

4.2.1.2.12 Budget

In order to develop a suitable M&V plan for determination of the energy savings after the retrofitting action, careful attention must be paid to the provided budget and to the needed resources.

The cost of determining savings depends on many factors and each project will have its own budget. Depending on the IPMVP option it is possible to highlight the key-governing factors unique to each selected option.

Option C "Whole facility"
- Number of static factors to be tracked during the reporting period. - Number of independent variables to be used for routine adjustments.

Option D "Calibrated Simulation"
- Number and complexity of systems simulated. - Number of field measurements needed to provide input data for the calibrated simulation. - Skill of professional simulator in achieving calibration.

The budget and resources required for the savings determination are the followings:

Concept	Price
M&V Plan	- €
Energy savings report	- €
Energy monitoring systems installed	- €
Total	**- €**

Table 59: Example of M&V budget for a Living Lab

4.2.1.2.13 Report Format

M&V reports should be prepared and presented as defined in the M&V Plan. Complete M&V reports should include at least:

- Project background.
- ECM description.
- M&V option chosen for the ECM or project as part of the M&V plan.
- Observed data of the reporting period (measurement period, energy data, and independent variables).
- Description and justification for any corrections made to observed data.
- Energy price scheme.
- Any baseline non-routine adjustment performed.
- Computed savings in energy (kWh) and monetary units (€).

The final results will be reported and documented in D6.8 "Final Project Evaluation".

4.2.1.2.14 Quality Assurance

The quality-assurance procedures that will be used for savings reports and any interim steps in preparing the plans and reports are the following:

1. Variables measurements
    a. Check the measurement equipment is the same during the whole reporting period.
    b. Use of calibrated measurement equipment.
    c. Measurement points are the same in each period.
2. Periodic verification of the correct functioning of ECMs.
3. Lost data will be generated from previous records available and the application of suitable statistics and interpolation techniques.
4. Check the quality of the energy and economic savings reports by a third part within the PROBONO project.
5. PROBONO partners in charge on developing the M&V plans and reports are Certified Measurement and Verification Professionals (CMVPs).

Depending upon the IPMVP option, some additional specific topics should also be discussed in a complete M&V Plan. In this case for Option D the following additional points should be defined.

4.2.1.2.15 Software Name

At the time of defining the current M&V plan is still not clear which energy simulation software will be used for the calculation of the savings through IPMVP Option D. At this stage a list of possible energy simulation software for which the PROBONO partners have usage skills are mentioned:

- Design Builder.
- TRNSYS.
- Open Studio.
- Digital twins developed in WP5.

4.2.1.2.16 Input/Output Data

Once the energy model and the simulations will be done for the specific Living Lab building, an electronic copy of the input files, output files and weather files used for the simulations will be provided.

4.2.1.2.17 Measured Data

Measured data from the reporting period will be used for the calibration of the energy model.

As all the activities related with modelling and simulation will be developed in T6.4, all these aspects will be described in detail n D6.6 & D6.7 “Monitoring and Impact Assessment of Operation Activities”.

4.2.1.2.18 Calibration

The calibration only will be necessary for Madrid LL so it is the only one Living lab with Option D.

All the data collected in D6.2 “Baseline Evaluation for LLs” and all the energy and operating data that will be collected during the reporting period will be used for the calibration of the energy model.

The calibration requirements are defined within the sub-section Expected Accuracy and the methodology to follow within the sub-section Analysis procedure.

The calibration process will be made with the energy data available and will be included in D6.6 & D6.7.

4.2.2 Life cycle methods (LCA, LCC, s-LCA)

4.2.2.1 Introduction

In PROBONO, the "Life Cycle Methods" should be used to assess the implementation of the project's actions in the context of Green Building Neighbourhoods (GBN) from different sustainability perspectives. Each Living Lab will adopt their own set of sustainable solutions, and some of them will be subject to a comprehensive analysis in terms of their impacts throughout their life cycle, to demonstrate the fulfilment of the ambitious objectives set for the project. This assessment includes the environmental, economic and socials aspects, by applying the methodologies of the Life Cycle Assessment (LCA), Life Cycle Costs (LCC) and Social Life Cycle Assessment (s-LCA), respectively.

For the LC methods evaluation framework and guidance, we will borrow some common concepts and terminology from the environmental Life Cycle Analysis that can be extended to the economic and social aspects, such as project phases and the definition of the initial processes for the analysis (e.g., scope definition, inventory analysis and results interpretation). Nevertheless, each methodology will have their own set of rules that will serve as guideline for the partners in the project to apply them in their Living Labs.

Each Living Lab have their own motivations, context, scale, and innovative technologies to be applied that can range from the scale of a product to the entire neighbourhood. Thus, this section of the document serves as a general guideline for applying LC methods only. More information can be found directly at the standards and normative indicated under each LC methodologies, and the overall conduction of the analysis and decisions on how to perform them are within the responsibility of the partners in each Living Lab.

4.2.2.1.1 Built Environment x Building Scale

To cover the different scales in which the LC methods might be used within PROBONO (from a single building to a block or district), it is necessary to understand in which ways the assessments might differ. According to Hauschild, Rosenbaum & Olsen (2018), LCAs of buildings and the built environment are not identical in methodology and have distinct framings of the systems they assess. Thus, some aspects of the assessments need to be considered, such as:

1. **Scale:** Building LCAs focus on a single building or building type and attempt to model this to a high degree of accuracy. Built environment LCAs model an agglomeration of buildings (neighbourhood, city, conurbation) and attempt to model this to a reasonable degree of accuracy.
2. **Temporal Scope:** Building LCAs focus on the entire lifetime of a building, typically decadal. LCAs of the built environment take a snapshot of the material, energy demands and waste generation of the study system over a short period, typically a calendar year.
3. **LCI Method and Data:** Building LCA strives for accuracy and concerns itself with minutia (exact masses and lifetimes of building components, precise construction techniques, etc.) preferably with buildings specific data. Built environment LCAs are more interested in capturing general trends in a city's environmental loading

(construction aggregates, metals, transport fuels, etc.) based off of coarser data sets (waste statistics, household consumption surveys, census data, etc.)

4. **LCA Method:** Building LCA is predominantly done using process based LCA. Input–output LCA is equally as popular as process-based LCA in assessing built environments.

4.2.2.1.2 Product scale

Within the innovative solutions proposed in PROBONO, there are some that fall into the product category and, for that reason, will need to have an Environmental Product Declaration (EPD), following the principles set on the Product Category Rules (PCR) they belong.

EPDs and PCRs are documents regulated by the standards ISO 14025:2006 and EN 15804:2012+A2:2019, and they communicate environmental information that can be used to compare the environmental performance of different products fulfilling the same function and is especially used in the construction sector for building products. Their assessments are quantified based on environmental data from LCA (life cycle inventory data or impact assessment results) according to the rules established in their PCR.

A Product Category Rule provides the rules, requirements, and guidelines for how the LCA should be conducted for developing an EPD for all products of a certain category, regarding, for instance, the system boundaries, functional unit, and impact categories to be analysed (EPD, n.d.). By following these rules instituted by the International EPD System, an EPD ensures to deliver data about products and services' environmental performances from a lifecycle perspective reports that are transparent, comparable, and third-party verified. Existing PCRs and EPDs can be found on the International EPD System's website library (www.environdec.com).

4.2.2.2 Life cycle concept

A life cycle approach entails that a certain subject of analysis has consecutive and interrelated stages that go from raw material extraction to final disposal. Different evaluation methodologies of the built environment use the life cycle as reference to have a comprehensive understanding of the impacts throughout their entire lifespan, by collecting and evaluating the inputs and outputs of the system, and their different impacts over its entire life cycle.

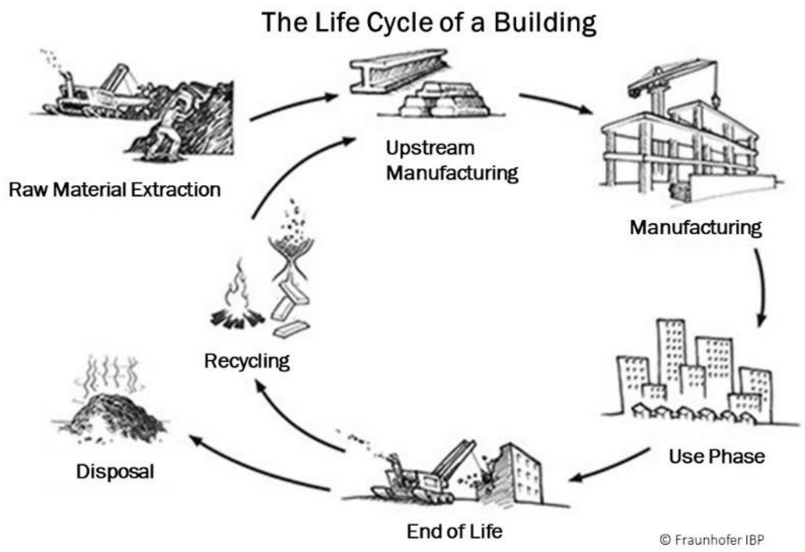

Figure 7: Illustration of a product Life Cycle. Source: Fraunhofer IBP.

There is also a commonly known and used terminology to refer to certain stages of the life cycle. For instance, the starting point is also referred to as the "cradle," while the exit point of the manufacturing facilities is known as the "gate," and the end of the life cycle is known as "grave." This helps to understand the different ranges of LCA scope, such as cradle-to-gate, cradle-to-grave, and cradle-to-cradle. Each one analyses different phases and is used depending on the objectives of the assessment:

- The **cradle-to-gate** assessment includes the initial phases of a product, known as the construction product manufacturing. It assesses a partial product life cycle from resource extraction to the factory gate (i.e., before it is transported to the consumer), and they are often used as the basis for environmental product declarations (EPD).
- **Cradle-to-grave** is the full life cycle assessment from resource extraction to the use phase and disposal phase, involving all phases in a linear approach from start to end.
- **Cradle-to-cradle** is a specific kind of full life cycle assessment with a circular approach, in which the end-of-life disposal step for the product is a recycling process, and the output of the recycling could be the raw material of a new product, thus closing the cycle. It is a methodology used to minimize the environmental impact of products by employing sustainable production, operation and disposal practices, and it aims to incorporate social responsibility into product development.
- Finally, **gate-to-gate** is a partial LCA method, looking at only one value-added process in the entire production chain. Gate-to-gate modules may also later be linked in their appropriate production chain to form a complete cradle-to-gate evaluation.

4.2.2.3 Life Cycle Stages

For the purposes of the PROBONO's evaluation framework, we will use the life stages determined in the regulations *EN 15978:2011* (Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method), and *EN 15643:2021* (Sustainability of construction works - Framework for assessment of buildings and civil engineering works).

These standards provide concepts and requirements for the sustainability assessment of buildings and civil engineering works considering their technical characteristics and functionality in terms of environmental, social and economic performances. According to the documents, the entire life cycle is divided in different modules that include the stages from the acquisition of raw materials to their disposal, or to the point at which the materials leave the system boundary either during or at the end of the life cycle of the building, as illustrated in Figure 8 and explained below.

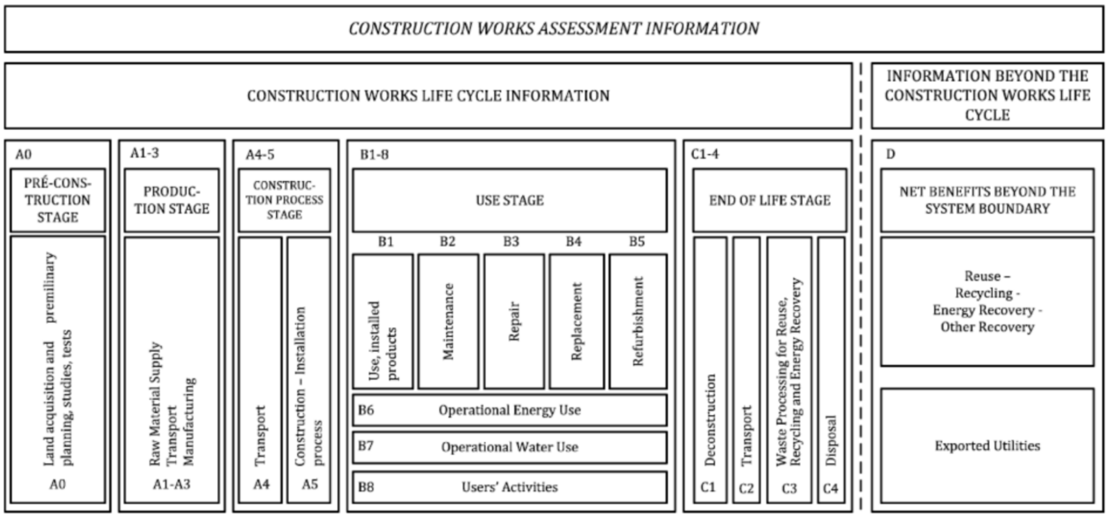

Figure 8: Life Cycle Modules and Stages. Source: EN 15643:2021.

Each step belongs to a module that corresponds to a life cycle stage. Following, we will bring the basic understanding of each phase. More details about what should be included on every step can be found on the existing standards EN 15978:2011 and ISO 14040:2006.

A) Before the use stage (modules A0 – A5)

- A0 represents the physical processes of pre-construction, such as impact evaluation, risk evaluation, stakeholder engagement, preliminary technical studies and analyses, and acquisition costs, e.g., land/plot including planning and project.
- A1-A3 are the product stage, and the boundaries include the cradle to grave processes for the materials and services used in the construction, including raw material extraction, transportation, production, and acquisition). The standards to define their impact are found in the standard EN 15805.
- A4-A5 represent the construction stage, covering the processes from the gate of the industry of the different materials in the construction until the completion of the construction works.

B) Use Stage – B1-B8

This stage covers the period from the construction completion up until the building's demolition/deconstruction. The system boundary includes the use of products and services to protect, conserve, regulate or control the building that is object of assessment. This means, services such as heating, cooling, lighting, water supply, energy demand for lifts and functioning of the building, and overall maintenance, including cleaning, and equipment replacement.

- B1-B5 represent the aspects and impacts arising from the existence of the construction site itself.
- B6-B7 represent the operational energy and water flows of the construction, as well as the aspects and impacts of specific construction processes and activities on the site. The energy demand, the amount of energy supplied to a building, the amount of

energy generated in a building and the amount of energy exported from a building shall be assessed according to the framework set out in EN ISO 52000-1.

- B8 represents the aspects and impacts that arise as a consequence of user activities associated with the use of the built asset, excluding any in-service (operational) energy consumption, which is included in module B6.

C) End-of-life stage – C1-C4

- C1 represents the aspects and impacts of the deconstruction or decommissioning of the building.
- C2 – C4 represent the aspects and impacts of waste management processes, including the transport of waste from the site where deconstruction takes place to the point where the end of waste status is reached, including its final disposal

D) Net benefits beyond the system boundary – D1-D2

- Module D deals with the benefits and burdens in the following elements:
- D1 represents net flows from reuse, recycling, energy recovery and other recovery operations (e.g., backfilling); and separately,
- D2 represents services exported beyond the system boundaries.

4.2.2.4 Sustainability Assessment – Environmental, Economic and Social aspects

In this section, we will differentiate the different LC methods that will be applied in PROBONO, with a brief description of the different aspects that cover the three pillars of sustainability: environmental, social and economic assessments; and how they relate to the expected impacts and KPIs established in this evaluation framework.

4.2.2.4.1 Environmental Assessment: LCA

Life cycle assessment (LCA) is an important tool used to measure the environmental impacts of a certain service or product on the environment by classifying the impacts into categories such as climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, among others (Hauschild, Rosenbaum, & Olsen, 2018). The different end point indicators, or impact categories can be classified into three areas of protection: human health, ecosystem quality or natural environment, and natural resources and ecosystem services, as seen on Figure 9.

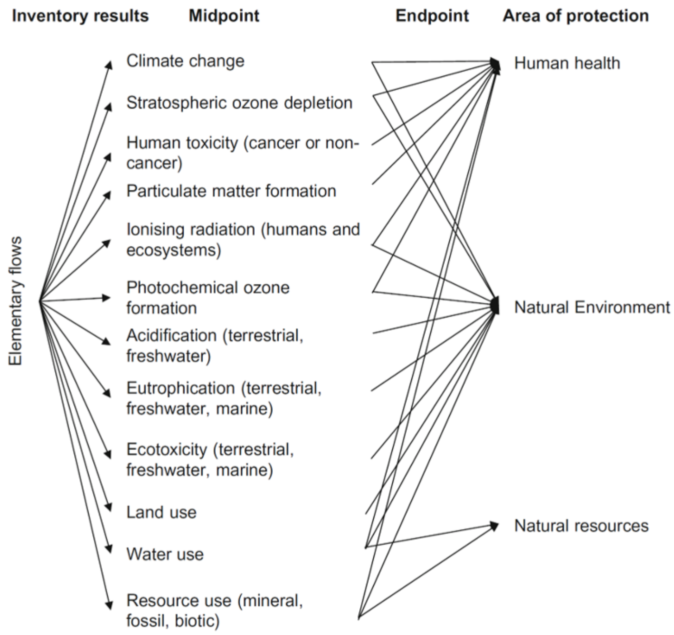

Figure 9: Links between indicator results for impact categories and areas of protection. Source: Hauschild, Rosenbaum, & Olsen, 2018

The applications of LCA can be used in the design and development of products and services, including entire life cycle perspective considering environmental criteria to identify possible “hot spots” of potential environmental impacts. The outcomes of an LCA can be used by the design industry and decision-makers in order to improve the efficiency of a product or give recommendations through policies regarding environmental targets to be reached.

The LCA is a methodology that is not only applied on its own to assess the potential environmental impacts, but also but can also be one mean to calculate indicators in sustainable building certifications and frameworks, such as BREEAM, DGNB, and Level(s). In some certification schemes it is possible to obtain credits for using materials and products with EPD, and for the development of a Life Cycle Assessment (LCA) of the building.

Within PROBONO, this methodology will be used for assessing the expected impacts described above in this document, and their related KPIs, such as:

- Expected Impact 1 - Primary energy savings triggered by the project.
- Expected Impact 5 - Reduction of GHG emissions for the total life cycle.
- Expected Impact 6 - Reduction of the embodied energy in buildings.
- Expected Impact 7 - Reduction of air pollutants for the total life cycle.

Regulation

As mentioned before, in this evaluation framework we can find important concepts and a preliminary guideline for implementing the methods to evaluate the different expected impacts in PROBONO. These recommendations are based on existing standards and literature, since these methodologies are complex but well-known and with already established procedures. For more detailed information, we list some of the relevant standards for consultation used in this document:

- **EN 15978:2011 (Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method)** - This document specifies the calculation method, based on Life Cycle Assessment (LCA) and other quantified environmental information, to assess the environmental performance of a building, and gives the means for the reporting and communication of the outcome of the assessment. The standard is applicable to new and existing buildings and refurbishment projects.

- **ISO 14040:2006 (Environmental management - Life cycle assessment - Principles and framework)** - This document covers the principles of life cycle assessment (LCA) studies and life cycle inventory (LCI) studies. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual phases of the LCA.
- **ISO 14044:2006 (Environmental management — Life cycle assessment — Requirements and guidelines)** - This document specifies requirements and provides guidelines for life cycle assessment (LCA) including all phases of the assessment, as well as reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.
- **EN 15643:2021 (Sustainability of construction works - Framework for assessment of buildings and civil engineering works)** - This document provides principles and requirements for the assessment of environmental, social and economic performance of buildings and civil engineering works taking into account their technical characteristics and functionality.
- **EN 15804:2012+A2:2019 (Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products)** - This European standard provides core product category rules (PCR) for Type III environmental declarations for any construction product and construction service.
- **ISO 14025:2006 (Environmental labels and declarations — Type III environmental declarations — Principles and procedures)** - This document establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations.

Calculation Tools

Nowadays there are many options of tools and software that facilitate the calculation of the Life Cycle Assessment and operate aligned with the existing standards. These tools vary in their database, affordability, and user friendliness, for instance.

Level(s) has created a list of software and database that can be used for the calculation of the life cycle impacts of a building for their indicator 1.2 – Life Cycle Global Warming Potential (GWP) but can also be used for a multiple-indicator analysis, such as an LCA.

Each Living Lab should choose to assess their work within the project according to the tools and expertise they have available. Table 60 brings the non-exhaustive list of LCA tools applicable to the building sector, developed by Level(s).

Tool	Link	Applicability
Athena (Canada)	http://www.athenasmi.org/our-software-data/impact-estimator/	Building-specific
Arquimedes (Spain)	http://arquimedes.cype.es/	Building-specific

BEES (USA)	http://www.nist.gov/el/economics/BEESSoftware.cfm/	Building-specific
Bilan Produit ADEME (France)	http://www.base-impacts.ademe.fr/bilan-produit	Generic
Carbon Footprint (UK)	https://www.carbonfootprint.com/	Generic
COCON (France)	http://eosphere.fr/COCON-comparaison-solutions-constructives-confort.html	Building-specific
eToolLCD (Australia)	http://etoolglobal.com/	Building-specific
Eco-bat (Switzerland)	http://www.eco-bat.ch/index.php?option=com_content&task=blogcategory&id=14&Itemid=30	Building-specific
EcoCalculator (Canada)	http://www.athenasmi.org/tools/ecoCalculator/	Building-specific
EcoCalculator (Canada)	http://www.ecoeffect.se/	Building-specific
ECOSOFT (Austria)	http://www.ibo.at/en/ecosoft.htm	Building-specific
EIME (France)	http://codde.fr/en/our-software/eime-en/eime-presentation	Generic
ELODIE (France)	http://www.elodie-cstb.f/default.aspx	Building-specific
envest 2 (UK)	http://envestv2.bre.co.uk/	Building-specific
EQUER (France)	http://www.izuba.fr/logiciel/equer	Building-specific
GaBi (Germany)	http://www.gabi-software.com	Generic
GaBi-Build-IT (Germany)	http://www.pe-international.com/sweden/services-solutions/green-building/building-lca/	Building-specific
GreenCalc+ (The Netherlands)	http://www.greencalc.com/	Building-specific
Klimagassregnskap (Norway)	http://www.klimagassregnskap.no/	Building-specific
LEGEP (Germany)	http://www.legep-software.de/	Building-specific
One Click LCA (Finland)	http://www.oneclicklca.com/green-building-software/	Building-specific

OpenLCA (Germany)	http://www.openlca.org/	Generic
SimaPro (The Netherlands)	http://www.pre-sustainability.com	Generic
SBS (Germany)	http://www.sbs-onlinetool.com	Building-specific
SULCA (Germany)	http://www.simulationstore.com/sulca	Generic
TEAM (France)	http://ecobilan.pwc.fr/en/team.html	Generic
Umberto (Germany)	http://www.umberto.de/en/	Generic

Table 60: Calculation tools LCA. Source: Level(s) – Indicator 1.2 Life Cycle Global Warming Potential (GWP).

4.2.2.4.2 Economic Assessment: LCC

The LCC methodology will follow ISO standard 15686-5, Buildings and constructed assets - Service life planning - Part 5: Life-cycle costing, 2017 as guidance in the process of defining and developing the LCC models, ISO 15686-8 - Part 8: Reference service life and service-life estimation In addition to that, LCC will take into account the life cycle stages defined in EN 15978:2011 (Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method) and EN 156643:2021 (Sustainability of construction works - Framework for assessment of buildings and civil engineering works), in order to be aligned with LCA cycles stages.

The next figure shows the costs that should be considered in LCC assessment (inside the grey box). In addition, the figure presents wider costs and incomes that should be used for whole life costs (WLC) assessment.

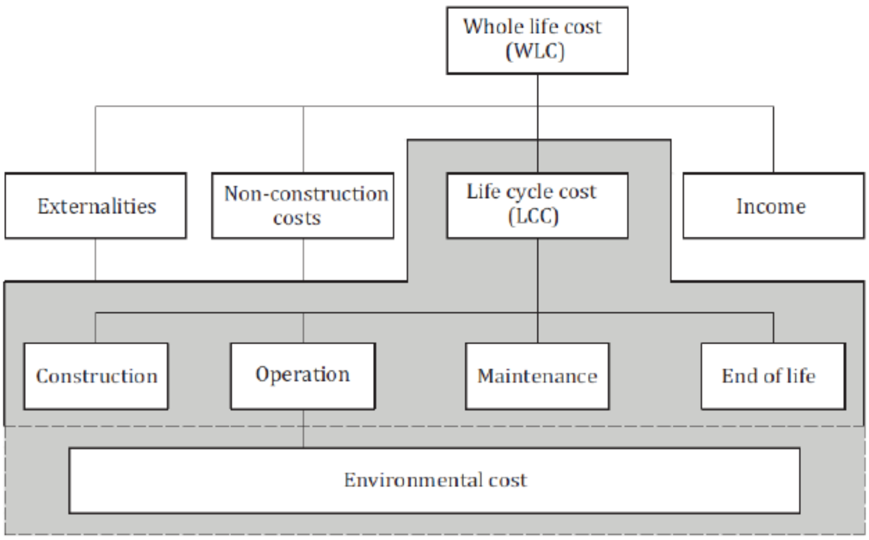

Figure 10. WLC and LCC elements based on the ISO 15686-5.

The scope or the present study is to assess only the LCC of the demo sites. Therefore, only the elements inside the grey box have been considered. On the other hand, the environmental costs (outside the dashed line) have not been included in the LCC models since they are not mandatory and usually negligible for building assets.

As a result, the components that make up the project's LCC models are:

- **Construction cost:** the initial construction costs (at time zero). For the PROBONO LCC models, construction costs cover the incurred costs of implementing each renovation action, including materials and components costs, transport to building site, construction and installation costs (including labour, machinery and energy consumption).
- **Operation Cost**: costs incurred in running and managing the facility or built environment. For PROBONO LCC models, operation costs refer to energy costs for heating, cooling and electricity over the period of analysis.
- **Maintenance cost:** total of necessarily incurred labour, material and other related costs incurred to retain a building or its parts in a state in which it can perform its required functions. For PROBONO LCC models it only refers to the replacement/renewal of components at the end of its life.
- **End of Life cost:** net cost or fee for disposing of an asset at the end of its service life or interest period.

Within PROBONO, this methodology will be used for assessing the expected impacts described above in this document, and their related KPIs, such as:

- Expected Impact 2 - Investments in sustainable energy triggered by the project.
    - KPI 2 - Operational cost of energy
    - KPI 13 - Costs along the life cycle (LCC) - Life Cycle Cost (LCC)

Regulation / certification

The reference standard for calculating the life cycle costs of each life cycle stage shall be EN 15459, ISO 15686-5 and EN 16627. The reference standard ISO 15686-8 provides a methodology for calculating and estimating the design life of elements and components.

Calculation Tools

A life cycle cost software tool (optional, instead of cost model for the project) can be used to make calculations according to a national cost optimal method, EN 15459 or ISO 15686-5.

4.2.2.4.3 Social Assessment: s-LCA

To date, the classical life cycle analysis (LCA) has been considered as a standard tool for sustainability assessment of emerging technologies. However, the application of LCA in real-life test and experimentation environments is not sufficient to evaluate research and innovation because societal values are not integrated. Hence, a major driver for development of a social life-cycle assessment (S-LCA) has been to create an evaluation method that encompasses the sustainability principles of LCA while addressing the social dimensions. This allows for the quantification of burdens in defined social impact categories such as working conditions and socioeconomic repercussions (UNEP/SETAC 2009).

Stakeholder	Social Impact	Subcategory	Inv. indicators	Inventory Data
Workers	Human rights			
Local community	Working conditions			
Society	Health and safety			
Consumers	Cultural heritage			
Value chain actors	Governance Socioeconomic repercussions			

Table 61: Assessment system from categories to unit of measurement. Source: UNEP-SETAC (2009).

The S-LCA is defined by the guidelines established by the 2009 UNEP/SETAC, as "*a technique for assessing social (real or potential) impacts with the aim of evaluating the socio-economic aspects of the products and their potential impacts, positive and negative, along their life cycle, including the extraction and processing of raw materials, production, distribution, use, reuse, maintenance, recycling, and final disposal.*"

4.2.2.4.3.1 Social Life Cycle Assessment Evaluation Framework

One setback of S-LCA is that it lacks stakeholder engagement to guide model construction, standard and code of practice. Furthermore, the s-LCA method requires methodological development in the context of research and innovation. To this end we present an s-LCA evaluation framework to serve as a guideline for PROBONO's six Living Labs. The present work identifies relevant social and socio-economic impact subcategories in S-LCA for the Living Labs by outlining a step-by-step social life cycle assessment framework within each category proposed by UNEP/SETAC. Note that as of June 2022, the International Organization for Standardization, ISO, is working on a publication on the "Principles and framework for social life cycle assessment".

4.2.2.4.3.2 Living Labs Stakeholders and a Multi-actor Consultation Process

In this framework a participatory approach implying all concerned Living Labs stakeholders is proposed to select relevant impact subcategories and thus contribute to a thorough interpretation of s-LCA results. As presented in Figure 11, the main actors of the Living Labs Quadruple Helix Model are citizens, government, industry, and academia.

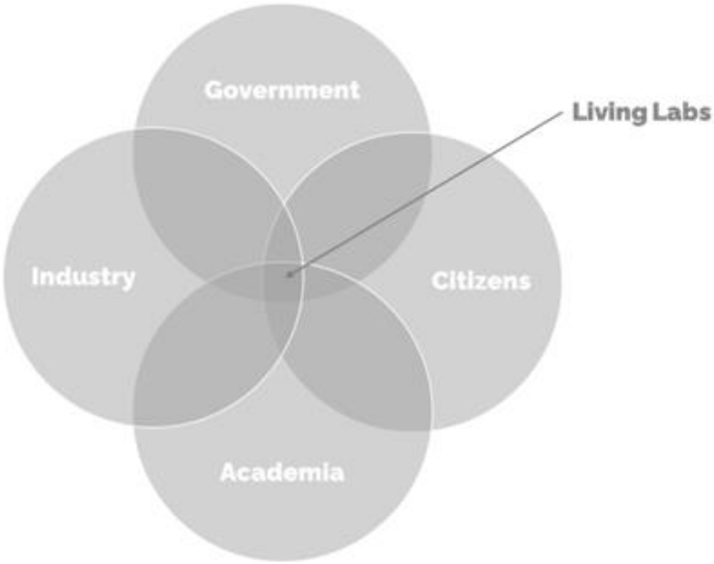

Figure 11. Quadruple Helix Model. Source: enoll.org

As shown in Figure 11, the Living Labs Quadruple Helix Model is then supplemented with stakeholders proposed in UNEP-SETAC (2009) to put forth a multi-actor consultation process example for the Living Labs.

Stakeholder	Users/Consumer	Worker Union	Public actors	Industrial actor	Academia
Workers	X	X			
Local community	X		X	X	X
Society			X	X	X
Users/Consumers	X		X	X	X
Value chain actors			X	X	X

Table 62: A multi-actor consultation process example for the Living Labs. Based on UNEP-SETAC (2009) and Bouillass et al. (2021).

As suggested by Boullass et al. (2021) the consultation process for the selection of relevant subcategories can be targeted to users, workers, industrial, academic, and public actors. The administered survey questions should cover social and socio-economic issues related to the specific stakeholder.

Within PROBONO, this methodology will be used for assessing the expected impacts described above in this document, and their related KPIs, such as:

- Expected Impact 10 - Improved indoor environmental quality (IEQ) and reduction of dust and noise.

4.2.2.5 Steps for implementing Life Cycle Assessments

The life cycle assessment has some determined phases that go from goal definition until the study application. Figure 12 shows a scheme that represents with accuracy how the whole procedure works, and what happens in the reality when performing an LCA. All the phases are interconnected with double-sided arrows, meaning that it can be required to go back to a prior step and revise its definition at all the stages, in a continuous improvement cycle. In other words, the life cycle interpretation phase should occur at every other stage in an LCA.

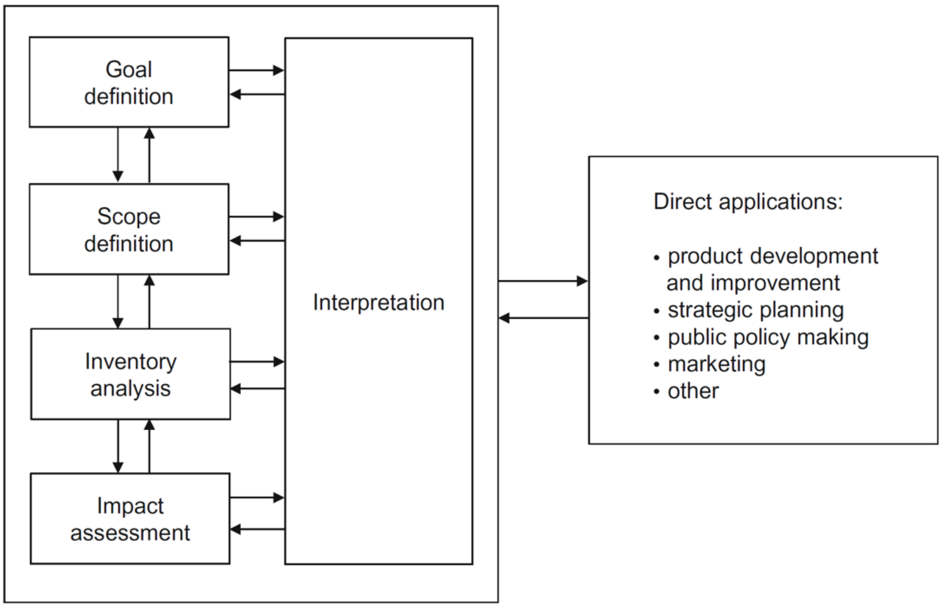

Figure 12: Framework of LCA. Source: ISO 14040 standard

The LCA steps are established by existing standards and need to be followed accordingly. In this section we bring a summarised guideline of the minimum requirements for performing an assessment, but the regulation and state-of-the-art studies should be consulted by the Living Labs for more details according to the specific needs and goals of their innovative solutions.

4.2.2.5.1 LCA Implementation Steps

Goal & Scope definition

The goal and scope of a LCA should be defined in the beginning, since it provides the general reason why the LCA is being done, and should answer to questions such as: why is this LCA being performed? Who is the target audience? What is my objective with this analysis? And what is the extension of the study? At this stage, it is also required to define the type of analysis, impact categories to be evaluated, and set of data that needs to be collected, timeframe of the analysis, and this will guide the study defining the system boundaries and its functional units.

- Functional Unit: The functional unit can be defined as the unit of comparison that assures that the products being compared provide an equivalent level of function or service. For a building LCA, the functional unit might be “the entire building supplied from design to demolition for a 50-year service life,” or it might be computed on a per-square-meter basis and limited to one life cycle stage (e.g., construction).

- System Boundary: It defines the activities and processes that will be included in each life-cycle stage for the LCA analysis and those that will be excluded, and the extent and depth of the analysis, specifying the decisions of the process, with corresponding justification. If a comparative LCA is anticipated, then it is critical that the system boundary be established in the same way for the systems being compared.

At this stage, information about the context of the analysis is also relevant, such as defining the geographical and temporal boundaries and settings of the study and the level of technology that is relevant for the processes in the product system. This will determine the effects of transportation, local energy matrix and climate, supporting the decision-making of choosing certain products and materials that represent less impact to the object of analysis, according to the goal and scope previously defined.

Finally, at this stage the perspective to apply in the study needs to be decided between a consequential study assessing the impacts that can be expected as a consequence of choosing one alternative over another, or an attributional study assessing the impacts that are associated with the studied activity.

Inventory Analysis

In the next step, the inventory analysis collects information about the physical flows in terms of inputs of resources, materials, semi-products and products and the output of emissions, waste and valuable products for the product system. The outcome of the inventory analysis is the life cycle inventory, a list of quantified physical elementary flows for the product system that is associated with the provision of the service or function described by the functional unit.

According to Gervasio & Dimova, 2018, certain aspects must be considered to ensure quality of the data for the inventory analysis:

- Time-related coverage - datasets should be recent or updated within the last 10 years for generic data and 5 years for specific data from producers.
- Geographical coverage – according to the aim of the study, the geographical area from which data is collected should be representative.
- Technological coverage – all relevant technologies should be covered, and they should reflect the reality for each product.
- Completeness – datasets should be complete according to the goal and scope of the analysis. (Gervasio & Dimova, 2018)

Impact Assessment (Impact categories)

Evaluation of significance of potential environmental impacts using the LCI results, by associating inventory data with environmental impact categories selected on the scope definition phase. It is the transformation of those emissions or waste on environmental impacts and these impacts are grouped on Impact Categories.

More information of each of the steps can be found directly in ISO 14040 standard. Transparency is critical to the impact assessment to ensure that assumptions are clearly described and reported.

Interpretation

Final phase of the life cycle, and it is the moment to draw the conclusions once the results of the impacts assessment are gathered. At this phase, the LCA can be checked for significant issues at the previous stages, and when a problem is identified, its significance is determined by checking its completeness, sensitivity and consistency. Depending on issue, if it cannot be solved by strengthening the data in the LCA, the goal and scope should be reviewed and reconsidered for the outcome to respond to the question posed in the goal definition

(Hauschild, Rosenbaum, & Olsen, 2018). The impacts results of an LCA can only be considered positive or negative when compared to the goal and scope of the analysis, which may vary according to the purposes set initially.

LCA results should be reported in the most informative way possible for a better understanding of the hot spots and the opportunities to reduce the impact of the product or service evaluated. The results can be presented in detail in tables or graphs, which is especially helpful when comparing two different scenarios.

The outcomes of an LCA should be used as a decision-making tool, and as such, the results found on the interpretation phase can be part of an iterative process in which the outcomes can lead to changes in the proposed design, which then leads back to the inventory analysis step in the process.

It is important to highlight the importance of transparency in all stages of the LCA. One must describe at all times the choices made when including or excluding a certain data, or even when some assumptions are needed due to lack of more precise information.

4.2.2.5.2 LCC Implementation Steps

Goal & Scope definition

LCC is a valuable technique that is used to predict and to analyse the cost performance of assets parts over the course its life cycle.

An economic assessment should consider all costs of a product or system throughout its lifetime (Boverket, Energimyndigheten, 2013).

Life Cycle Costing is a technique that "enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors, both in terms of initial capital costs and future operational and asset replacement cost"[2]. It is particularly relevant to achieving an improved environmental performance because higher initial capital costs may be required to achieve lower life cycle running costs.

A life cycle cost perspective encourages clients and designers to consider the relationship between upfront capital costs and use stage costs.

Savings associated with energy and water efficient buildings can be cash-flowed in order to capitalise the value of the savings and reflect this in property valuations and investment decisions. This may be in comparison with benchmarks of performance in a local market, across a portfolio or the asset performance prior to a major renovation.

Inventory Analysis

Development of the life cycle cost model for a building will require the collection of a range of data. For the whole life cycle, costs will need to be represented or modelled at different points in time. An overview of the data requirements and the building professionals that would usually be responsible for collecting and estimating the cost data are described as follows:

- **Construction costs**: cost data obtained from suppliers and contractors. Obtained during the design and contracting stages by the cost consultant.

[2] Davis Langdon, 2007. Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology, Literature review prepared for the European Commission, May 2007

- **Operational (utility) costs:** During the design and construction stage, on the basis of the energy and water use performance assessments. Upon completion, property managers and owner occupiers may obtain data from metering. Obtained from design and as-built calculations, or in-use measured performance. Obtained from design and as-built calculations, or in-use measured performance.
- **Maintenance, repair and replacement costs:** At a basic level, estimates require data on:

– The design life of elements and components,

– The environmental exposure conditions that building elements may be exposed to,

– The service conditions that building elements will be subjected to, the potential causes and probability of early failures.

Estimated by cost consultants working with property managers during the acquisition of (a) building(s).

- **Refurbishment cost:** Based on currently available products and technologies at current prices. For offices, this could range from costing of a renewal of the fit-out and servicing, to a change of use from office to residential or short stay units (or vice versa). Potential scenarios for the future adaptation of a property to changing market conditions will need to be developed and costed by cost and property surveyors
- **End of life costs:** Revised cost estimates could be obtained from contractors on the basis of design features intended to make the building easier to deconstruct, reuse and recycle. Potential scenarios for the deconstruction and demolition of the building will need to be developed and costed. Cost estimates would need to be made based on current technologies and prices.

Impact Assessment (Impact categories)

The table below shows the LCC impact categories, according to Level(s) indicator 6.1: Life cycle costs)

Type of cost	Normalised cost by life cycle stage (€/m²/yr)			
	A Product and construction stages	B Use stage		C End of life stage
Initial costs	*Construction*	*Refurbishment and adaption*		*Deconstruction and demolition*
Annual costs	-	*Energy*	*Water*	-
	-	*Maintenance, repair and replacement*		-
Periodic costs	-	*Maintenance, repair and replacement*		-
Global costs by life cycle stage	*Sum of stage A costs*	*Sum of stage B costs*		*Sum of stage C costs*

Table 63: LCC Impact Categories

Interpretation

Interpretation of the results, could include analysis of different designs, the identification of opportunities to optimise life cycle costs, as well as accounting for uncertainty and variability in the quality of data.

In terms of the quality of data, there is always a risk and uncertainty in the calculation of LCC, as it involves predictions of future behaviour, as well as input data which are often based on estimates or assumptions. ISO 156865 defines a sensitivity analysis as a test of the outcome of an analysis by altering one or more parameters from initial value(s). It further recommends it as a suitable technique for indicating the range of uncertainty and risk associated with specific LCC analyses. The sensitivity analysis can be used to investigate how variations in uncertain input data affect the LCC results, thereby indicating the robustness of the outcome and conclusions. According to ISO 15686-5, the selected data variation ranges for the sensitivity analysis should be probable and be examples of key assumptions which may have a significant effect on the LCC result the standard state e.g. assumptions on discount rates (Hedström, ”Kalkylhandbok för fastighetsföretaget,” Utveckling av vastighetsföretagande i offentlig sektor (U.F.O.S), 2006).

4.2.2.5.3 s-LCA Implementation Steps

To date, the classical life cycle analysis (LCA) has been considered as a standard tool for sustainability assessment of emerging technologies. One strength of the life cycle methodologies is that all components of a product are followed from cradle to cradle, allowing for a comprehensive, systematic and structured assessment of social impacts throughout the life cycle of a specific product. However, the application of LCA in real-life test and experimentation environments is not sufficient to evaluate research and innovation because societal values are not integrated. Hence, a major driver for development of a social life-cycle assessment (S-LCA) has been to create an evaluation method that encompasses the sustainability principles of LCA while addressing the social dimensions. This allows for the quantification of burdens in defined social impact categories such as working conditions and socioeconomic repercussions (UNEP/SETAC 2009).

The S-LCA is defined by the guidelines established by the UNEP/SETAC, as “*a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal”* (UNEP/SETAC 2009, p. 37). As such, it follows the life cycle stages defined in the ISO 14040 framework for an E-LCA. Furthermore, the S-LCA follow the same steps (goal and scope definition, inventory assessment, impact assessment and interpretation) although it differs on the methodological approach as well as object(s) of analysis. However, it is important to stress that this is a reiterative process, meaning that in practice, one would need to go back and forth between the different steps when conducting an S-LCA.

As pointed out by Ghada Bouillass, Isabelle Blanc and Paula Perez-Lopez (2021), one setback of S-LCA is that it often lacks stakeholder engagement to guide model construction, standard and code of practice. Furthermore, the S-LCA method requires methodological development in the context of research and innovation. To this end we present an S-LCA evaluation framework to serve as a guideline for PROBONO’s six Living Labs. The present work identifies relevant social and socio-economic impact subcategories in S-LCA for the Living Labs by summarizing a step-by-step social life cycle assessment framework within each category proposed by UNEP/SETAC. Note that as of June 2022, the International Organization for Standardization, ISO, is working on a publication on the principles and framework for social life cycle assessment (ISO/CD 14075, 2022). Upon their publication it is recommended to investigate the benefits of following this framework to align with the LCA and LCC methodologies.

As a final remark to the introduction, it should be mentioned that a primary source for developing the guidelines presented in this section are the *Guidelines for Social Life Cycle Assessment of Products and Organizations* (UNEP, 2020) developed by UNEP. When performing an actual S-LCA it is recommended to consult these guidelines for more detailed information on the different steps.

Goal and scope definition

According to the S-LCA methodological sheets developed by UNEP (2013), the first phase of S-LCA covers the definition of the purpose of the study and system boundaries, as well as the considered stakeholders and social impact subcategories. In the context of an S-LCA, the *goal* can vary but it should answer the basic question of why the S-LCA is being conducted. Is it for instance to support sustainable design of products or, to understand if the product value chain contributes to the social development of its stakeholders? Once the goal is identified, next step is the scope definition which is about clarifying the object of the study, the *system boundaries* (defining which parts of the product system are part of the assessment) and the right methodology to assess this (UNEP 2020, pp. 41-42).

A key part of this first step, is to identify directly and indirectly related stakeholders through each life cycle stage (here following the life cycle stages as defined in Section 4.2.2.3. The main stakeholder categories suggested in the UNEP framework are *workers, local community, society, users/consumers* and *value chain actors*. In some cases, it will also be relevant to consider *children* as an isolated stakeholder group. These stakeholder categories will need to be specified in the context of the specific object of analysis, according to the different life cycle stages.

Next step is to identify the relevant *impact subcategories,* that is, identify where there will potentially be social or socio-economic impacts along the life cycle. This will require careful consideration of the as-is situation in the specific context. A good starting point is offered in the UNEP guidelines which are summarized in Table 64: List of stakeholder categories and impact subcategories (adapted from UNEP 2020, p. 23). The suggested impact subcategories should be adapted to the relevant sector and context specific social impact categories.

Stakeholder categories	Impact subcategories
Worker	Freedom of association and collective bargaining Child labour Fair salary Working hours Forced labour Equal opportunities / discrimination Health and safety Social benefits / social security Employment relationship Sexual harassment Smallholders including farmers
Local community	Access to material resources Access to immaterial resources Delocalization and migration Cultural heritage Safe and healthy living conditions Respect of indigenous rights

	Community engagement Local employment Secure living conditions
Value chain actors (not including consumers)	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights Wealth distribution
Consumer/users	Health and safety Feedback mechanism Consumer privacy Transparency End-of-life responsibility
Society	Public commitments to sustainability issues Contribution to economic development Prevention and mitigation of armed conflicts Technology development Corruption Ethical treatment of animals Poverty alleviation
Children	Education provided in the local community Health issues for children as consumers Children concerns regarding marketing practices

Table 64: List of stakeholder categories and impact subcategories (adapted from UNEP 2020, p. 23)

This work will include a preliminary assessment of existing data sources which should be based on both *generic* and *site-specific* data sources as the relevant social impact indicators for the S-LCA will differ across countries. Following the Methodological Sheets, *generic data* refers to existing research and studies or information found on governmental, inter-governmental and multilateral web sites whereas *site-specific data* will be data or information gathered through site-visits, site-specific, existing research, interviews and surveys (UNEP 2013, p. 11).

As a final step in this phase, we suggest to consult the relevant stakeholders to prioritize and refine the impact subcategories. This could be done through surveys distributed to all stakeholders (for details on this, see Bouillass et al 2020, p. 2417-2418).

Inventory analysis

At this stage, the data and information needed to perform the assessment will be gathered. The information gathering should cover social and socio-economic issues related to the specific stakeholder for each of the social impact indicators.

The S-LCA will depend on three types of data: *Quantitative, semi-quantitative* (yes/no or rating scale responses) and *qualitative* (descriptive text) (UNEP 2013, p. 10). These data types should not be regarded as exclusive as they will often supplement each other. When defining the scope of the S-LCA and the assessment methodology for each social impact indicator, it is necessary to consider carefully the optimal solution. This should include ethical considerations of engaging with stakeholders in sometimes vulnerable contexts. Hence, the choice of methodology for performing the analysis of any given aspect of the S-LCA will have to be described and justified to ensure transparency and the possibility to go back and verify results.

One important distinction to make is between *actual* and *potential* social impacts as these are closely linked to the quality of the data. Actual social impacts must be assessed through primary, site-specific data collected directly from stakeholders, whereas an assessment based on proxy indicators and secondary, generic data only can form the basis for an assessment of potential impacts (UNEP 2020, p. 26).

With regards to the data gathering needed to perform an S-LCA, there will be several limitations related to this. Sometimes, the gathering of site-specific data will be limited due to political challenges in the given context or, the resources allocated to perform the necessary data gathering are insufficient. Hence, to ensure the validity and reliability of the study, *data quality management* is an important aspect of the inventory analysis. It is proposed to use a pedigree matrix adapted to the S-LCA by Franziska Eisfeldt (2017). The indicators are assessed in five scores, from 1 (meaning very good performance) to 5 (meaning very bad performance) The suggested indicators relate to the data quality on parameters such as reliability, time, geography technology and completeness as visualised in Table 65: The pedigree matrix for data quality assessment of social data, used in PSILCA (adapted from Eisfeldt, 2017, p. 19). The pedigree matrix allows for a structured assessment of data quality across research methodologies and different types of data which is one benefit in the context of an S-LCA.

Score / Indicator	1	2	3	4	5
Reliability of the source(s)	Statistical study, or verified data from primary data collection from several sources	Verified data from primary data collection from one single source or non-verified data from primary sources, or data from recognized secondary sources	Non-verified data partly based on assumptions or data from non-recognized sources	Qualified estimate (e.g. by expert)	Non-qualified estimate or unknown origin
Completeness conformance	Complete data for country-specific sector/ country	Representative selection of country-specific sector / country	Non-representative selection, low bias	Non-representative selection, unknown bias	Single data point / completeness unknown
Temporal conformance	Less than 1 year of difference to the time period of the dataset	Less than 2 years of difference to the time period of the dataset	Less than 3 years of difference to the time period of the dataset	Less than 5 years of difference to the time period of the dataset	Age of data unknown or data with more than 5 years of difference to the time period of the dataset
Geographical conformance	Data from same geography (country)	Country with similar conditions or average of countries with slightly different conditions	Average of countries with different conditions, geography under study included, with large share, or country with slightly different conditions	Average of countries with different conditions, geography under study included, with small share, or not included	Data from unknown or distinctly different regions
Further technical conformance	Data from same technology (sector)	Data from similar sector, e.g. within the same sector hierarchy, or average of sectors with similar technology	Data from slightly different sector, or average of different sectors, sector under study included, with large share	Average of different sectors, sector under study included, with small share, or not included	Data with unknown technology / sector or from distinctly different sector

Table 65: The pedigree matrix for data quality assessment of social data, used in PSILCA (adapted from Eisfeldt, 2017, p. 19)

Impact assessment

The impact assessment of an S-LCA aims at "*measuring and understanding potential social and socio-economic impacts related to a product system"* (UNEP 2020, p. 80). At a general level, the impact assessment primarily concerns the *potential* impact as opposed to the *actual* impact. There are several methodologies available to conduct an impact assessment and they fall primarily in two categories. One is the *Reference Scale Assessment* (formerly Type I or RS S-LCIA) and one, the *Impact Pathway Assessment* (formerly Type II or IP S-LCIA). Which methodology to use depends on the specific goal and scope. For the purpose of this deliverable we will not go into details with these methodologies but a detailed introduction can be found in the Guidelines developed by UNEP (2020) and an example of the application of the Type 1 Impact Assessment are demonstrated by Bouillass et al. (2021).

To provide an overview of the inventory indicators and the assessment of their impact, the inventory indicators developed for each life cycle stage should be scored, as presented in Table 66: Example of S-LCA for users through various stages of Living Labs. The score system can be based in a Likert-scale that ranges from positive effect to very negative effect, for instance, 1-7, or 0 for a missing subcategory. The results can then be summarized and aggregated in the tabular form to provide an easily accessible overview (Hosseinijou, 2014).

Stakeholder	Subcategory	Indicator	Impact subcategory by Life Cycle Stages						
			Pre-Building		Building-Phase			Post-Building	
			Raw material acquisition	Construction material production	Construction/ Manufacturing	Use	Maintenance and Rehab	Demolition	Disposal/Recycle
User	Health	Indoor thermal quality				1	1		

Table 66: Example of S-LCA for users through various stages of Living Labs

Furthermore, the indicators in the S-LCA can be assembled in a taxonomic order as shown in Figure 13: Taxonomies of S-LCA Indicators (Tokede & Traverso 2020, based on the International Organization for Standardization). These indicators can be categorized according to the nature of the assessment method, impact pathways, impact categories, impact effects, and variable levels (Neugebauer et al. 2015; Tokede and Traverso 2020). Social indicators can be classified according to the nature of the assessment method as quantitative, i.e., in physical units, semi-qualitative, i.e., in scores and qualitative, i.e., descriptive. The impact pathways of midpoint and endpoint classification can include health, autonomy, safety, security, tranquillity, equal opportunities, participation and influence, resource productivity, human capital, cultural heritage, and human well-being. Finally, indicators can be categorized into additive or descriptive indicators. Additive indicators can be measured quantitatively and relate to functional units, i.e., production costs and value added. Descriptive indicators can be either quantitatively or qualitatively described and/or measured at each point in the chain and they cannot be related to functional units, i.e., fair wage and contribution to personal income (Kruse et al., 2009). This categorisation and classification will be useful to provide a comprehensive overview of the types and quality of data gathered.

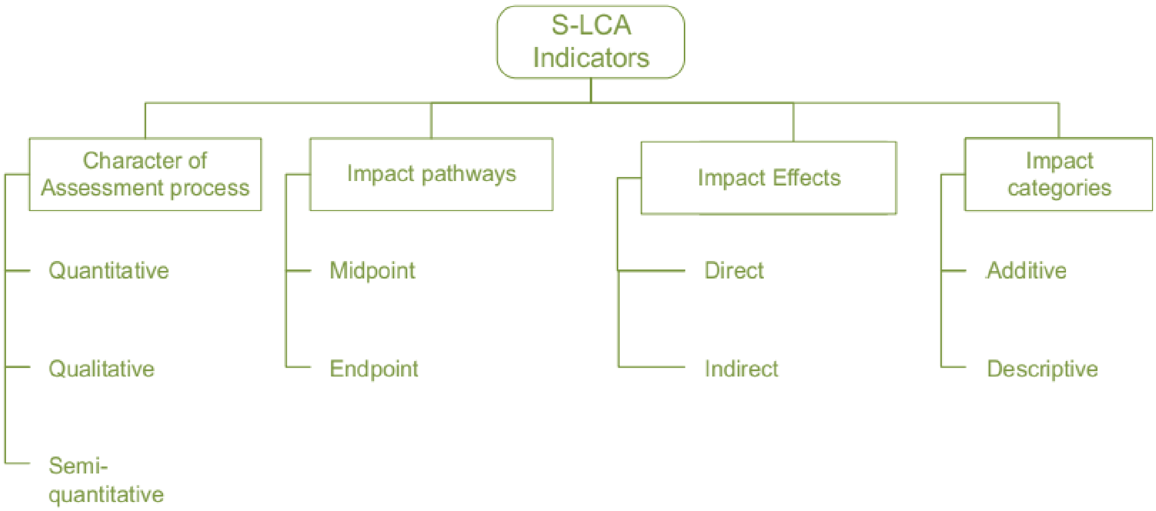

Figure 13: Taxonomies of S-LCA Indicators (Tokede & Traverso (2020), based on the International Organization for Standardization).

Interpretation

The final phase of the S-LCA is to interpret the results of the previous steps. This work entails a critical analysis of the data gathered and if it answers to the scope and goal definition performed at the first step. The result of the interpretation will, at its best, be a comprehensive basis for recommendations, conclusions and informed decision-making.

Following the UNEP Guidelines (2020) the interpretation should follow the requirements of ISO 14044 including *completeness check, consistency check, sensitivity* and *data quality check, materiality assessment* and, *conclusions, limitations,* and *recommendations*. Each component is described in detail in the UNEP Guidelines (2020, pp. 108-115). Again, it should be noted that these are iterative processes. For instance, the data quality check might reveal the need for gathering more data, which then again might lead to a revision of the goal and scope. FIG XXX below visualises the relation between the different phases in the S-LCA where the iterative processes are marked with dashed arrows. The aim of this step is to ensure a systematic and comprehensive review of the quality of the research conducted as part of the S-LCA; to allow for a diligent and transparent review of the research methodologies and, to draw valid conclusions and recommendations. During the interpretation phase, the questions raised as part of the goal and scope definition should be answered.

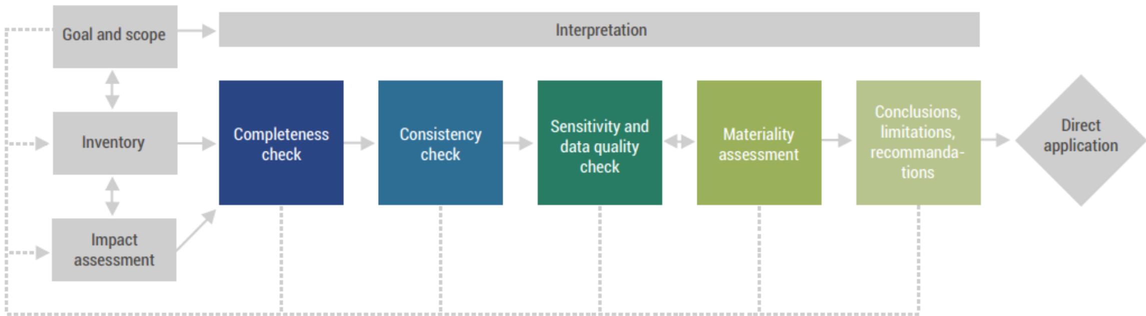

Figure 14: Illustration of the elements of the interpretation phase in S-LCA and their relation with the other life cycle phases (Source: UNEP 2020, p. 109).

As a final step, it is proposed to send the overall assessment, presented in a report with easy access to data sources and references to peer-review.

5 Conclusions

This document reports the PROBONO Evaluation Framework representing a very flexible guideline to be adapted to the specific assessment needs for each of the Living Labs throughout the different stages of the project.

This guideline will allow the Livings Labs to deploy their specific assessment activities since the begin through the identification of the baseline data requirements (defining the reference conditions prior to the implementation of the actions), going through the definition of the monitoring requirements (to be deployed and commissioned in each of the Living Labs through WP7 and then integrating the produced data-sets in the Digital platform in WP5), until the complete evaluation of the Living Labs actions once the innovations have been implemented in each of them comparing the situation before and after under operation and life cycle perspectives.

The Evaluation Framework is composed by Main KPIs which are linked with the PROBONO Expected Impacts. These Main KPIs are selected with the idea to follow the progress and measure the impacts achieved at the end of the project, both at general and individual level.

Impacts Vs Main KPIs summary
Expected Impact 1. Primary energy savings triggered by the project
[Main KPI 1] Primary Energy Consumption [kWh/year]
Expected Impact 2. Investments in sustainable energy triggered by the project
[Main KPI 2] Operational cost of energy [€/year]
[Main KPI 3] Cost along the life cycle (LCC) [€]
Expected Impact 3. Demonstration sites that go beyond nearly-zero energy building performance
[Main KPI 4] Energy demand [kWh/year]
[Main KPI 5] BER – Building Energy Rating [Energy Label]
Expected Impact 4. High energy performance
[Main KPI 6] Renewable energy production [kWh/year]
[Main KPI 7] Self-consumption ratio [%]
[Main KPI 8] Final energy [kWh/year]
Expected Impact 5. Reduction of GHG emissions for the total life-cycle
[Main KPI 9] CO2 emissions operational stage [$kgCO_2eq$/year]
[Main KPI 10] GHG emissions along the life cycle (LCA) [$kgCO_2eq$]
Expected Impact 6. Reduction of the embodied energy in buildings
[Main KPI 11] Embodied energy [MJ/kg] or [MJ/m^2] or [%]
Expected Impact 7. Reduction of air pollutants for the total life-cycle
[Main KPI 10] GHG emissions along the life cycle (LCA) [kg]
[Main KPI 12] Air pollutants operational stage [kg/year]
Expected Impact 8. Potential for replicability using new or existing innovation clusters
[Main KPI 13] Replicability [nº]
Expected Impact 9. Shortened construction/retrofitting time and cost
[Main KPI 14] Shortened construction/retrofitting time [%]
[Main KPI 15-1] Shortened construction/retrofitting cost – manufacturing [%]
[Main KPI 15-2] Shortened construction/retrofitting cost – transportation [%]
[Main KPI 15-3] Shortened construction/retrofitting cost – stock keeping [%]
[Main KPI 15-4] Shortened construction/retrofitting cost – space costs/warehouse establishment [%]
Expected Impact 10. Improved indoor environmental quality (IEQ) and reduction of dust and noise
[Main KPI 16] Thermal comfort – Occupant perception [% - Likert]
[Main KPI 17] IAQ Indoor Air Quality – Occupant perception [% - Likert]

[Main KPI 18] Acoustic comfort – Occupant perception [% - Likert]
[Main KPI 19] Dust quality – Occupant perception [% - Likert]
[Main KPI 20] Visual comfort – Occupant perception [% - Likert]

Table 67: Summary table of Impacts vs Main KPIs

In addition to the Main KPIs, there are some additional KPIs coming from the needs of the different WPs of the project (mainly WP1 “GBN transition and strategic plan”; WP2 “social innovations”; WP3 and WP4 “innovative technologies”; WP8 “Dissemination and Communication” and WP9 “Exploitation”). These KPIs are included as an Annex of this document and are defined based on the scope and current stage of development of each of the WPs. Some of them will be updated in later stages of the project once the scope and details within each WP are clearer and most of them will be calculated through the specific activities within each of the WPs.

For the calculation of some of the KPIs, it is needed the applicability of supporting methodologies and tools. This is needed for those KPIs with a life cycle perspective or those which need an accurate estimation of the energy savings in the operational phase of the building. To cover these needs LCA, LCC and s-LCA methodologies and M&V plans based on IPMVP have been defined and included as part of this Evaluation Framework.

PROBONO Evaluation Framework, is very well aligned with the Sustainable Development Goals supporting the progress towards the achievement of some of their goals and the Level(s) methodology developed by the European Commission.

The Evaluation Framework will be a live document which will be adapted in next stages of the project once the scope and interventions of each of the LLs will be clearer. In a second stage and once the scopes and innovative actions are clear for each of the Living Labs, the general evaluation framework will be adapted to the Living Labs specific needs and context through the more specific LLs activities in the next WP6 activities.

6 References

Antonio Garrido Marijuán, Ghazal Etminan, Sebastian Möller (2017). EU Smart Cities Information System. Key Performance Indicators Guide.

Bouillass, G., Blanc, I., & Perez-Lopez, P. (2021). Step-by-step social life cycle assessment framework: a participatory approach for the identification and prioritization of impact subcategories applied to mobility scenarios. The International Journal of Life Cycle Assessment, 26(12), 2408-2435.

Efficiency Valuation Organization, “International Performance Measurement and Verification Protocol”, Concepts and Options for Determining Energy and Water Savings, Volume 1, EVO 10000-1:2012, January 2012.

Efficiency Valuation Organization, “International Performance Measurement and Verification Protocol”, Core Concepts, EVO 10000-1:2016, October 2016.

Efficiency Valuation Organization, “International Performance Measurement and Verification Protocol”, Renewables Application Guide, EVO 10200-1:2017, March 2017.

Efficiency Valuation Organization, “International Performance Measurement and Verification Protocol”, Generally accepted M&V principles, October 2018.

Efficiency Valuation Organization, “International Performance Measurement and Verification Protocol”, Measurement & Verification – Issues and examples, EVO 10300-1:2019, February 2019.

Eisfeldt, Franziska (2017). PSILCA – A Product Social Impact Life Cycle Assessment Database (Database version 2.1). Accessed 28/11/2022 at https://www.openlca.org/wp-content/uploads/2017/12/PSILCA_documentation_update_PSILCA_v2_final.pdf

EN 15643:2021. Sustainability of construction works - Framework for assessment of buildings and civil engineering works, 2021.

EN 15804:2012+A2:2019. Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products, 2019.

EN 15978:2011 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation methods, 2011.

Eurostat, Sustainable development in the European Union, Monitoring report on progress towards the SDGs in an EU context.

Dodd N., Donatello S. & Cordella M., 2021. Level(s) indicator 1.2: Life cycle Global Warming Potential (GWP) user manual: introductory briefing, instructions and guidance (Publication version 1.1)

Gervasio, H. and Dimova, S., Model for Life Cycle Assessment (LCA) of buildings, EUR 29123 EN, Publications Office of the European Union, 2018, ISBN 978-92-79-79973-0, doi:10.2760/10016, JRC110082.

Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. (2018). Life cycle assessment. Springer International Publishing. https://doi. org/10.1007/978-3-319-56475-3.

Hosseinijou, S. A., Mansour, S., & Shirazi, M. A. (2014). Social life cycle assessment for material selection: a case study of building materials. The International Journal of Life Cycle Assessment, 19(3), 620-645.

ISO 14025:2006. Environmental labels and declarations — Type III environmental declarations — Principles and procedures, 2006.

ISO 14040:2006. Environmental Management – Life Cycle Assessment – Principles and Framework; 2006.

ISO 14044:2006. Environmental management — Life cycle assessment — Requirements and guidelines, 2006.

ISO/CD 14075. (2022/under development). Principles and framework for social life cycle assessment Accessed 28/11/2022 at https://www.iso.org/standard/61118.html

Kruse SA, Flysjö A, Kasperczyk N, Scholz AJ (2009). Socioeconomic indicators as a complement to life cycle assessment—an application to salmon production systems. International Journal of Life Cycle Assessment. 14:8–18

JRC Technical Reports, European Commission, Level(s) – A common EU framework of core sustainability indicators for office and residential buildings.

Neugebauer S, Martinez-Blanco J, Scheumann R, Finkbeiner M (2015) Enhancing the practical implementation of life cycle sustainability assessment–proposal of a tiered approach. J Clean Prod.

Tokede, O., & Traverso, M. (2020). Implementing the guidelines for social life cycle assessment: past, present, and future. The International Journal of Life Cycle Assessment, 25(10), 1910-1929.

UNEP/SETAC (2009). Guidelines for social life cycle assessment of products. Edited by Catherine Benoît, Bernard Mazijn, CIRAIG, et Processes and Services Interuniversity Research Centre for the Life Cycle of Products. Paris, France: United Nations Environment Programme. Accessed 28/11/2022 https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2009%20-%20Guidelines%20for%20sLCA%20-%20EN.pdf

UNEP (2020) Guidelines for social life cycle assessment of products and organizations. Edited by Catherine Benoît Norris, Marzia Traverso, Sabrina Neugebauer, Elisabeth Ekener, Thomas Schaubroeck, Sara Russo Garrido, Marcus Berger, et al. Accessed 28/11/2022 at https://www.lifecycleinitiative.org/ wp-content/uploads/2020/12/Guidelines-for-Social-Life-CycleAssessment-of-Products-and-Organizations-2020-sml.pdf

UNEP (2013) The Methodological Sheets for Subcategories in Social Life Cycle Assessment (S-LCA). Edited by Catherine Benoît Norris, Marzia Traverso, Sonia Valdivia, Gina Vickery-Niederman, Juliane Franze, Lina Azuero, Andreas Ciroth, Bernard Mazijn, Deana Aulisio. Accessed 28/11/2022 at https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S-LCA_methodological_sheets_11.11.13.pdf

Annex – Additional KPIs

As annex of this document, there are included the Additional KPIs coming from the needs from the different WPs (WP1, WP2, WP3, WP4, WP8 and WP9). The idea of these additional KPIs is to have the complete picture of the Evaluation Framework in only one document covering the complete needs of the PROBONO project. The level definition of the additional KPIs included in this Annex is different depending on the scope and progress of each of the WPs. It is expected that these definitions will be polish in later stages of the project once the scope is clearer. In addition, some additional KPIs could be added or deleted based on the final needs from each WPs and Living Labs.

WP1 Macro-Knowledge Base and GBN Framework

In D1.3 "GBN strategic Vision and KPI formalisation (I)", a preliminary set of KPIs have been identified for the different dimensions defined within a GBN. These KPIs will be more defined within the PROBONO WP1 activities during the next steps of the project and will be included as a final version in D1.4 "GBN Strategic Vision and KPIs Formalization (FINAL)" by M32. These KPIs will be calculated through the different WP1 activities.

- Climate neutral energy supply for GBNs - KPIs:
    - [WP1- KPI 1] Self-supply share = climate-neutral energy quantity generated in the GBN / energy consumed in the GBN (in each case electricity, heating, cooling and local mobility).
    - [WP1- KPI 2] High efficiency = energy consumption in the neighbourhood < XX% of the energy consumption of a comparable new-build neighbourhood.
- Green buildings for high air quality, pleasant microclimate and biodiversity – KPIs:
    - [WP1- KPI 3] Energy demand (electricity, heat) per m^2 of floor space.
    - [WP1- KPI 4] Proportion of envelope area used for solar energy generation.
    - [WP1- KPI 5] Proportion of envelope area used for greening.
    - [WP1- KPI 6] Offer of digital services.
- Future oriented Mobility – KPIs:
    - [WP1- KPI 7] Number of cars per 1,000 inhabitants.
    - [WP1- KPI 8] Size of public transport offer and sharing offers.
    - [WP1- KPI 9] Ratio of footpaths, cycle paths and squares to carriageways and car parking spaces.
- Public spaces and nature based solutions: High quality of stay and a lively neighbourhood – KPIs:
    - [WP1- KPI 10] Building density: proportion of public footpaths and amenity areas in relation to the built-up footprints and use areas in the GBN.
    - [WP1- KPI 11] Classification of public spaces and their proportions: low-traffic and traffic-free public spaces, paths along roads, public spaces with and without nature-based elements, etc.
- Digitalisation: Efficient infrastructure, high comfort and social participation – KPIs:
    - [WP1- KPI 12] Availability of broadband internet in the GBN.

    - [WP1- KPI 13] Availability of a digital platform offering local content.
    - [WP1- KPI 14] Extent of provision of local digital services.
    - [WP1- KPI 15] Possibility of active participation in the development of digital services and use of open data
- Social inclusion: High quality of life through social networks – KPIs:
    - [WP1- KPI 16] Barriers identified and measures taken to reduce them.
    - [WP1- KPI 17] Number and type of measures to promote participation in social life in the GBN.
    - [WP1- KPI 18] Provision of places and opportunities for participation in social life.
- Financing GBNs: Perspective of the investors – KPIs:
    - [WP1- KPI 19] Availability of well-defined ESG criteria.
    - [WP1- KPI 20] Use of the MOATA[3] tool or comparable tools to measure ESG criteria.
- GBN Living Labs: Framework for testing and demonstrating innovative solutions – KPIs:
    - [WP1- KPI 21] Availability of the description of the innovations and monitoring of the results.
    - [WP1- KPI 22] Measures to involve potential users in the development of innovations.

In addition to the above list of KPIs for WP1, in D1.10a it is mentioned a preliminary list of certifications, research projects and studies, etc. as a basis in how to assess and measure the success of a GBN. This will be matured and advanced through the next series of associated deliverables in WP1.

- DGNB certification.
- ISO 37120:2018 – Sustainable cities and communities – Indicators for city services and quality of life.
- The United for Smart Sustainable Cities (U4SSC).
- MySMARTLife H2020 project.
- CITYKEYS project.
- The Circularity Gap Report 2022.

<u>WP2 Social innovations</u>

What is suggested in this specific section is a social KPIs based Evaluation Framework which covers the social dimensions that are common to a GBN. It covers dimensions relevant for all the Living Labs but also consider aspects specific to each Living Lab. It offers a comprehensive evaluation framework as it assesses the user experience with deployed technologies, citizen and stakeholder satisfaction with PROBONO innovations and activities in the Living Labs and

[3] https://www.mottmac.com/digital/moata

makes use of the collaborative engagement tools developed to collect the engagement and user satisfaction data. The framework highlights the multiple social elements of sustainability in the GBNs. It has a strong focus on indoor environmental quality, spatial qualities, occupant satisfaction, co-use, shared services and infrastructure and community engagement, as well as sustainable and market behaviour.

The social KPIs that will be calculated are divided in different categories. Here a preliminary list of those social KPIs:

- Social performance – Equity – KPIs:
  - [WP2 – KPI 1] Access to services [GIS based assessment)]
  - [WP2 – KPI 2] Affordability of energy [Income share spent on energy]
  - [WP2 – KPI 3] Affordability of housing [Share of housing cost overburden]
  - [WP2 – KPI 4] Democratic legitimacy [BREEAM Survey]
  - [WP2 – KPI 5] Living conditions [HQI Survey]
- Social performance – Community – KPIs:
  - [WP2 – KPI 6] Social cohesion Sense of belonging [Scanlon Foundation survey]
- Social performance – People – KPIs:
  - [WP2 – KPI 7] Personal safety [Eurostat metrics survey]
  - [WP2 – KPI 8] Energy consciousness [TBP Likert survey]
- Public Behaviour – Company rewards – KPIs:
  - [WP2 – KPI 9] Branding, Reputation and Social responsibility [Survey based study]
  - [WP2 – KPI 10] Marketing adv. [Metric availability]
- Public Behaviour – Market acceptance – KPIs:
  - [WP2 – KPI 11] Percentage of green buildings [m^2 of certified green buildings]
  - [WP2 – KPI 12] Behavioural barriers [survey-based study]

These KPIs are not directly related to WP2 activities but to a comprehensive evaluation of GBNs, that is, how will GBNs impact the social/behavioural aspects of a neighbourhood. Hence, there is a very direct relation to WP1 KPIs as what we suggest here are in fact ways to measure and monitor the impact of GBNs on the "social pillar". The evaluation of WP2 activities will be defined in T2.6 at a later stage when we know more about what we will actually be doing in WP2.

WP3 Technical innovations "Construction and Renovation"

Within WP3 all the innovative solutions related with the Construction and Renovation activities are defined. Here a preliminary list of KPIs from those already identified innovations. This preliminary list can be adapted or expanded once the scope of each LL and the specific implementations are clearer. The specific WP3 KPIs has been defined by the technical partners involved in WP3.

[WP3 - KPI 1] Amount of reused material				
Unit	%	Pillar	Environmental	
Detailed description				
Mass % of material in the building/GBN being reused materials/products. For the evaluation of reused materials in the buildings, the materials reuse- or recycling potential should be evaluated and specified. It could be divided into: - Landfill. - Material utilization, i.e. as road-fill or similar. - Material recycling. - Direct reuse or upcycling.				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 68: WP3 - KPI 1 definition

[WP3 - KPI 2] Number of EPDs or material-specific data being linked to the new project				
Unit	TBD	Pillar	Environmental	
Detailed description				
% of materials/products in the project having EPD or relevant material specific data. In general, but especially in relation to reused materials, it is important to link relevant materials specific information into the new projects.				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 69: WP3 - KPI 2 definition

[WP3 - KPI 3] Expected remaining life of materials/building/GBN			
Unit	years	Pillar	Environmental
Detailed description			
Estimated remaining lifetime of specific material or the whole building/GBN. The remaining lifetime and expected maintenance is of interest, especially when working with reused materials (but also in relation to operation cost and maintenance/replacement).			

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 70: WP3 - KPI 3 definition

[WP3 - KPI 4] Consumption of drinking water				
Unit	m^3	Pillar	Environmental	
Detailed description				
m^3 of drinking quality water used in the building/GBN. Reducing the drinking water consumption reduces the operation cost and the pressure on the natural water cycle.				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 71: WP3 - KPI 4 definition

[WP3 - KPI 5] Discharge of waste water				
Unit	m^3	Pillar	Environmental	
Detailed description				
m^3 of waste water discharged from the building/GBN. Reducing the discharge of waste water reduces the operation cost and the pressure on the natural water cycle.				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 72: WP3 - KPI 5 definition

[WP3 - KPI 6] Service life of novel materials			
Unit	years	Pillar	Environmental
Detailed description			
Estimated durability of the materials without performance loss, in years.			

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 73: WP3 - KPI 6 definition

[WP3 - KPI 7] Roof cooling efficiency of the outdoor environment				
Unit	% or kWh/m^2·y	Pillar	Environmental	
Detailed description				
Performance in counteracting urban warming. Percentage of Heat released to the outdoor environment compared to a reference solution or a baseline. Using an averaged outdoor surface temperature of a roof-centric innovation and the outdoor air temperature, the convected heat could be evaluated (numerically with a BEM, or experimentally with measurements). The ratio between this value and the chosen reference gives its efficiency to not contribute to the Urban Heat Island.				
Baseline data needed	Yes	Calculation frequency	TBD	
Variables needed / Data requirements				
Experimental determination: Surface temperature of at least 2 positions free of remote shading of the roof before retrofitting. numerical simulation: - Albedo and Thermal Emissivity of the roof before retrofitting (taking 3 samples from a 200 x 200 test specimen) - Weather data (temperature, radiation, relative humidity, etc.). - Occupancy schedule vs. Temperature set-points. - Energy consumption submetered on last floor. - Building envelope geometry and thermal & physical values of layers.				
Assessment mechanism / Formula				
Energy simulations or On-site measurements - monitoring systems ηFRout = 100 * (Qoref -Qo)/Qoref Qo, the transmitted heat to the urban environment				
Life cycle stages				
Product stage	Construction	Use	End of Life	Beyond the

(A1-A3)	stage (A4-A5)	(B1-B7)	(C1-C4)	Building Life Cycle (D)

Table 74: WP3 - KPI 7 definition

[WP3 – KPI 8] Roof energy cooling efficiency			
Unit	% or kWh/m²·y	Pillar	Energy
Detailed description			
Percentage of Heat avoided to the indoor environment compared to a reference solution or a baseline. Using an averaged indoor surface temperature of a roof-centric innovation and the indoor air temperature, the convected heat could be evaluated (numerically with a BEM, or experimentally with measurements). The ratio between this value and the chosen reference gives its efficiency to not contribute to the Building Energy Demand.			
Baseline data needed	Yes	Calculation frequency	TBD
Variables needed / Data requirements			
Experimental determination: Surface temperature of at least 2 positions free of remote shading of the roof before retrofitting. Numerical simulation: --> For roof-centred innovation, necessity of investigating specifically last floor "Thermal zone", in order to attribute properly the benefits from the retrofitting actions. Sub-metering of last floor would help. --> A temperature sensor on this last floor could also allow to correct the measured energy consumption from the eventual changes in building usages. --> Occupant schedules estimate (per rooms). · Weather data (temperature, radiation, relative humidity, etc.) - occupancy schedule vs. Temperature set-points - Energy consumption sub-metered on last floor - Building envelope geometry and thermal and physical values of layers			
Assessment mechanism / Formula			
Energy simulations or On-site measurements - monitoring systems $\eta_{CEP} = 100 * (C_{EP, ref} - C_{EP})/C_{EP, ref}$ CEP: Primary energy consumption			

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 75: WP3 - KPI 8 definition

[WP3 - KPI 9] Roof cooling efficiency for the indoor environment			
Unit	% or °C.h	**Pillar**	Energy
Detailed description			
Mitigation potential of thermal discomfort during the cooling season. The cooling season is the period in which the building presents cooling needs and may vary according to the climate and the passive solution implemented. This efficiency is computed only for the occupied periods and based on the degree-hours (DH) according to the adaptive thermal comfort standard (EN 16798).			
Baseline data needed	Yes	**Calculation frequency**	TBD
Variables needed / Data requirements			
Experimental determination: Surface temperature of at least 2 positions free of remote shading of the roof before retrofitting. Numerical simulation: identical to Impact: --> For roof-centred innovation, necessity of investigating specifically last floor “Thermal zone”, in order to attribute properly the benefits from the retrofitting actions. Sub-metering of last floor would help. --> A temperature sensor on this last floor could also allow to correct the measured energy consumption from the eventual changes in building usages. --> Occupant schedules estimate (per rooms). · Weather data (temperature, radiation, relative humidity, etc.). - Occupancy schedule vs. Temperature set-points. - Energy consumption sub-metered on last floor. - Building envelope geometry and thermal and physical values of layers. - Measured indoor temperature in 1 or 2 rooms located directly under the roof.			
Assessment mechanism / Formula			
Energy simulations or On-site measurements - monitoring systems $\eta\ FRin = 100 * (DHref - DH)/Dhref$ DH, degree.hour on the summer period according to standard EN 16978			

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 76: WP3 - KPI 9 definition

WP4 Technical innovations "Energy production, Storage and Distribution"

Within WP4 all the innovative solutions related with the Energy production Storage and Distribution activities are defined. Here a preliminary list of KPIs from those already identified solutions. This preliminary list can be adapted or expanded once the scope of each LL and the specific implementations are clearer. The specific WP4 KPIs has been defined by the technical partners involved in WP4.

[WP4 - KPI 1] Electricity generation capacity installed within the LL (capacity per source)				
Unit	MW_{el}	**Pillar**	Energy	
Detailed description				
Type of power plant with resource used and its nominal power				
Baseline data needed	Yes	**Calculation frequency**	Once before and after the implementation	
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 77: WP4 - KPI 1 definition

[WP4 - KPI 2] Heat generation capacity installed within the LL (capacity per source)				
Unit	MW_{th}	**Pillar**	Energy	
Detailed description				
Type of heat generation plant with resource used and its nominal heating power				
Baseline data needed	Yes	**Calculation frequency**	Once before and after the implementation	
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 78: WP4 - KPI 2 definition

[WP4 - KPI 3] Cold generation capacity installed within the LL (capacity per source)			
Unit	MW_{th}	**Pillar**	Energy
Detailed description			
Type of cold generation plant with resource used and its nominal cooling power			

Baseline data needed	Yes	Calculation frequency	Once before and after the implementation

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 79: WP4 - KPI 3 definition

[WP4 - KPI 4] Electrical storage capacity installed within the LL			
Unit	kWh_{el}	Pillar	Energy
Detailed description			
Type battery installed and its capacity			
Baseline data needed	Yes	Calculation frequency	Once before and after the implementation

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 80: WP4 - KPI 4 definition

[WP4 - KPI 5] Thermal storage capacity installed within the LL			
Unit	kWh_{th}	Pillar	Energy
Detailed description			
Type of thermal storage and its capacity			
Baseline data needed	Yes	Calculation frequency	Once before and after the implementation

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 81: WP4 - KPI 5 definition

[WP4 - KPI 6] Share of heat consumer connected to the district heating system			
Unit	%	Pillar	Energy

Detailed description				
Share of heat consumer connected to the district heating system				
Baseline data needed	Yes	Calculation frequency	Once before and after the implementation	
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 82: WP4 - KPI 6 definition

[WP4 - KPI 7] Share of cold consumer connected to the district cooling system				
Unit	%	Pillar	Energy	
Detailed description				
Share of cold consumer connected to the district cooling system				
Baseline data needed	Yes	Calculation frequency	Once before and after the implementation	
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 83: WP4 - KPI 7 definition

[WP4 - KPI 8] Energy demand supplied the renewable energy storage system				
Unit	kWh	Pillar	Energy	
Detailed description				
Amount of energy demand covered by the renewable energy storage system				
Baseline data needed	Yes	Calculation frequency	Once before and after the implementation	
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 84: WP4 - KPI 8 definition

[WP4 - KPI 9] Energy saved thanks to bidirectional charging system				
Unit	kWh		**Pillar**	Energy
Detailed description				
Amount of primary energy not demanded from the network due to the deployment of bidirectional charging solutions				
Baseline data needed	Yes		**Calculation frequency**	Once before and after the implementation
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 85: WP4 - KPI 9 definition

[WP4 – KPI 10] RESS capacity vs. Energy storage ratio				
Unit	%		**Pillar**	Energy
Detailed description				
This indicator evaluates the performance and usefulness (in practical operation) of the Renewable Energy Storage System (RESS), by establishing the ratio between the total capacities of the RESS system versus the energy effectively stored.				
Baseline data needed	No		**Calculation frequency**	Monthly/Yearly
Variables needed / Data requirements				
- Total capacity of the RESS network - Energy in/out of the RESS network along time				
Assessment mechanism / Formula				
On-site measurements - monitoring systems				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 86: WP4 – KPI 10 definition

[WP4 – KPI 11] CO_2 savings due to the use of recycled materials				
Unit	kgCO_2eq	Pillar	Environmental	
Detailed description				
This indicator aims at quantifying the CO_2 emissions saved due to the use of recycled materials (plastic, composite) in GBN buildings, instead of petrol-derived ("primary") ones.				
Baseline data needed	Yes	Calculation frequency	Once, during the construction stage.	
Variables needed / Data requirements				
- Energy required for the production of primary materials - Amount of recycled material used - - Energy required per kg of primary and recycled materials produced				
Assessment mechanism / Formula				
BIM, LCA				
Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 87: WP4 – KPI 11 definition

[WP4 – KPI 12] CO_2 emissions per MWh of primary energy consumed in the GBN			
Unit	kgCO_2eq	Pillar	Environmental
Detailed description			
This indicator characterizes the CO_2 emissions associated to the energy mix feeding the GBN (both imported from the network and produced within the GBN).			
Baseline data needed	Yes	Calculation frequency	Monthly/Yearly
Variables needed / Data requirements			
- Historical recordings (e.g. monthly) of the energy mix. - Historical recordings of the GBN energy consumption. - Source of the energy consumed in the GBN.			
Assessment mechanism / Formula			
Energy bills			

Life cycle stages				
Product stage (A1-A3)	Construction stage (A4-A5)	Use (B1-B7)	End of Life (C1-C4)	Beyond the Building Life Cycle (D)

Table 88: WP4 – KPI 12 definition

WP8 Communication and dissemination activities

Within Communication and dissemination activities, there are some relevant KPIs which PROBONO should consider in order to show the final impacts achieved. These KPIs will allow at the end of the project to assess the Communication and dissemination impact achieved in PROBONO. All these KPIs will be calculated through the WP8 activities.

Here is the list of WP8 KPIs per type of Dissemination activity:

- Website:
  - [WP8 – KPI 1] Nº of page visits to the website.
  - [WP8 – KPI 2] Nº of references to the project on search engines.
- Newsletter:
  - [WP8 – KPI 3] Nº of newsletter subscriptions.
  - [WP8 – KPI 4] Nº of newsletters sent.
  - [WP8 – KPI 5] Open rate.
- Events:
  - [WP8 – KPI 6] Nº of conferences as speaker.
  - [WP8 – KPI 7] Nº of conferences with PROBONO presentations.
- Publications:
  - [WP8 – KPI 8] Nº of press releases published in the local, national or EU level journals.
  - [WP8 – KPI 9] Nº of academic publications in international conferences and journals.
- Instagram community:
  - [WP8 – KPI 10] Nº of followers.
  - [WP8 – KPI 11] Nº of post published.
  - [WP8 – KPI 12] Nº of post reached.
- Twitter community:
  - [WP8 – KPI 13] Nº of followers.
  - [WP8 – KPI 14] Nº of tweets published.
  - [WP8 – KPI 15] Total Nº of tweet impressions.
  - [WP8 – KPI 16] Nº of engagements (retweet, like, link click).
- Facebook community:

  - [WP8 – KPI 17] Nº of subscribers.
  - [WP8 – KPI 18] Nº of post published.
  - [WP8 – KPI 19] Nº of post reached.
- LinkedIn community:
  - [WP8 – KPI 20] Nº of subscribers.
  - [WP8 – KPI 21] Nº of news published.
- YouTube community:
  - [WP8 – KPI 22] Nº of views.
  - [WP8 – KPI 23] Nº of videos published.

WP9 Replicability and Exploitation activities

Within Replicability and Exploitation activities, there are some relevant KPIs which PROBONO should consider in order to show the final impacts achieved. These KPIs will allow at the end of the project to assess the Replicability and Exploitation impact achieved in PROBONO. All these KPIs will be calculated through the WP9 activities.

- [WP9 – KPI 1] Utility and/or Design patents [nº]
- [WP9 – KPI 2] Exploitation pathways developed [nº]
- [WP9 – KPI 3] Commercialisation plans explored [nº]
- [WP9 – KPI 4] Organisations, projects, networks, etc. [nº]
- [WP9 – KPI 5] Standardisation routes identified [nº]