ARV
CLIMATE POSITIVE CIRCULAR COMMUNITIES

D8.1 MONITORING, EVALUATION AND IMPACT ASSESSMENT FRAMEWORKS

WORK PACKAGE 8

Gianluca Grazieschi
Daniele Vettorato
Iuliia Maskova
Adriano Bisello
Aaron Estrada
Caroline Cheng
Daniel Herrera
Nicola Lolli
Elena Lucchi
Patricia Schneider-Marin
Judith Thomsen
Pietro Zambelli

31.12.2022

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036723

PROJECT INFORMATION

Project acronym	**ARV**[1]
Project title	Climate Positive Circular Communities
Project number	101036723
Coordinator	Norwegian University of Science and Technology / Inger Andresen
Website	www.GreenDeal-ARV.eu

DOCUMENT INFORMATION

Deliverable Number and Title	**D.8.1 Monitoring, evaluation and impact assessment frameworks**			
Due Month	Month 12 (December 2022)			
Work Package Number and Title	WP 8. Monitoring, Evaluation, and Impact Assessment			
Task number and Title	Task 8.1 Development of monitoring, evaluation and impact assessment specifications and guidelines.			
Dissemination Level	PU = Public, fully open			
Date of Delivery	31.12.2022			
Lead Authors	Gianluca Grazieschi - EURAC research Daniele Vettorato - EURAC research			
Contributors	Iuliia Maskova – IREC, Adriano Bisello – EURAC research, Aaron Estrada – EURAC research, Daniel Herrera – EURAC research, Elena Lucchi – EURAC research, Pietro Zambelli – EURAC research, Patricia Schneider-Marin – NTNU, Caroline Cheng – SINTEF, Nicola Lolli – SINTEF, Judith Thomsen – SINTEF			
Reviewers	Inger Andresen - Norwegian University of Science and Technology (NTNU), Dennis Lange - Center Denmark			
Status	Final DRAFT version (Pending European Commission approval)			
Revision Log	**Version**	**Author**	**Main changes**	**Date**
	V.01	Gianluca Grazieschi		07.12.2022
	V.02	Iuliia Maskova	Addition of Appendix D	19.12.2022
	V.03	Inger Andresen	Final review	22.12.2022

[1] *ARV is a Norwegian word meaning "heritage" or "legacy". It reflects the emphasis on circularity, a key aspect in reaching the project's main goal of boosting the building renovation rate in Europe.*

ABOUT THE ARV PROJECT

The vision of the ARV project is to contribute to a speedy and wide scale implementation of Climate Positive Circular Communities (CPCC) where people can thrive and prosper for generations to come.

The overall aim is to demonstrate and validate attractive, resilient, and affordable solutions for CPCC that will significantly speed up the deep energy renovations and the deployment of energy and climate measures in the construction and energy industries.

To achieve this aim, the ARV project will employ a novel concept relying on a combination of 3 conceptual pillars, 6 demonstration projects, and 9 thematic focus areas.

The 3 conceptual pillars are integration, circularity, and simplicity. **Integration** in ARV means the coupling of people, buildings, and energy systems, through a multi-stakeholder co-creation and the use of innovative digital tools. **Circularity** in ARV means a systematic way of addressing circular economy through an integrated use of Life Cycle Assessment, digital logbooks, and material banks. **Simplicity** in ARV means to make the solutions easy to understand and use for all stakeholders, from manufacturers to end-users.

The 6 demonstration projects are urban regeneration projects in 6 locations around Europe. They have been carefully selected to represent the different European climates and contexts, and due to their high ambitions in environmental, social, and economic sustainability. Renovation of social housing and public buildings are specifically focused. Together, they will demonstrate more than 50 innovations in more than 150,000 m^2 of buildings.

The 9 thematic focus areas are 1) Effective planning and implementation of CPCCs, 2) Enhancing citizen engagement, environment, and well-being, 3) Sustainable building re(design) 4) Resource efficient manufacturing and construction workflows, 5) Smart integration of renewables and storage systems, 6) Effective management of energy and flexibility, 7) Continuous monitoring and evaluation, 8) New business models and financial mechanisms, policy instruments and exploitation, and 9) Effective communication, dissemination, and stakeholder outreach.

The ARV project is an Innovation Action that has received funding under the Green Deal Call LC-GD-4-1-2020 - Building and renovating in an energy and resource efficient way. The project started in January 2022 and has a project period of 4 years, until December 2025. The project is coordinated by the Norwegian University of Science and Technology and involves 35 partners from 8 different European Countries.

EXECUTIVE SUMMARY

The establishment of a set of key performance indicators to evaluate the Climate Positive Circular Communities promoted by ARV involves developing specific guidelines for calculating and evaluating the performance targets. This deliverable builds upon the Assessment Framework for CPCCs developed within Work Package 2 (D2.1), were the key performance indicators of the ARV project were defined.

Three main frameworks methodologies were developed in this work:

- monitoring framework, that is mainly dealing with the collection of time series data related to energy consumptions, renewable energy production, decentralized energy exchange, indoor environmental quality, local weather conditions
- evaluation framework, that is deployed to evaluate subjective parameters or static measurements
- impact assessment framework, that integrates the information gathered through the monitoring and evaluation activities and that provides a comprehensive overview of the sustainability level achieved by the demos in relation to the environmental, economic, and social dimensions.

A brief introduction of the Multiple Benefits Analysis is also provided in this work. This kind of activity, that will be further implemented in the future developments of Work Package 8, is dealing with the evaluation of the expected impact of the call (that are already measured through the key performance indicators) but also of the unexpected results or benefits achieved by the ARV project that involve the overall stakeholders affected by the interventions proposed.

The target audience is represented by the people working in the demo groups who were asked to discuss and validate the guidelines proposed, check for implementation feasibility, and select the topics of interest.

TABLE OF CONTENTS

1. INTRODUCTION

The definition of an assessment framework for the evaluation of the projects targeting sustainable neighborhoods proposed by the ARV Project implies, in some ways, the elaboration of specific guidelines on how the performances required should be calculated. The calculation methodologies suggested by ARV make use of real data that are gathered from the demos. This activity, that is entrusted to the demo groups, is quite labor intensive and will be performed as the demo projects are developed to verify how the assessment framework is implemented. Some workshops or dissemination events will be organized to discuss the results obtained by the interventions proposed to accomplish the CPCC objectives.

The present guidelines are structured in three main frameworks: monitoring, evaluation, and impact assessment. The monitoring framework deals with the collection of time dependent indicators and implies the installation of automatic sensors. The evaluation framework is, instead, focused on the collection of static data that can be employed in the calculation of different indicators. Finally, the impact assessment framework integrates, enriches and enhances the information gathered in the previous ones with the goal of determining cumulative and aggregated indicators that can describe the environmental, economic and social sustainability performances of the ARV demo cases.

This deliverable is organized as follows:

- section 2 recalls the objectives of the protocols proposed;
- section 3 deploys the guidelines for monitoring;
- section 4 reports the protocols and calculation methodologies that should be employed in the evaluation activities;
- section 5 describes the boundary conditions and assumptions characterizing the impact assessment methodologies (LCA, LCC and SLCA) that are proposed for the evaluation of the comprehensive sustainability performance of the ARV interventions.

2. OBJECTIVES

After the definition of a set of Key Performance Indicators (KPIs) of the ARV project as described in Deliverable 2.1 'Assessment Framework for CPCCs', this report provides guidelines for monitoring and evaluation for the implementation of the KPIs in the ARV demo projects. In particular, the guidelines in this report aim at providing a harmonized methodology for the calculation and evaluation of the KPIs and at establishing the minimum data quality requirements for their determination. Moreover, the guidelines provide a series of requirements for the collection of the data necessary for forecasting and modelling activities addressed by the ARV project in Work Package 7 'Efficient Operation and Flexibility'.

These guidelines should therefore represent a reference instrument for the participants in the development of the ARV demo interventions, that are the recipients of this document. The guidelines were developed following a practical and operational formulation in order to provide to each group working on a ARV demo the necessary protocols to design and manage the monitoring, data collection, and evaluation activities.

3. MONITORING FRAMEWORK

The two concepts of *monitoring* and *measuring* are described in the Standard ISO 90001:2015 as follows: *Monitoring* gives the state of a system, process, or activity, while *measuring* provides only one value that describes the actual characteristics of something. Monitoring is thus an activity that assesses the variability of a physical dimension in time. Within this definition, the output of the monitoring campaign can be considered the individuation of a time series that describes the fluctuation of the variable in analysis over time. When speaking about time series, the granularity of the data collected is very important: the frequency of the instrumentation used should permit to reconstruct a time series that is able to describe properly the variability of the monitored quantity.

Different kinds of sensors, monitoring systems, and technical instrumentation are usually employed for monitoring purposes. Depending on the data granularity, the collection of the data can be very demanding, and automatized procedures are necessary to succeed in the scope.

In ARV, monitoring campaigns are necessary to assess the different aspects of the demo cases concerning their energy and environmental requirements, the construction activities, the interaction between the CPCC studied and the external energy grids, and the indoor environmental quality. In particular, the scope of the monitoring activities is to provide useful information to calculate the key performance indicators (KPIs) defined in the Deliverable 2.1 of the project: Figure 1 links the parameters that should be monitored and the related KPIs proposed by ARV.

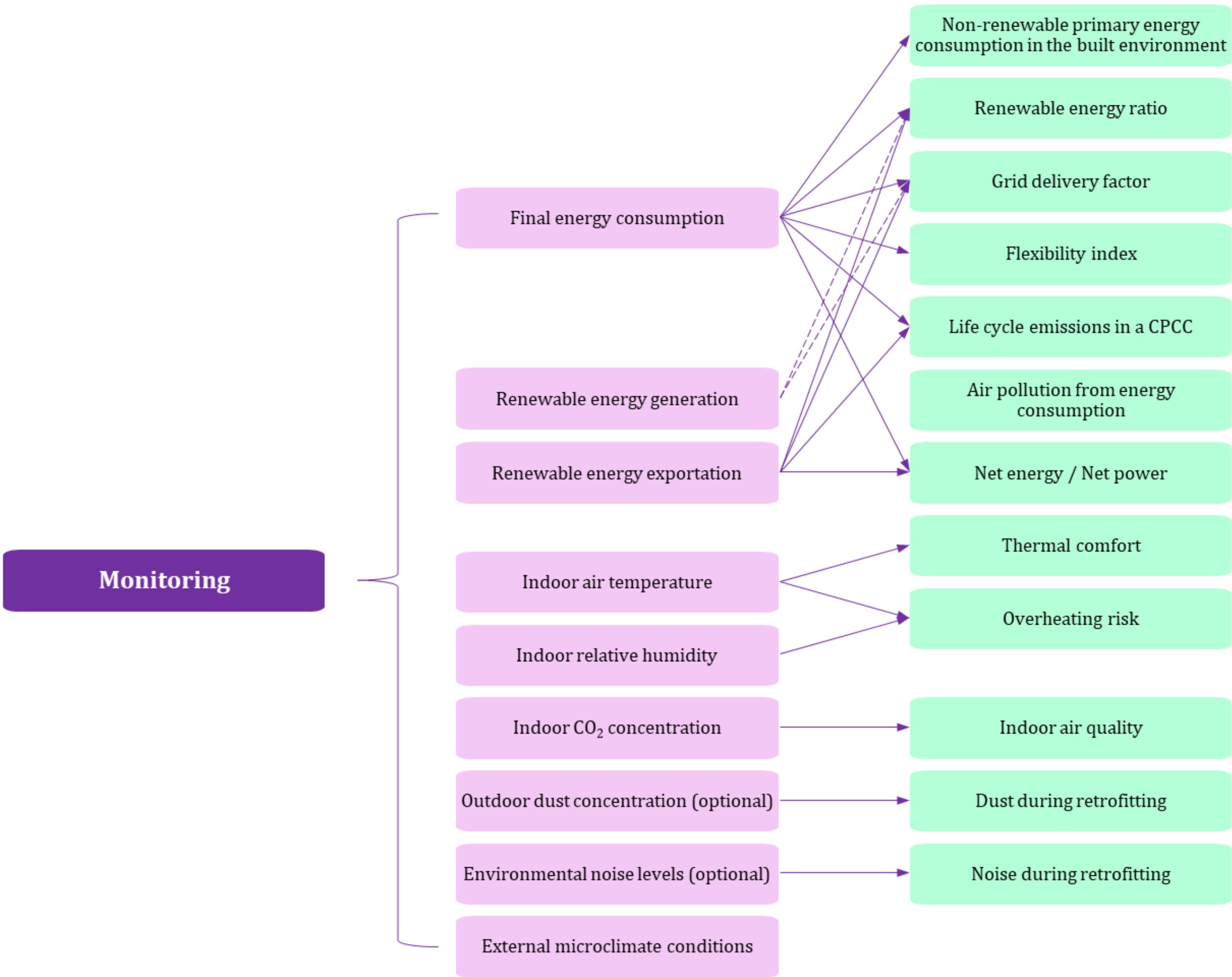


Figure 1*. KPIs and calculation parameters that are determined through monitoring activities.*

Particularly, when considering energy related aspects or comfort conditions in buildings, a high variability in time can be detected and it does not permit to describe the related parameters with a single measured value. The definition of these parameters requires a data collection with a frequency that is often hourly or sub-hourly and that cannot be performed manually. On the contrary, other parameters, such as the construction time or the characteristics of materials that are embedded in the construction, are not characterized by a time variability, and thus can be determined through measuring activities. The detailed data provided by the monitoring campaigns should also be used, after some elaborations and aggregations, in the environmental, economic, and social impact assessment analyses that are introduced in the following sections.

Monitoring is an activity realized by the members of the demo teams who are responsible for the correctness of the overall methodology, for the acquisition of the instrumentation and for the collection of the results.

3.1. OPERATIONAL ENERGY CONSUMPTION

The monitoring of the energy consumptions aims at acquiring a deep knowledge of the energy uses and consumptions of a building.

The monitoring plan should respect three essential criteria:

- Distinction between primary energy, net final energy and useful energy
- Distinction of the single energy carriers (e.g., electricity, steam, hot water, air) regardless the different energy uses (heating, cooling, domestic hot water, lighting, appliances)
- Distinction between the buildings that have different functions (e.g., residential, office, educational, hospital) and that are characterized by different activities and energy consumption patterns.

Final energy: definition
The *gross final energy* consumption is defined by the Renewable Energy Directive (2009/28/EC) as the sum of the energy used by the end consumers (transport, services, industry, households, agriculture, and fisheries and forestry) plus the self-consumption of power plants (of both heat and electricity) and grid losses.
The *net final energy* represents the energy that is delivered to the end consumer such as households, industry, and agriculture. It is the energy that reaches the final consumer's door and excludes the amount that is used by the energy sector itself for energy conversion/transformation purposes or during the energy transportation processes.

Primary energy: definition
Primary energy refers to the direct use of natural energy at the source when it has not been subjected to any conversion or transformation process. Primary energy sources can generally be classified in *renewable or non-renewable* based on whether they draw on depleting energy resources.

Useful energy: definition
The useful energy is the energy delivered by conversion and emission devices (e.g., fan coils, radiators, etc.) in the form required to provide an energy service (e.g., sensible heating or cooling).

This section includes a description of monitoring procedures, instrumentations and standards to be employed in each demo case study.

Scope
The monitoring campaign should permit the determination of following synthetic KPIs:

- Non-renewable Primary Life Cycle Energy in the Built Environment
- Renewable Energy Ratio
- Grid Delivered Factor

- Net energy/Net power
- Flexibility index
- Lifecycle GHG emissions in CPCC

The calculation of the above listed KPIs ensures the achievement of the requirements established in the following EIC (Expected Impacts of the Call) of the ARV project:

– EIC1 - Primary energy savings triggered by the project;
– EIC3 - Demonstration sites that go beyond nearly-zero energy building performance;
– EIC4 - Nearly zero energy level for retrofitted buildings and positive energy level for new constructions;
– EIC5 - Reduction of greenhouse gas emissions towards zero (in tCO_2- eq/year) for the total life cycle compared to the current situation shown through cradle-to-cradle LCA;
– EIC7 - Reduction of air pollutants towards zero (in kg/year) for the total life cycle compared to the current situation shown through cradle-to-cradle LCA.

Finally, the monitoring of the energy requirement of the ARV interventions can be useful to define detailed load profiles that can be used for optimization and forecasting scopes.

Legislative framework

- Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD)
- Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency

Monitoring standards

- ISO 50001:2018 Energy management systems — Requirements with guidance for use
- ISO 50002:2014 Energy audits — Requirements with guidance for use
- EN 16247:2012 Energy audits
- EN17267:2019 Energy measurement and monitoring plan - Design and implementation - Principles for energy data collection

Monitoring instrumentation

The choice of the instrumentation should be based on a logic of efficacy (ability of capturing the desired physical measures) and efficiency (in terms of cost/quality of the device/accuracy of the measures). Power meters, gas meters, or mass/volume balances will be employed in the monitoring activities to measure the electrical and thermal final energy consumption. The data provided by the energy providers can be employed if they meet the following requirements: they are real and not based on estimations, and their temporal and spatial resolution is adequate to the scopes of the project.

Monitoring procedures and recommendations

The monitoring campaign should focus on the **net final energy requirement** of the building that is analyzed. The related primary energy consumptions will be determined employing energy conversion factors specific to the country where the case study is located. In the case of district heating or cooling grids, the heat delivered to the building analyzed should be monitored, and reliable and specific final energy conversion factors should be provided by the demo groups. Their determination should be based on real data about the energy requirement of the generation systems and also considering the losses in the grid and the different energy sources (renewable and not) that are exploited.

The minimum **frequency** for the data collection should be equal to 1 hour, but sub-hourly data with at least a 5 minute resolution are strongly recommended, particularly in the case of optimization and forecasting scopes. The **duration** of the monitoring campaign must not be lower than 1 year because the information required should be representative of all the seasons. A longer duration can provide more reliable data that are less affected by uncommon annual climatic conditions. The **spatial resolution** of the monitoring is the building level, more detailed levels (e.g., apartments or thermal zones) are out of the scopes of the ARV project.

If energy retrofits interventions are proposed, the monitoring of the final energy requirement of the buildings involved should be performed before and after the renovation to verify the magnitude of the energy savings that is achieved. If the monitored consumption before the intervention is absent or not representative (e.g., the function of the building changed after the ARV intervention or the building was abandoned), it is possible to use a dynamic energy model of the building (e.g., using EnergyPlus) to quantify the energy requirement of a twin building that was not subjected to the implementation of any retrofit. The model can be calibrated using the ex-post data on the energy consumption and operation. Alternatively, statistically representative data related to the energy consumptions of similar buildings can be considered.

The **unit of measure** adopted for the energy consumption is kWh. In case of decentralized renewable energy generation, the self-consumption of the building should not be included in its net final energy requirement but should be reported separately.

Output expected

The expected output is a dataset containing the net final energy requirement of the interventions, monitored and reported as a time series. The dataset should also be enriched with metadata that describe the monitoring procedure (e.g., typology of the energy vector, devise used, building monitored, if data refer to the ex-ante or ex-post scenario, etc.). Table 1 proposes a structuring scheme for the data derived from the monitoring campaign.

Table 1: *Possible structuring scheme of the data related to the energy consumption monitoring.*

Metadata: building 1, ex-ante, bidirectional power meter, gas meter, HDD, CDD, etc.				
Time	**Net final energy [kWh]**	**Description**	**Net final energy [kWh]**	**Description**
00:15:00 01/01/23	…	Electricity grid	…	Gas/biomass etc.
00:30:00 01/01/23	…	Electricity grid	…	Gas/biomass etc.
…	…	Electricity grid	…	Gas/biomass etc.
23:45:00 31/12/23	…	Electricity grid	…	Gas/biomass etc.

3.2. RENEWABLE ENERGY GENERATION

The interventions proposed by the ARV demo cases put in place different renewable energy generation systems that range from building integrated photovoltaics (BIPV), to solar panels and geothermal probes, etc. The installation of monitoring systems for these kind of systems is generally quite important not only to fulfill the ARV objectives but also to correctly manage their operation and maintenance. An overview of the scopes, standards, instrumentations, procedures, and expected outputs linkable to the monitoring activities proposed by ARV, is reported in this section.

Scope

The first scope of the monitoring of the renewable energy produced by these systems is to detect if they are properly working: the loss of efficiency results in an economic loss and can be caused by different aspects, such as the lack of maintenance, the failure, or the dirtying of single components.

Secondly, the monitoring campaign should provide useful information to guarantee the calculation of the KPIs that are defined in detail in the Deliverable 2.1 and that will permit to check the achievement of ARV EIC. The addressed KPIs are:

- Renewable Energy Ratio
- Grid Delivered Factor
- Net energy/Net power
- Lifecycle GHG emissions in CPCC

Finally, the monitoring of the renewable energy production is also important for the development of the forecasting and flexibility models that are proposed within the ARV project.

Monitoring instrumentation

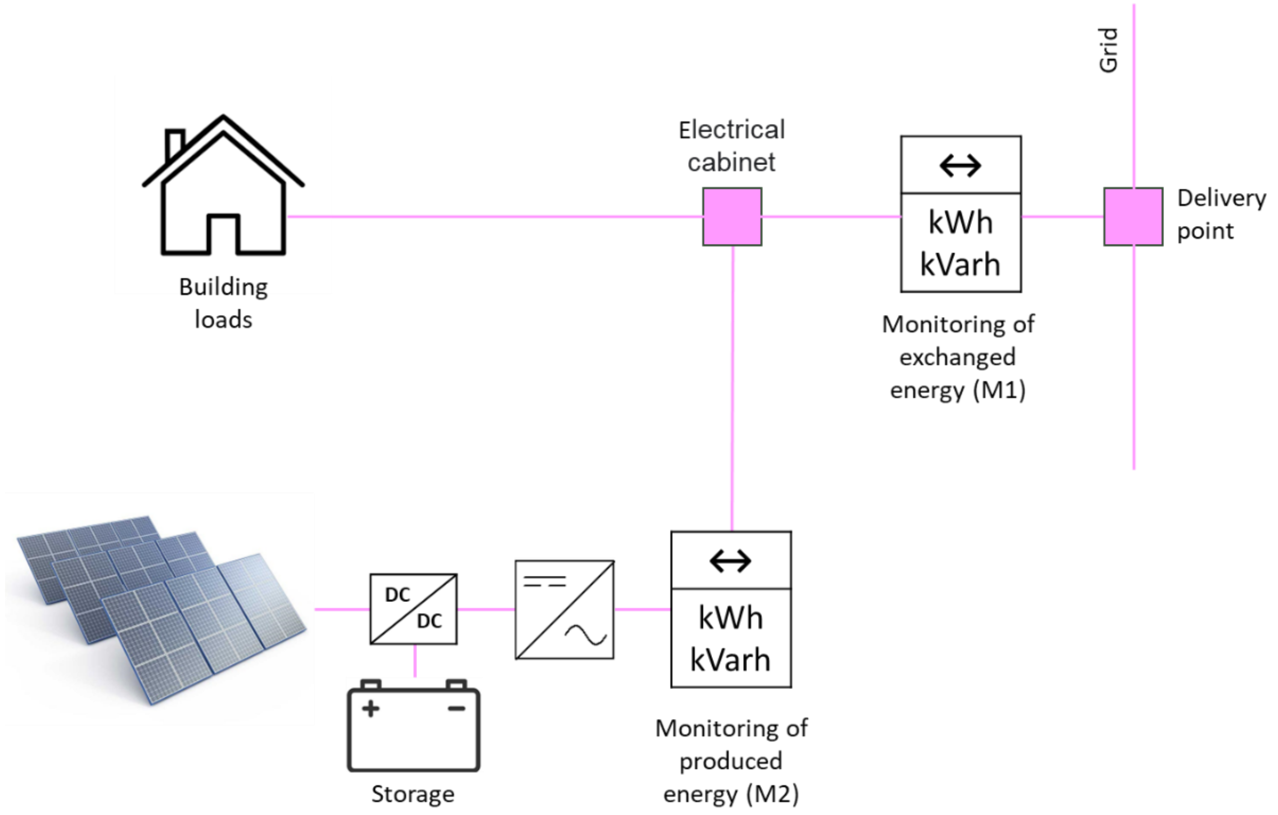
The monitoring instrumentation depends on the typology of energy systems. In the case of electrical systems, three typologies of power meters can be installed: here labelled as M1, M2 and M3. The M1 devise is a bidirectional power meter that is installed in the delivery point and that quantifies the energy that is exported into the external electrical grid. The same devise is used to monitor the energy that is imported from the grid. M2 is a monitoring devise that quantifies the energy that is produced by the renewable generation system and that should be installed downstream of the inverter. In this way, when the storage is installed on the production side (see Figure 2a and Figure 2b), the monitored energy production is net of the energy for auxiliar services and accounts also for the effect of the storage system. M3 is, instead, the monitoring device that quantifies the charging and discharging current of the storage systems when it is installed in the post-production side (see Figure 2c).

Thermal systems should be monitored using “heat meters”. These devises are basically based on the following equation:

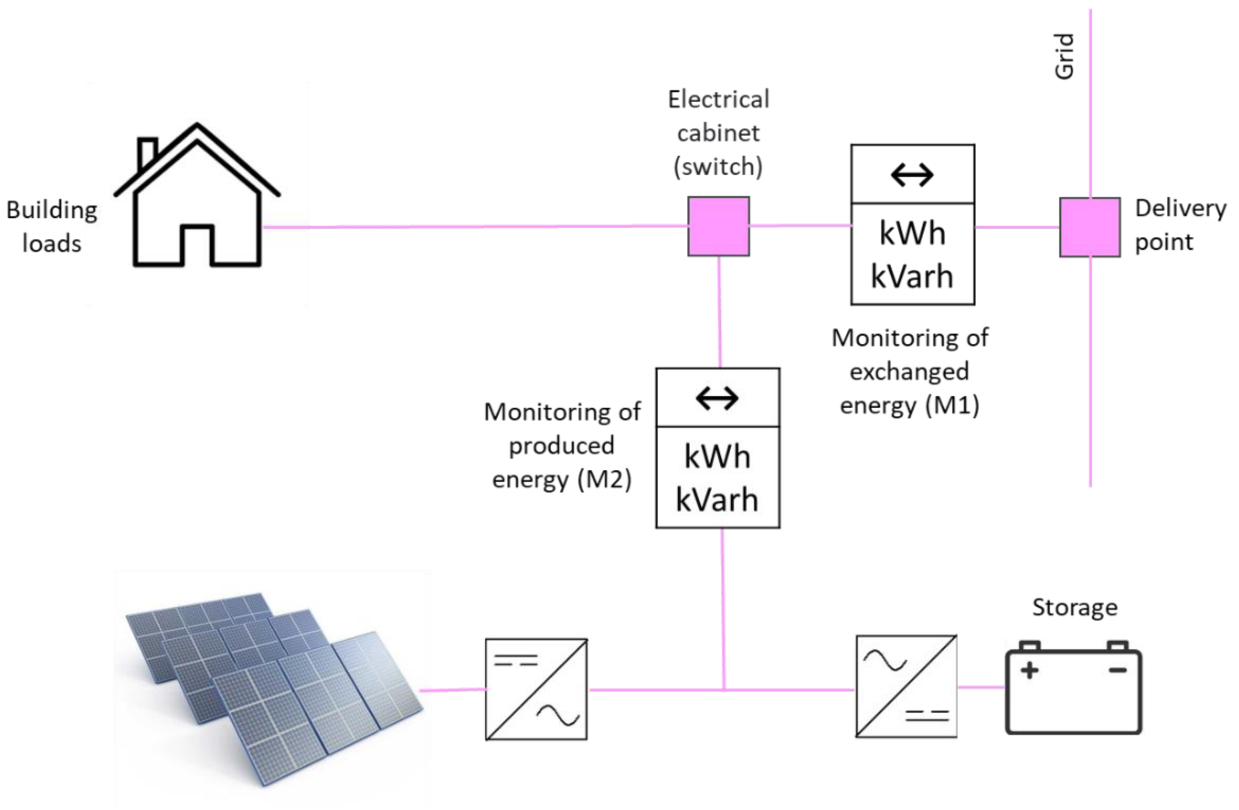
$$E_{th}(t) = q * c_p * (T_{in} - T_{out})$$

The system is composed of an instantaneous mass flow meter and of two thermometers since the $\boldsymbol{c_p}$ (J/kg K) of the fluid is known. They are so able to determine the power exchanged measuring the mass flow rate $\boldsymbol{q}$ (kg/s) and the inlet and outlet temperatures ($\boldsymbol{T_{in}}$, $\boldsymbol{T_{out}}$). The integration of the power in time provides then the energy exchanged between the two systems. The effect of the storage is also important for thermal renewable energy installations and the monitoring system should be installed downstream of the storage unit.

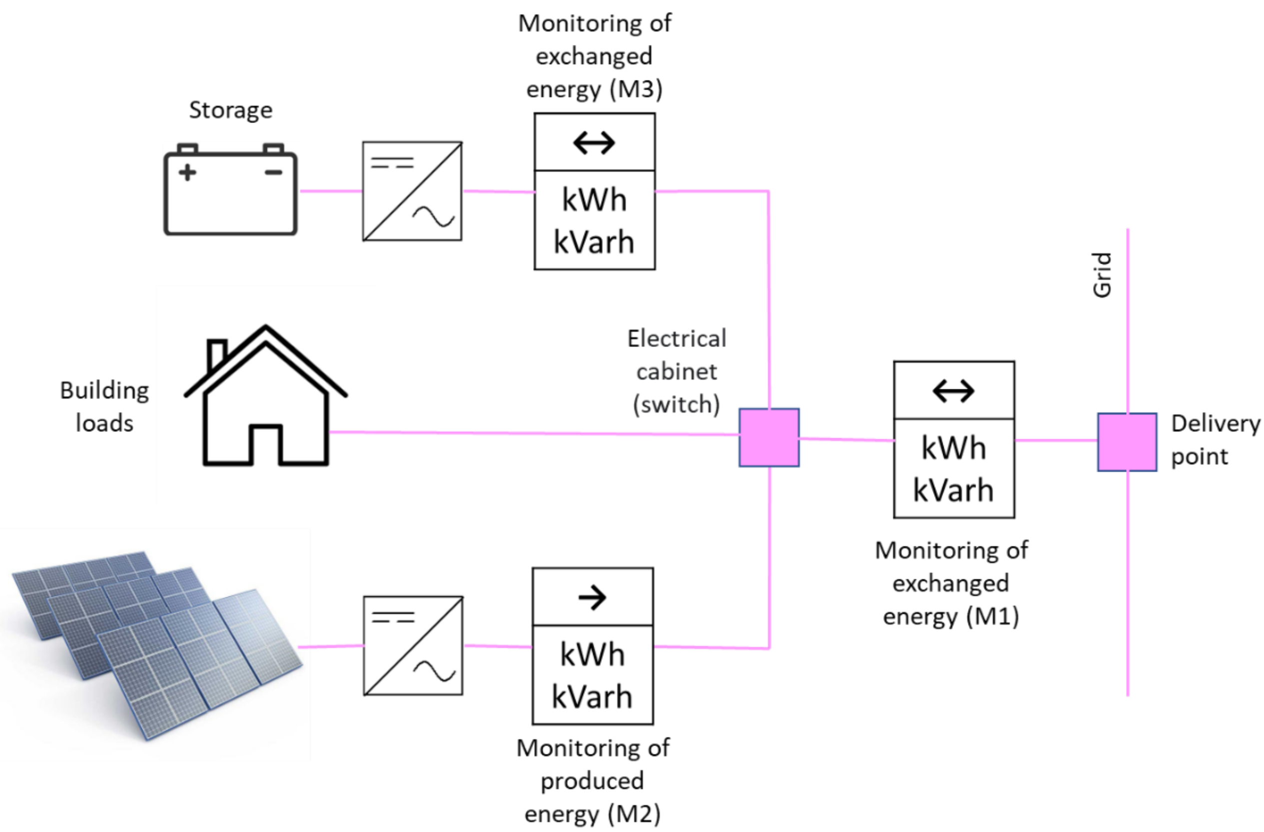
Figure 2 shows the configurations that should be adopted for the monitoring of the PV energy produced and exchanged with the external grid.


Grid
Electrical
cabinet
Delivery
point
Building
loads
kWh
kVarh
Monitoring of
exchanged
energy (M1)
DC
DC
kWh
kVarh
Storage
Monitoring of
produced
energy (M2)

(a)


Grid
Electrical
cabinet
(switch)
Building
loads
kWh
kVarh
Delivery
point
Monitoring of
exchanged
energy (M1)
Monitoring of
produced
energy (M2)
kWh
kVarh
Storage

(b)



(c)

Figure 2*. Configurations of the monitoring system for PV installations: (a) storage on the production side in DC, (b) storage on the production side in AC, (c) storage on the post-production side.*

Monitoring procedures and recommendations

The monitoring campaign should start after the realization of the interventions for a **time frame** that is equal to 1 year. The minimum **frequency** that is recommended for the determination of the KPIs is equal to 1 hour. The **spatial resolution** consists of a building unit or a residential block. A higher spatial resolution (e.g., at the apartment scale in case of residential blocks) can be considered based on the scopes and characteristics of the demo's activities. The **unit of measure** adopted is kWh.

Table 2*: Proposed structuring scheme for the data related to the renewable energy monitoring.*

Metadata: building 1, ex-ante, bidirectional power meter, heat meter, etc.				
Time	**Energy generated [kWh]**	**Description**	**Energy exported [kWh]**	**Description**
00:15:00 01/01/23	…	Photovoltaic	…	National electricity grid
00:30:00 01/01/23	…	Photovoltaic	…	National electricity grid
…	…	Photovoltaic	…	National electricity grid
23:45:00 31/12/23	…	Photovoltaic	…	National electricity grid

Output expected
The result of the monitoring campaign consists of a dataset that contains some data, reported in a time series format, about the renewable energy produced by each system installed by the demo cases and, in case of electrical systems, also about the energy that is exported into the external energy grid. The data structuring scheme that is shown in Table 2 is recommended for the outputs of the monitoring of renewable energy generation systems.

3.3. INDOOR ENVIRONMENTAL QUALITY

The indoor environment represents all the confined spaces where people spend part of their life. The maintenance of adequate comfort conditions inside these spaces has a fundamental importance for the explication of the function they should perform. The indoor environmental quality can be evaluated through a broad set of indicators, such as the ones reported in Table 3. This set is not exhaustive since the perceived comfort conditions depend on temperature (air, radiant), relative humidity and air velocity, but they are also affected by other personal parameters such as the clothing, the level of activity and the metabolic rate of people.

***Table 3**: Indicators for an indoor environmental quality check.*

Parameter	Unit
CO_2 concentration	ppm (parts per million)
CO concentration	ppm (parts per million)
PM 10	$\mu g/m^3$
PM 2.5	$\mu g/m^3$
Indoor air temperature	°C
Time outside indoor thermal comfort range	%
Relative humidity	%
R'_w Noise insulation (between units)	dB
$D_{2m,nT,w}$ Noise insulation of façades	dB
$L'_{n,w}$ Noise transmission between floors (tapping)	dB
L_{Aeq} Noise of continuous functioning systems	dB
Luminance (E)	lux
Daylight Factor (DF)	%
Luminous intensity (L)	cd/m^2

Considering economic and feasibility issues, the evaluation proposed by ARV is to monitor only some of the parameters of Table 3: CO_2 concentration, air temperature and relative humidity measures will be employed for the determination of three indicators that concern the air quality and the thermal comfort in indoor rooms. The choice can be explained by the fact that not all aspects are equally important in the subjective evaluation of IEQ: Humphreys (Humphreys, 2005), for example, showed that satisfaction with warmth and air quality is more important than satisfaction with the level of lighting or humidity. However, temperature and relative humidity are the two main parameters to be considered during the design of building energy systems while the concentration of CO_2 is a good indicator of indoor air quality and of the appropriateness of the ventilation system.

Indoor CO_2 can accumulate if ventilation is not able to dilute the CO_2 that is continuously produced by building occupants. The CO_2 concentration in an occupied indoor space indicates if the air exchange balance between the building and the outdoor environment is appropriate, thus if an optimal amount of outdoor air is being mixed with the air that has been circulating inside the building. CO_2 is produced when people breathe. Each exhaled breath by an average adult contains from 35 000 to 50 000 parts per million (ppm) of CO_2 – 100 times higher than it is typically found in the outside environment. The CO_2 levels in the air outside a building are usually 380 ppm or higher (usually up to 500 ppm), depending on local conditions, such as the presence of traffic, combustion sources or wind and temperature inversions that can cause gases to build up locally. A high indoor CO_2 concentration is directly related to the number of occupants in the building, to the ventilation rate, and to the CO_2 level that characterizes the outside environment.

The effects of CO_2 exposure in indoor environment are generally the following ones:

- 1000ppm: in areas where the unique source of CO_2 is human metabolic activity, CO_2 levels above 1000ppm would produce the appearance of bio-effluents in occupants.
- 2500ppm: at this level, cognitive functions of occupants may begin to be impaired.
- 30000ppm: this is the 15-minute short term exposure limit set by OSHA.
- 40000ppm: for exposures longer than 5 minutes, it causes an immediate danger to health.
- 50000ppm: if exposition is longer than 30 minutes, this concentration is lethal for humans and causes unconsciousness.

Scopes of the activity

The scope of the IEQ monitoring activity is linked to the achievement of EIC that were defined in the project proposal and that are verified through a set of KPIs that have already been defined in Deliverable 2.1. The KPIs involved in the IEQ monitoring activities are:

- Indoor air quality
- Thermal comfort
- Overheating risk

In case of energy retrofits, the EIC foresees an improvement of 30% in the IEQ compared to local practice or pre-intervention levels: that is why measures about IEQ should be performed before and after the realization of the ARV interventions. The values measured for new buildings should instead be compared with reference quality values (see Table 4).

***Table 4**: Ideal comfort quality values for the ARV interventions.*

Parameter	Objective	Reference
Air quality (CO_2 concentration in occupied spaces)	New constructions: 80% of hours in categories IEQI, IEQ II. Renovations: reduction of the 30% in the amount of hours in categories IEQI, IEQ II. Maximum 650 ppm above the outside level (350-500 ppm).	EN 16798-1:2019 (CEN, 2019) ASHRAE 62.2.2012 (American Society of Heating, Refrigerating, and Air Conditioning Engineers, 2012) Deliverable 2.1 – section 7.6
Thermal comfort (temperature with heating and cooling ON)	New constructions: 80% of hours in categories IEQI, IEQ II. Renovations: improvement of the 30% in the amount of hours in categories IEQI, IEQ II.	EN 16798-1:2019 (CEN, 2019) Deliverable 2.1 – section 7.7
Overheating risk (systems ON)	New constructions: 60% of hours with Humidex<35. Renovations: improvement of the 30% in the amount of hours with Humidex<35.	EN 16798-1:2019 (CEN, 2019) Deliverable 2.1 – section 7.8

The comfort categories displayed in Table 4 are defined following the EN 16798-1:2019 (CEN, 2019). Concerning carbon dioxide concentration, the current ventilation guidelines of the American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE) (American Society of Heating, Refrigerating, and Air Conditioning Engineers, 2012) recommend that indoor CO_2 levels do not exceed the local outdoor concentration by more than about 650 ppm. The EN 16798-1:2019 (CEN, 2019) indicates four quality categories for CO_2 concentration in indoor environments regardless of the outdoor concentration.

Normative references

- ASHRAE Standard 62.2.2012: Ventilation for Acceptable Indoor Air Quality. Atlanta, USA, 2012.
- EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting, and acoustics - Module M1-6.

Monitoring instrumentation

Ideally, the instrumentation used should simultaneously measure all IEQ parameters such as internal air temperature, relative humidity, and CO_2 concentration: the adoption of these kind of devices would permit to avoid synchronization issues. Alternatively different devices may be used to monitor the different IEQ parameters: e.g., a CO_2 meter can be used to measure CO_2 levels in specific areas of the demo building. Table 5 shows the technical characteristics that the monitoring devises should guarantee.

***Table 5**: Instrumentation technical characteristics.*

Technical parameter	Description
Temperature range	0-50 °C
Humidity range	20-95%
CO_2 range	350-2000 ppm
CO_2 measurement error	± 50 ppm
Calibration certificate	Required
Measuring frequency	1-30 seconds

Monitoring procedures

The measures should be performed when the indoor space is occupied, and the heating and conditioning systems are continuously operating (if possible stationary conditions should be sought and transition phases should be avoided).

Addressing the **spatial resolution** of the monitoring campaign, some representative rooms of the building must be considered for the monitoring campaign, excluding circulation spaces, unoccupied spaces, technical rooms. The sampling **frequency** should be at least equal to 1/h for temperature and relative humidity. The measurement campaign should last at least 24 h for CO_2 concentration and, if possible, 1 year for temperature and relative humidity. In case the **1-year monitoring** is not possible, a representative monitoring time frame should be considered and discussed by the group that will perform the campaign.

The **units of measure** adopted by the project are:

- Temperature - °C
- Relative humidity - %
- CO_2 concentration - ppm

Outputs expected

The activity should produce a report containing:

1. A description of the instrumentation used, its accuracy, and frequency of measuring;
2. A description of the ventilation system that characterizes the building;
3. A map with the selected rooms where the monitoring is performed with a discussion about the reason that brought to their selection;
4. A dataset with the values of CO_2, temperatures, and relative humidity measured in the selected rooms of the demo (before and after the interventions in case of retrofitting). An average value of CO_2 concentration measured outside nearby the inlet of the ventilation system should also be provided.
5. A comparison of average values with reference or ex ante values. A reduction of the 30% in the time outside the comfort range and CO_2 concentration should be demonstrated.

Table 6 shows the expected structure of the data collected. Table 8 resumes the units of measure, the monitoring frequency, and periods (pre or post the realization of the intervention in case of retrofits) for each one of the parameters that should be monitored in the IEQ monitoring activities.

Table 6*: Proposed structuring scheme for the data gathered through the IEQ monitoring.*

Metadata: Thermal zone 1, ex-post, sensor 1, etc.				
Time	**Temperature [°C]**	**Relative humidity [%]**	**CO_2 [ppm]**	**Notes**
00:15:00 01/01/23	…	…	…	Heating on, 4 people
00:30:00 01/01/23	…	…	…	Heating on, 4 people
…	…	…	…	….
23:45:00 31/12/23	…	…	…	Heating on, 4 people

3.4. EXTERNAL MICRO-CLIMATE CONDITIONS

External microclimate conditions can influence the indoor comfort level as well as the energy consumption and generation from the renewable energy systems that are integrated in the building.

Scope

The scope of the monitoring of local micro-climate conditions is connected to the forecasting simulations that are proposed within Work Package 7 - Task 7.4 'Deployment of solutions for forecasting'. The development of these forecasting models requires a fine spatial resolution of the weather data that is not commonly available from municipality/metropolitan weather stations. The parameters that are involved are: weather conditions (sunny, rainy, cloudy, etc.), solar irradiation, external air temperature, wind velocity and direction, relative humidity. The monitoring of these parameters is not mandatory for all the demo cases, but it must be carried out only if the demo is involved or interested in the weather and performance forecasting activities proposed within the WP7 that are linked with PV forecasting.

Monitoring instrumentation

The campaign can be performed using an external weather station. The use of a sky camera can be necessary for a very short-term solar irradiance forecasting and for the forecasting of PV energy production. Some existing weather stations should instead be considered for the collection of the data at the metropolitan scale.

Considering the PV generation and the storage management, the monitoring instrumentation has already been described in the section "Renewable Energy Generation".

Table 7 reports some recommendations regarding the devices that are involved in this activity.

***Table 7**: Reference technical characteristics of the instrumentation.*

Device	Technical specifications
Pyranometer	Range: 0-1750 W/m^2 Resolution: 1 W/m^2 Accuracy: ±5%
Thermometer	Range: 0-50 °C Resolution: 0.1°C Accuracy: ±0.6°C
Anemometers	Range: 0-30 m/s – 0-359° Resolution: 0.1 m/s – 1° Accuracy: 3% * measurement (>0.3 m/s)
Hygrometer	Range: 0-100% Resolution: 0.1% Accuracy: 2%
Precipitations sensor	Range: 1-400 mm/h Resolution: 0.02 mm/h Accuracy: 5% (between 0-50 mm/h)
Sky camera	CCD type Resolution: 1392 x 1040 pixels

Monitoring procedures and recommendations

A sub-hourly **frequency** is required to carry out the forecasting activities: a 5 min resolution is the minimum requirement to accomplish the scope of the monitoring campaign, the **duration** of which can be lower than 1 year, based on the modelling data necessities. The monitoring instrumentation should be installed in a **location** that is representative of the climatic conditions and solar irradiation of the area where the PV systems are installed (ideally the weather station should be installed in the proximity of the PV panels measuring the irradiation on the same plane). Additionally public/private weather stations should be considered to gather data about the metropolitan weather conditions with a spatial resolution of 1 km.

Output expected

The result of the campaign should be the creation of a set of data about the local weather conditions, the metropolitan ones, the PV production, and energy flows characterizing the battery pack that is installed in case.

3.5. SUMMARY

The following Table 8 summarizes the monitored parameters with the related units of measure, monitoring devices, time and space resolutions, and duration of the acquisition campaign.

***Table 8**: Parameters and related monitoring devices and requirements.*

Description	Unit	Device	Time resolution	Duration	Spatial resolution
Net final energy	kWh	Power meter, gas meter, mass/volume balance	hourly	1 year	Building
Generated/exported energy	kWh	Power meter, heat meter	hourly	1 year	Building
Indoor air temperature	°C	Thermometer	hourly	1 year	Thermal zone
Relative humidity	%	Hygrometer	hourly	1 year	Thermal zone
CO_2 concentration	ppm	CO_2 sensor	hourly	1 year	Thermal zone
Solar radiation	kWh/m^2	Pyranometer	5 min	1 year	Close to the PV and at district/ metropolitan scale
External air temperature	°C	Thermometer	5 min	1 year	Close to the PV and at district/ metropolitan scale
Wind velocity and direction	m/s - °(N)	Anemometers	5 min	1 year	Close to the PV and at district/ metropolitan scale
External relative humidity	%	Hygrometer	5 min	1 year	Close to the PV and at district/ metropolitan scale
Sky coverage	image	Sky camera	<5 min	1 year	Close to the PV
Precipitations	mm/h	Rain sensor	5 min	1 year	Close to the PV and at district/ metropolitan scale

4. EVALUATION FRAMEWORK

The evaluation framework differs from the monitoring one because it is characterized by a data collection that is not carried out continuously in time. The results addressed are not time dependent, thus the evaluation can be considered as a measuring activity that provides a specific typology of information.

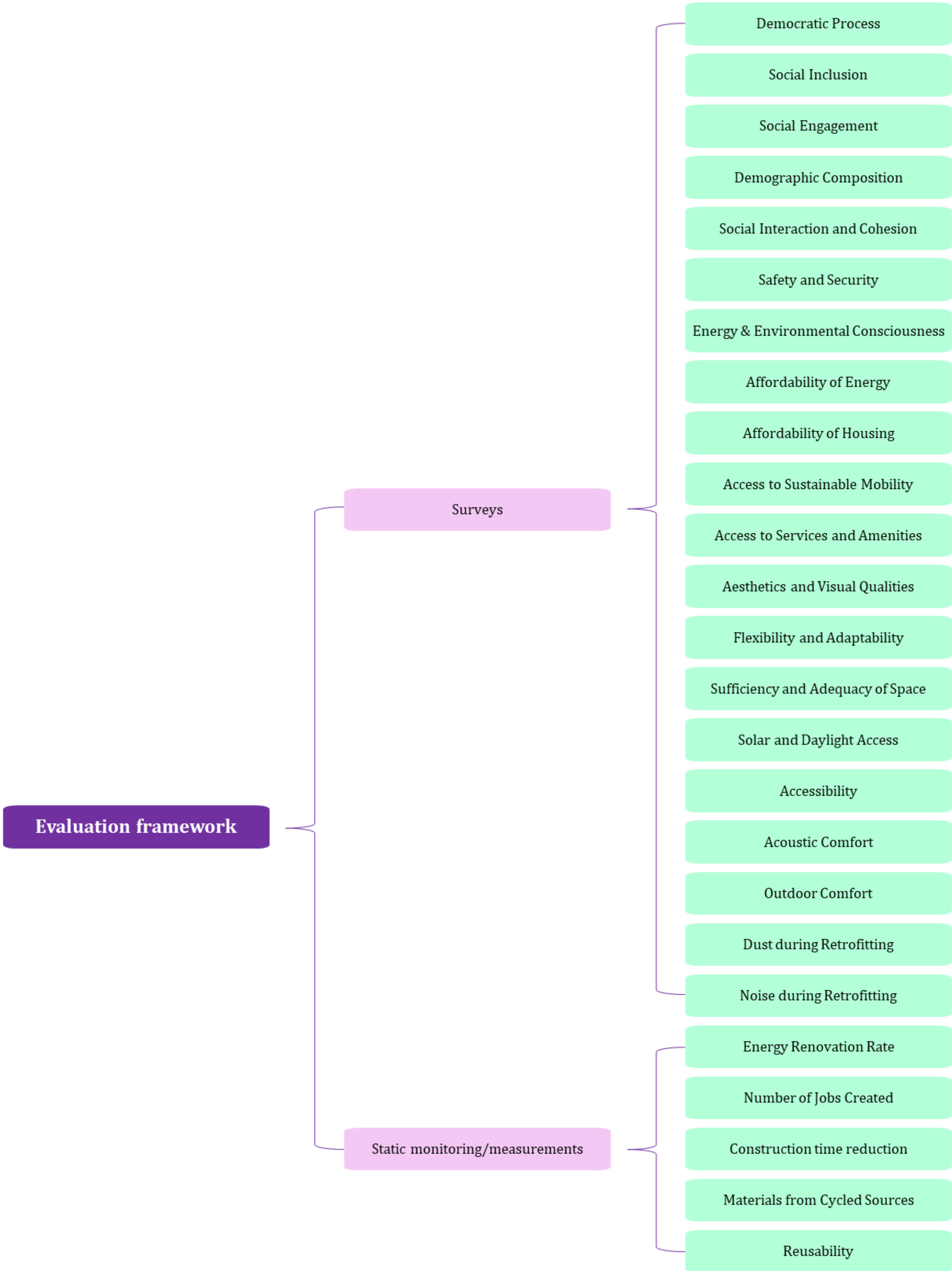


***Figure 3**: Evaluation framework: KPIs involved.*

The evaluation framework will guide an effective and systematic data collection and form the evidence base for the assessment of the progress of the demo cases and of their impact over time. Therefore, the evaluation framework proposed captures key information about how the progress and the impacts of the project will be evaluated. As for the monitoring, the scope of the evaluation framework is to provide useful information for the calculation of the KPIs defined in the Deliverable 2.1 of the ARV project and to support the objectives of the environmental, economic, and social impact assessment analyses of the demo cases that are introduced in the following sections. As shown in Figure 3, the evaluation framework is characterized by a subjective approach that employs surveys as a methodological instrument, and by an objective approach that is based on the measurement of some quantities related to the KPIs determination.

4.1. SOCIAL, ARCHITECTURAL & CONSTRUCTION WORKS ASPECTS

In the ARV project, the evaluation of social and architectural qualities involve various factors such as the promotion of a democratic decision-making process, the involvement of different social groups, the quality of housing, the affordability of housing and energy, the experienced health and security, the conditions of transportation and accessibility, etc.
Since social sustainability is often **context dependent**, it should be evaluated locally since different communities can have variable necessities, interests, relations, or dynamics.

Scope
The scope of the evaluation of social and architectural qualities, and construction works aspects is to gather information from the determination of the related KPIs. The KPIs involved in this analysis are:

Social quality

Democracy
- *Democratic process*
- *Social inclusion*
- *Social engagement*

Community
- Demographic composition
- Social interaction and cohesion
- Safety and security
- Energy and environmental consciousness

Equity
- Affordability of energy
- Affordability of housing
- Access to sustainable mobility
- Access to services and amenities

Architectural quality

- Aesthetics and visual qualities
- Flexibility and adaptability
- Sufficiency and adequacy of space
- Solar and Daylight Access
- Accessibility
- Acoustic comfort
- Outdoor comfort

Construction works performances:

- Noise during retrofitting
- Dust during retrofitting

Methodology

People living in the neighbourhood, such as tenants and students, are the *reference population* of the survey. Only people older than 19 years should be involved due to GDPR issues.

The evaluation of social and architectural aspects is performed through a survey campaign that takes place in three different moments of the realization of the ARV interventions:

1. Ex-ante, in the case of renovation interventions
2. During the construction works
3. Ex-post, namely when the intervention is concluded

Three questionnaires were prepared (see Appendix A, B, C) that represent a catalog of all the possible questions that demos can select to prepare their own surveys:

- Questionnaire 1
- Questionnaire 2
- Questionnaire 3

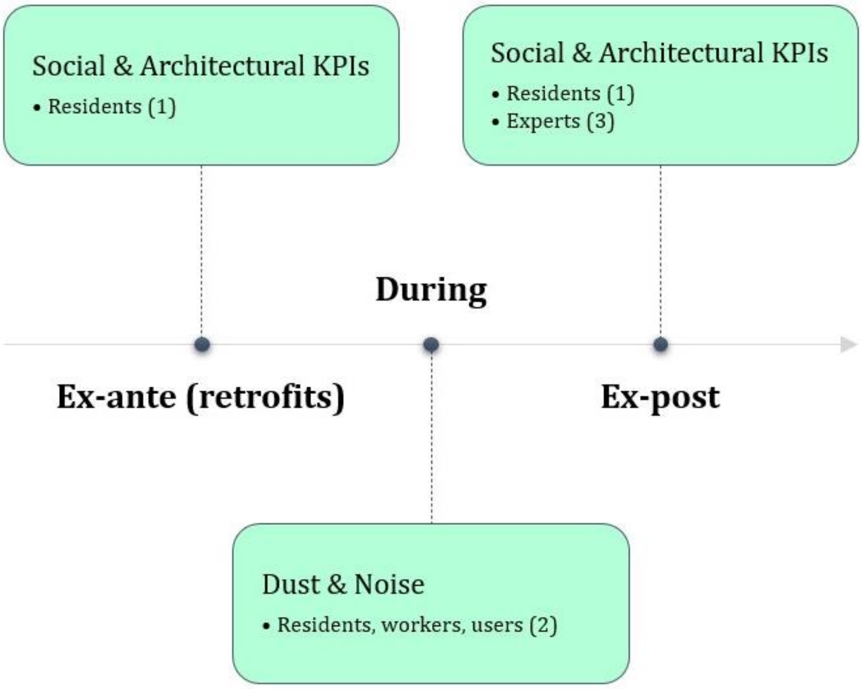


***Figure 4**: Phases, topics, and target population of the survey campaign: questionnaire (1) – see Appendix A, questionnaire (2) – see Appendix B, questionnaire (3) – see Appendix C.*

Questionnaire 1 is tailored to the residents of the area where the ARV interventions are located and focused on social and architectural qualities. In the case of renovation interventions, questionnaire 1 should be submitted before the beginning of the design stage and after the realization of the intervention in order to verify that the project produced the improvements targeted by ARV. For new buildings, the submission is performed only ex-post.

Questionnaire 2 is tailored to the residents and workers or habitual users of the area that are affected by the presence of the ARV construction activities. The topics that are addressed are related to the generation of dust and noise from construction works and how they are impacting the target population of the evaluation.

Questionnaire 3 is designed for experts of the construction sector: engineers, architects, members of the design team, technical consultants, developers, constructors and all the technicians who were involved in the realization of the ARV interventions. The focus on the ex-post evaluation of social and architectural aspects.

Figure 4 recaps the moments, topics and target populations that characterize each phase of the evaluation while Figure 5 shows the workflow that should be followed to operationalize the surveys. The demo groups should collect a significant target sample for the submission of the survey as well as a set of topics/questions they are interested in. The demos are responsible for the correctness of the overall methodology, for the submission of the survey and for the collection of the results.

The submission procedure should preferably be performed through digital instruments: the questionnaires will be transposed in an online survey creator (e.g., SurveyMonkey, Microsoft Forms, Google Forms) eventually after the translation into local language. If a digital management is not possible, face-to-face interviews in the streets or in houses are allowed, but a responsible person should be individuated for the transposition of the answers in the online tool.

The proposed survey is anonymous since it should not be possible to identify the respondent (name, email, IP address, etc.). The participation in the study is voluntary: by completing the survey, the respondent voluntarily agrees to participate. It is possible to withdraw from the study at any time for any reason. Only people over 19 years old people should be involved due to GDPR issues. A contact person for the management of the survey should be individuated for each case study.

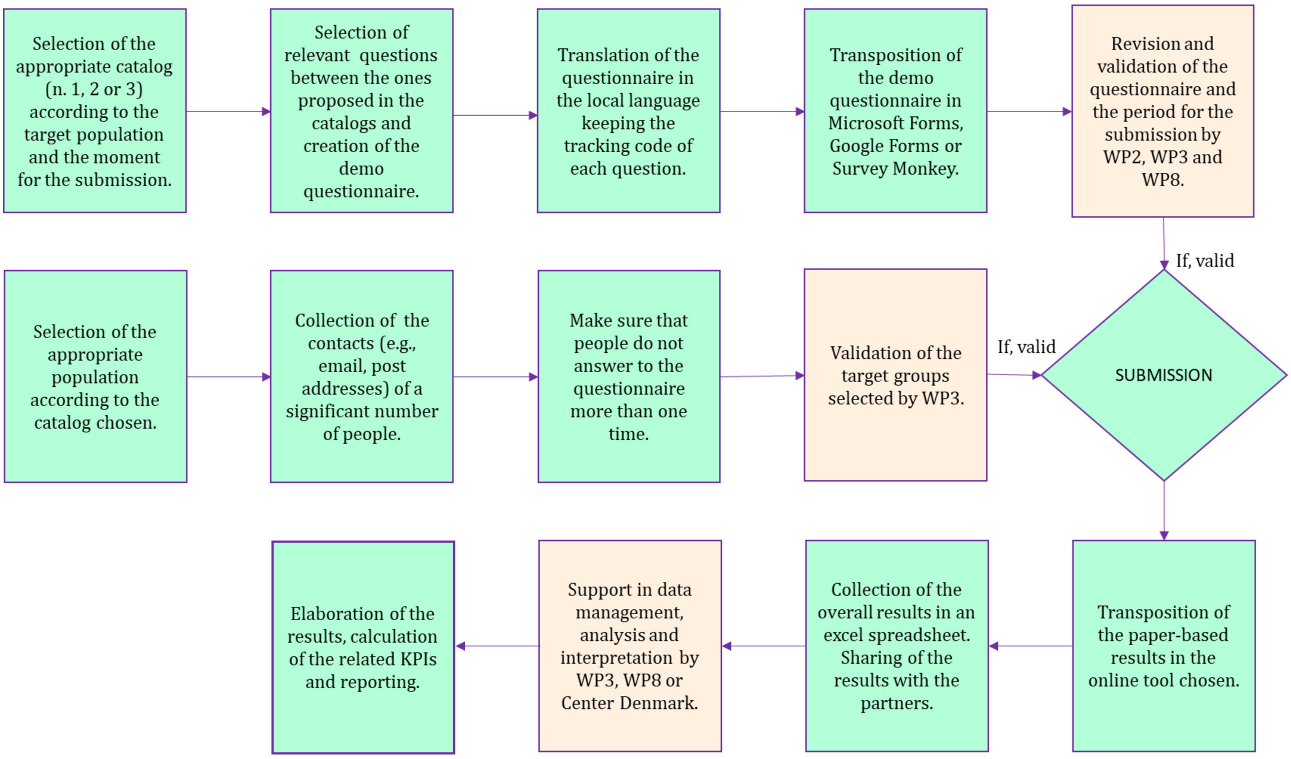


Figure 5: *Process flowchart for operationalizing the surveys (green: activities in charge of the demo groups, orange: activities that will be managed by work packages).*

Results

The results of the survey proposed in this section should be presented in a report and discussed with the partners. A group for the management and analysis of the results will be created and charged with the activities related to the interpretation and evaluation of the outcomes through the scoring system proposed in the Deliverable 2.1.

4.1.1. NOISE DURING RETROFITTING

The KPI defined in Deliverable 2.1 for the certification of the achievement of this goal is the percentage of people (more than 60% of the total sample) asserting that the noise generated by the present construction site is significantly lower (-30%) than the one generated by a traditional construction activity.

The Demo partners should adopt a mixed methodology for the evaluation of the noise produced by the construction works. The mixed approach suggested in the Deliverable 2.1 for the evaluation of the perception of the noise generated by the construction activities of the ARV demo projects is based on subjective and objective measures.

Scope

The scope of this activity is to demonstrate that the construction activities are performed with the minimum annoyance for the occupants of the retrofitted buildings that can remain in their homes/buildings continuing their normal life habits and activities. In the case of new constructions, the effect of the construction site on the people living in neighboring spaces or frequenting close by public spaces should be investigated. The evidence for the achievement of this objective is based on majority votes from the surveys/interviews, and through further supporting subjective and objective measures, as explained below.

Two kinds of measurements will be performed to achieve the goal:

- Qualitative measurement (compulsory)
- Quantitative measurement (optional)

Qualitative measurement

The subjective evaluation will be performed through the questionnaire 2, that has already been introduced in the Section 4.1. The questionnaire is displayed in Appendix B.

When preparing the survey and tailoring the questionnaire displayed in Appendix B to the local context, it is important to acquire a thorough understanding of the noise sources and receptors that characterize the location being examined (e.g., in relation to the typology of noisy or acoustically significant activities or machineries that characterize the area and the construction site).Only non-stochastic airborne noise should be considered.

For the submission, it is important to select a significant number of people for the evaluation, also considering the availability of residents and neighbours in being interviewed. Additionally, the locations for the submission of the questionnaire should be varied in order to be representative of the entire area. Moreover, a special attention should be paid to the presence of noise sensible receptors, such as schools or hospitals, in the proximity of the construction site in addition to residential areas (for the definition of the boundaries it is possible to refer to Figure 6).

In the case of a manual paper-based submission, the interference of the human speaking in the noise perception should be avoided during the compilation of the questionnaire: the reason is that the respondent should be focused solely on noise perception, which should not be untainted by the interaction with the interviewer.

Quantitative measurement

The objective noise measurement will be tackled using a phonometer. Standard procedures, and instrumentation will be detailed below.

Normative references

- ISO 1996-1:2016 Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures. 2016.
- ISO:1996-2:2017 Acoustics — Description, measurement and assessment of environmental noise — Part 2: Determination of sound pressure levels. 2017.

- IEC 61672-1:2002 Sound level meters – Part 1: Specifications. 2002.
- ISO/TS 12913-1:2014 Acoustics — Soundscape — Part 1: Definition and conceptual framework
- ISO/TS 12913-2:2018 Acoustics — Soundscape — Part 2: Data collection and reporting requirements
- ISO/TS 12913-3:2019 Acoustics — Soundscape — Part 3: Data analysis

Noise monitoring instrumentation

Some free-field measures are required for an evaluation of the environmental noise produced by the construction activities. The noise will be measured using a phonometer (see Table 9 for the recommended specifications). Measurements may be accepted as valid only if the calibration level agrees within 0.5 dB.

***Table 9**: Instrumentation specifications.*

Devise	Specifications
Acoustic calibrator	At least IEC 60942 (International Electrotechnical Commission, 2017) Class 1.
Sound level meter	At least IEC 61672-1 (International Electrotechnical Commission, 2002) Class 1 —general purpose grade for field use with a tolerance of ±0.5 dB.
Windproof cap	Diameter ≥ 90 mm
Audio recording instruments	Preferably if embedded with noise anomalies detection.
Weather station	Measuring rain, average wind speed (<5 m/s), average wind direction, average temperature.

Procedures and recommendations

The evaluation should be performed on a normal working day (e.g. from 08:00 to 18:00) while the construction activities are in place. While collecting the feelings about the acoustic environment experienced by the people living in or frequenting the area through the survey/interviews, some contemporaneous measures of environmental noise the respondents are exposed to, should be performed in order to support the subjective results obtained. This task is accomplished using a phonometer or employing binaural head meters. The measure of some psychoacoustic parameters is optional, but it is recommended to also consider the effects of the spectral distribution of noise. The characterization of the sound pressure levels (dbA), loudness (sone), roughness (asper), sharpness (acum) and tonality (tu) can, in fact, further support the results obtained from the subjective evaluation of noise.

The description, measurement and assessment methodologies of the environmental noise are provided by the ISO 1996 part 1 and 2 (International Standardization Organization, 2017, 2016). The number of outdoor measures to be performed depends on the number of respondents that are interviewed. The microphone shall be positioned approximately 1.5 meters above local site level, while the measures should be performed in a radius of about 5 meters from each respondent and should last at least 5 minutes, paying attention not to influence the measure speaking. The weather conditions during the campaign (wind speed, rain, …) should be declared and compatible with the prescriptions of the IEC 61672-1 (International Electrotechnical Commission, 2002): for example the monitoring has to be performed in absence of rain, fog or snow.

The average sound pressure level can be calculated by a continuous integration, or from discrete sampling data collected every 5 minutes. The calculation of the logarithmic average sound pressure levels is carried out using the following equation:

$$L_{Aeq,TR} = 10 \log \frac{1}{n_{TR}} \sum_{j=1}^{n_{TR}} 10^{0.1\, L_{Aeq,5\,min\,J}}$$

where n_{TR} is the number of useful data picked up and TR is the overall measuring period considered. Alternatively, if different time frames (To)i are considered for the measure, the value $L_{Aeq,TR}$ can be calculated through the following relation:

$$L_{Aeq,TR} = 10 \log \left[\frac{1}{T_R} \sum_{i=1}^{n} (T_0)_i \; 10^{0.1 \, L_{Aeq,T_0 \, i}} \right]$$

The reception level is directly calculated from the measures performed executing the logarithmic average as described in the previous equations or by continuous integration. A significant number of measures should be collected until a steady average value is reached after the calculation of the average of the recorded data.

Expected outputs

The noise evaluation should produce a report describing the activities performed and containing:

1. A description of the noise sources and receptors that are present in the area;
2. A description of the instrumentation used for the monitoring;
3. The results derived from the questionnaires that include a description of the sample and the verification of the ARV objective (a reduction of -30% in noise perception compared with a traditional construction work);
4. The results (LAeq(TR)) of the noise monitoring campaign explaining how they agree or not with the subjective outcomes;
5. The mitigation strategies that are put in place to improve the noise perception in the case of high sound pressure levels or annoyance by the people interviewed.

Considering the fourth point, to effectively demonstrate the good performance of the construction site, the values of LAeq(TR) can be compared with the reference limit values of environmental noise reception that are established by the national legislation. The limits for Italy are reported in Table 10 (Italian Government, 1997).

***Table 10**: Diurnal reference values for reception sound pressure levels.*

Class	Description	Reception limit - Italy (dBA)
I	Hospitals, schools, urban parks, public facilities	50
II	Mainly residential areas	55
III	Mixed used areas	60
IV	Areas with intensive human activities	65
V-VI	Industrial areas	70

4.1.2. DUST DURING RETROFITTING

A hybrid quantitative and qualitative approach is suggested in Deliverable 2.1 for the evaluation of the dust produced by the construction works that characterize the ARV project. This section includes the definition of the methodologies and monitoring procedures that should be followed in the evaluation and measuring of dust. In a traditional construction site, it is possible to detect many routine tasks that are capable of producing high levels of dust: cutting blocks or tiles, demolitions, aggregates transportation and unloading, drilling or excavation processes, concrete preparation, scabbling or grinding concrete, etc. Moreover, meteorological conditions, such as the presence and direction of wind or rain, can significantly affect the amount of dust that is suspended in the air. The adoption of dry-building methodologies to carry out the interventions is expected to significantly reduce the amount of dust spread by the ARV construction activities.

Scope

The scope of the evaluation is to verify that the construction activities are carried on with a low annoyance for the residents, neighbors or for the people that frequently use the public spaces that are close by. This objective of the ARV project is explicitly to reduce the occupants' disruption generated by the construction works by at least 30% compared with the current practice. The ARV target is considered met if the largest part of the respondents (more than 60%) agree that the dust generated by the construction works is significantly less (-30%) if compared with traditional building sites. Two kinds of measurements will be performed:

- Qualitative measurement (compulsory)
- Quantitative measurement (optional)

Qualitative measurement

The subjective evaluation will be performed through a questionnaire n. 2, that is displayed in Appendix B.

Quantitative measurement

The quantitative measuring campaign is optional but can be useful to further validate the results of the questionnaires. The device that should be used for the monitoring is a continuous monitor that allows to measure PM10, PM2.5 and total suspended particles (TSP). Standard procedure, methodology and instrumentation are described below.

Normative references

- CEN, EN 12341:2014. Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter. Bruxelles, Belgium, 2014.
- European Commission, "Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe," OJ, vol. 152, pp. 1–44, 2008.
- Global Health Observatory (WHO), "Ambient (outdoor) air pollution." 2021.

Methodology and instrumentation

The first step that needs to be defined regards the definition of the reference area. This task is accomplished following the recommendations given by the IAQM in the "Guidance on the assessment of dust from demolition and construction" (Institute for Air Quality Management, 2014).

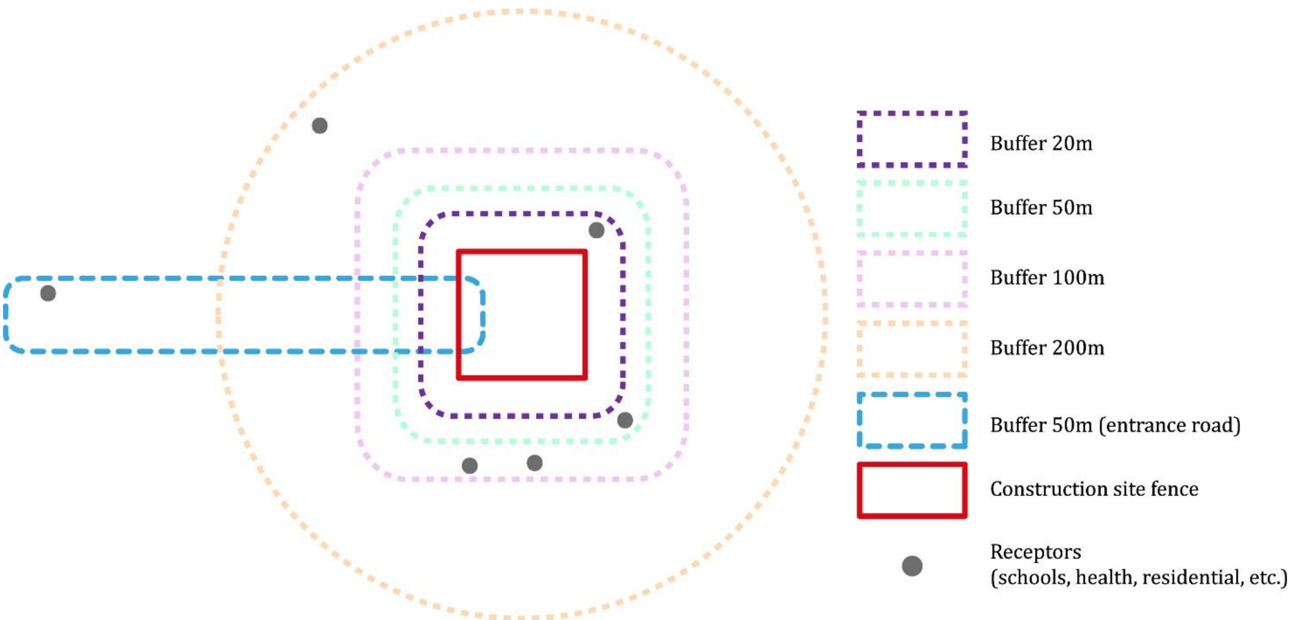


***Figure 6**: Example of reference area for dust evaluation.*

As shown in Figure 6, the IAQM Guidance requires a dust assessment where there is:

- A human receptor within 350 m from the boundaries of construction site.

- A human receptor located in a buffer of 50 m from the street used by construction vehicles up to 500 m from the entrance(s) of the construction site.

Closer buffers should be defined to check the dust soiling effect of people and properties at the following distances from the construction site boundaries: <20m, <50m, <100m and <200m. The closest the buffer, the higher the sensitivity of the area to the dust spread by construction activities is. The evaluation is based on a survey/questionnaire that is submitted to the inhabitants, neighbors or to the people that are users of the public spaces in the reference area. The questionnaire is displayed in Appendix B.

The parameters to be measured are specified in Table 11. The analysis is based on the beta ray attenuation measurement technique that determines the fine dust concentration by measuring the amount of radiation that a sample of extracted air flow absorbs. Low-energy beta rays are absorbed by collision with electrons, the number of which is proportional to the amount of material present. Absorption is thus a function of the mass of the irradiated material, independently from its physicochemical nature.

Table 11: *Indicators for an indoor environmental quality check.*

Parameter	Specifications
Particle size detected	0.5 mm or larger ($PM_{2.5}$, PM_{10} or TSP)
Lower detectable limit	0.5 µg/m^3
Measurement range	0 to 10 000 µg/m^3
Accuracy	±2 µg/m^3
Operating temperature	+5°C to +40°C
Sampling time	10 min, 15 min, 30 min, 1h

The positions of the monitoring points should be selected so that it is representative or in favor of security: close to the entrance of vehicles driving out and in of the construction site that can carry a large amount of dust and sediments to nearby roads, close to processes rising a sensible amount of dust, or nearby some specific activities (such as drilling ones) that are characterized by a high dust spreading. The weather conditions (wind speed, relative humidity) can significantly affect the amount of dust in the area and so they should be annotated during the monitoring campaign. Rainy days must be avoided for dust monitoring activities. The indicators that are considered for the monitoring are the concentrations of PM 2.5, PM10 and TSP (µg/m^3).

The methodology applied for the monitoring should be run in accordance with EN 12341 (CEN, 2014). The sampling cycle is 24 h and a normal working day (within working hours: e.g., from 09:00-16:00) should be considered to perform the monitoring. The measures should be carried out when dust spreading activities are taking place and coincide with the submission of the surveys that involves the subjective assessment.

The daily average results obtained will be compared with a reference threshold value (50 µg/m^3 for PM10 and 25 µg/m^3 for PM 2.5), based on international standards (European Commission, 2008; Global Health Observatory (WHO), 2021), to further validate the achievement of the ARV target of 30% dust reduction.

Expected outputs

The activity should produce a report containing:

1. An overview about the selection of a representative sample
2. The results obtained from the survey

3. Optionally, a table/dataset containing the information about time, average wind speed and humidity, main dust sources monitored, daily dust or monthly average concentration of PM2.5, PM10 and TSP (μg/m³)
4. The mitigation strategies put in place in the case the results of the evaluation do not meet the ARV target

4.2. CONSTRUCTION TIME REDUCTION

The time necessary for the realization of the ARV demo projects is included in the KPIs selected for the evaluation of the demos. The project promotes the design of prefabricated components that can be assembled on site with dry techniques. Certainly, the adoption of prefabrication implies a more complex and detailed design that requires a longer time frame; on the other hand, however, a one-time extensive design stage can shorten the construction time for a lot of projects.

Scope

The scope of the evaluation is the calculation of the KPI about the construction time that is connected to the achievement of the EIC9: 'Shorter construction/retrofitting time and cost by at least 30%, in order to allow market uptake and social affordability'. ARV aims in fact at demonstrating that through the prefabrication of building components and through a dry assembly in the construction site, it is possible to save up to the 30% of the time necessary for a traditional construction work allowing a quicker market uptake and a better social affordability. To demonstrate this achievement, the construction time experienced will be compared with statistical data about the average construction times published by independent local authorities for public buildings. Figure 7 reports the average time that is necessary for the realization of public infrastructures in Italy classified for classes of cost.

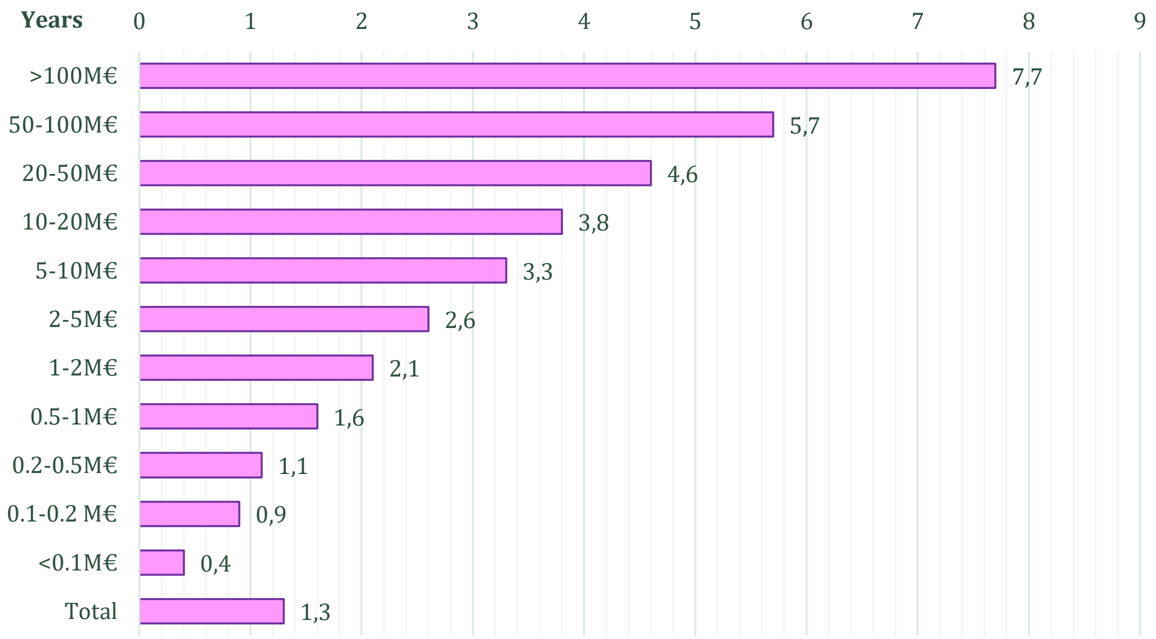


***Figure 7**: Average realization time of public infrastructures in Italy (Agency for Territorial Cohesion, 2018).*

Methodology

The methodology to be followed for the calculation of the construction time is based on the collection of official administrative documents, such as a certificate of the beginning-end of the works, and alternatively unofficial documents, such as project manager logbooks, that certify the dates when the construction activity started and when it is concluded.

The following activities should be considered to define the starting of the construction works:

- Covering the furniture to prevent dirt and damage
- Delimitation and signaling of the construction site
- Installation of construction machineries/equipment

The following activities should be considered to define the end of the construction works:

- Static testing
- Removal of construction site fences

Results

The expected result is the time that was necessary to carry out the construction works. It will be measured in days (8 working hours) or hours. Both the official and unofficial documentation employed in the calculations should be provided together with the results obtained.

5. IMPACT ASSESSMENT FRAMEWORK

The impact assessment framework aims at evaluating the performances of the ARV projects from a comprehensive perspective that embraces the whole life cycle of the interventions carried out. Moreover, the proposed impact assessment framework permits to evaluate the performance of the ARV demo cases from a broad sustainability point of view that includes the environmental, economic, and social fields. For this reason, as shown in Figure 8, three methodologies are proposed in the following sub-sections:

- The Life cycle analysis to assess the environmental concerns,
- The life cycle costs for the evaluation of the economic aspects,
- The social life cycle analysis for the assessment of social features.

The three methodologies proposed should complement each other and provide a comprehensive sustainability evaluation of the ARV interventions.

In order to accomplish these objectives, the impact assessment framework requires the use of information that has already been collected through the monitoring and evaluation activities while integrating them with other information.

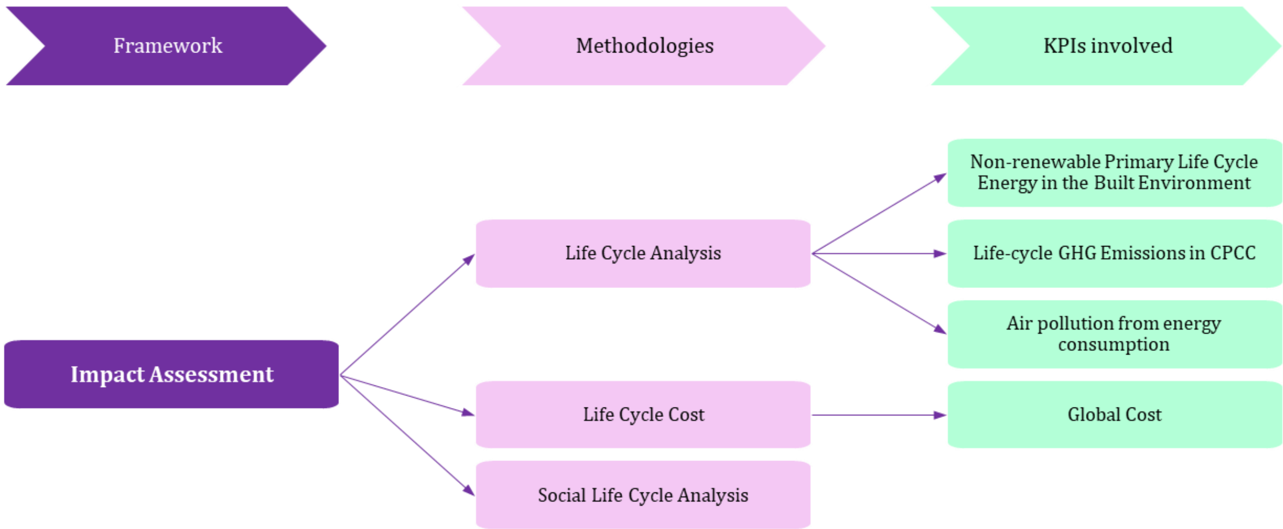


***Figure 8**. Impact assessment framework and related methodologies for KPIs computation.*

5.1. LIFE CYCLE ANALYSIS

The Life Cycle Assessment or Life Cycle Analysis (LCA) is a method aiming at the management and improvement of the environmental performances of a wide range of products, processes, and services. The analysis assesses the sustainability from an environmental point of view, excluding the social and economic aspects included in the broader concept of sustainability. Therefore, even if the LCA can be performed considering different time frames, it can include the impacts associated with the whole life span of the object analyzed, from the upstream processes of the supply chain like the extraction of the raw materials, to the disposal or recycling at the end-of-life.

The ARV project would like to encourage a life cycle thinking that considers a 'cradle to cradle' approach – from the manufacturing of the products and materials used to construct the building, right through to the building eventual deconstruction and re-use/recycle of materials. The LCA approach is adopted as a reference framework for the evaluation of energy and environmental aspects connected to the building sector. Moreover, the ARV project extends the environmental evaluation from the LCA application to the built environment to the CPCC scale for the assessment of climate change impacts.

5.1.1. LCA APPLICATIONS TO THE BUILT ENVIRONMENT

The building sector generates environmental impacts throughout its different life cycle stages, both directly and indirectly. There are direct impacts from energy consumption that is required to maintain adequate comfort conditions in the indoor environment (operational energy), to carry out the construction and demolition processes, and to maintain and refurbish a building. Indirect impacts are generated during the production of the materials that compose the buildings envelope and of technical installations: that is what we consider as embodied environmental impacts.

The determination of the embodied impacts is acquiring a significant importance in the case of buildings characterized by low operational energy consumptions.

Normative references

The international standards for Environmental Management (ISO 14040 (ISO, 2006a) and ISO 14044(ISO, 2006b)) define four phases of the LCA: goal and scope definition, inventory analysis, impact assessment and results interpretation. These phases are not in a rigid time succession, but they can be interrelated in an interactive approach where, as the study progresses, it is possible to re-visit aspects belonging to the phases already considered. Once obtained some results, for example, the necessity to refine the calculation done may raise and bring to a review of the assumptions already made and to the refinement of the data already used.

EN 15978 (CEN, 2011) regulates the LCA of whole buildings. According to this standard, the information on the embodied impacts (cradle to gate) of a building can be derived from EPDs or other LCA databases that are in accordance with EN 15804 (CEN, 2021).

The two standards EN 15804 and EN 15978 indicate a modular concept to perform an LCA. Thus, the LCA of a building can be seen as a summation of environmental impacts deriving from single modules that correspond to different life cycle stages (see Figure 9).

More detailed guidelines for the development of an LCA can be found in the Product Category Rules (PCR) that have already been defined for the compilation of Environmental Product Declarations(CEN, 2021). The PCR considered complies with the EN 15804 (CEN, 2021) that describes the methodology for producing EPD at the product-level, building-level in this case.

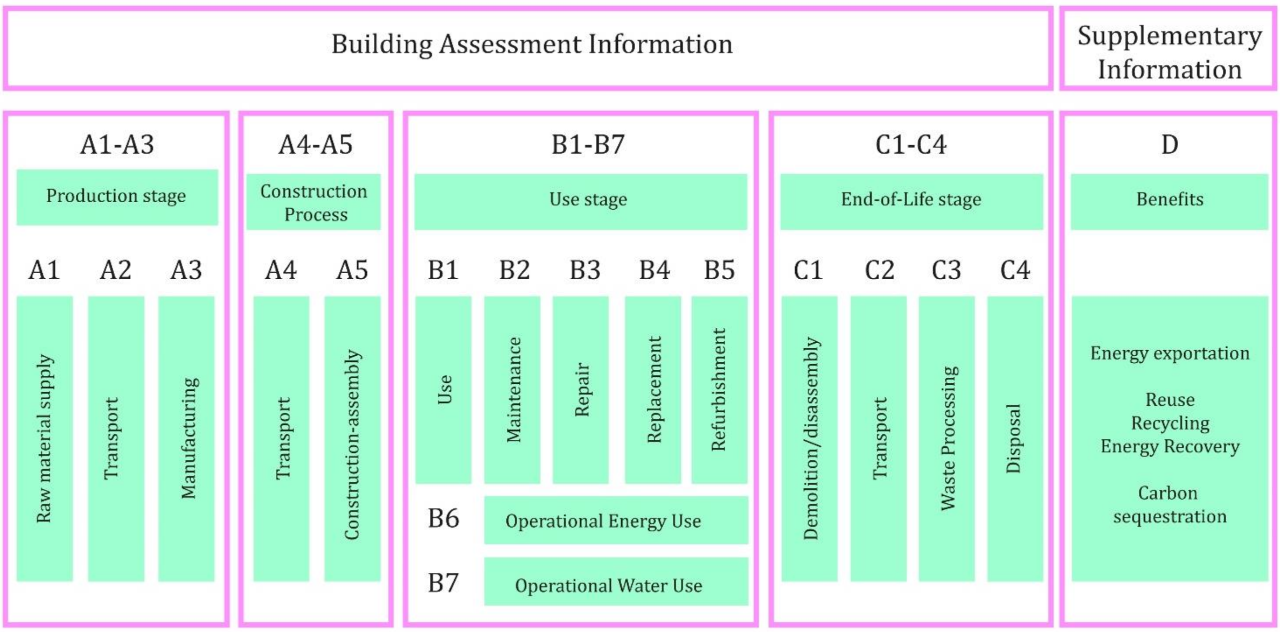


***Figure 9**. Life cycle stages for buildings LCA (EN 15804/EN 15978).*

Goal and scope definition

In ARV, the goal or scope of the analysis depends on the temporal stage of the realization and on the typology of interventions:

- Design Stage: quick selection of alternatives.
- Detailed post-realization assessment: verification of the environmental performance targeted during the design stage, after the calculation of KPIs defined within the ARV activities, and comparison with a baseline building defined by legal requirements.
- Retrofit intervention evaluation: comparison of the performances achieved before and after the intervention through the calculation of the set of KPIs individuated by ARV.

In particular, the scope of the evaluation activity is linked to the determination of the following KPIs:

- Lifecycle GHG emissions in CPCC
- Non-renewable Primary Life Cycle Energy in the Built Environment
- Air Pollution from the Energy Consumption in the Built Environment

Their calculation can provide evidence about the achievement of the following EIC that were specified in the ARV project proposal:

- **EIC5 -** Reduction of greenhouse gas emissions towards zero (in tCO_2-eq/year) for the total life cycle compared to the current situation shown through cradle-to-cradle LCA
- **EIC6 -** Reduction of the embodied energy in buildings by 50 % without concessions with respect to energy consumption and comfort
- **EIC7 -** Reduction of air pollutants towards zero (in kg/year) for the total life cycle compared to current situation shown through cradle-to-cradle LCA

The scope of the analysis implies the definition of its boundaries: time frame, functional unit, data quality requirements, allocation procedures, impact categories to be considered and type of review. The functional unit definition is fundamental because it permits to evaluate the performance related to a particular function and compare products, processes, or services with the same utility. The choice of the functional unit is generally arbitrary, but it has to be declared in detail also explaining the unit of measure. In ARV, the functional unit that should be adopted is:

- the square meter of gross internal area to normalize the results for the size of the building

As shown in Figure 10, the gross internal area is the surface enclosed by external walls, considering also internal walls (whether structural or not) and partitions. The gross internal area excludes perimeter wall thicknesses and external projections, open balconies, terraces, open fire escapes, open-sided covered ways, open vehicle parking areas, minor canopies, any area with a ceiling height of less than 1.5 m (except under stairways), and any area under the control of service or other external authorities.

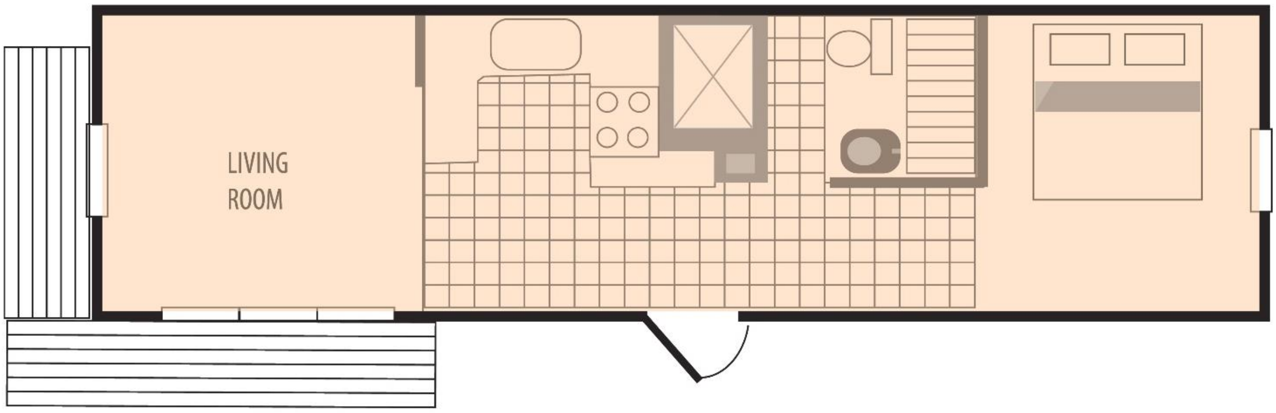


***Figure 10**. Gross internal area of a building.*

The adoption of the number of people living or working in the building as an additional functional unit is optional and would permit a normalization for the actual capacity of the construction: the reduction of floor space per capita is, in fact, a good strategy to spread the environmental impacts associated to the building sector on a higher number of people, reducing so the overall burden. That is particularly true in the case of constructions that are empty or that are used for only few days or at weekends during the year (e.g., holiday houses). The number of people that should be considered for the normalization is equal to the yearly average number of occupants, including the people that live, work, and make use of the indoor spaces (e.g., tenants, students, hospitalized, medical examinates, etc.). Reliable sources should be considered for the calculation of the annual average value based on real daily occupancy profiles.

Another choice to be done regards the outputs to be considered. The LCA is able to give a lot of impact indicators for different impact typologies and the selection of the right indicator is linked to the scope of the analysis. The ISO 14044 guarantees the possibility of neglecting some inputs and outputs if they are considered not significant for the overall conclusion of the study.

Finally, the data quality is very important to ensure the reliability of the conclusions obtained to meet the scope of the assessment; it depends principally on the age of data, on their geographical and technological relevance. The use of the last updated datasets referring to a specific geographical location and a specific technology is recommended.

***Table 12**. LCA system boundaries in ARV.*

Category	**Stage**	**Description**	**Mandatory**
Embodied upstream	A1	Raw material supply	Yes
Embodied upstream	A2	Transport to the manufacturer	Yes
Embodied upstream	A3	Manufacturing	Yes
Embodied upstream	A4	Transportation to the construction site	Yes
Embodied upstream	A5	Construction/installation process	Optional
Embodied downstream	B1	Use	Optional
Embodied downstream	B2	Maintenance	Optional
Embodied downstream	B3	Repair	Optional
Embodied downstream	B4	Replacement	Yes
Embodied downstream	B5	Refurbishment	Yes
Operational	B6	Operational energy use	Yes
Operational	B7	Operational water use	Optional
End-of-life	C1	Dismantling	Yes
End-of-life	C2	Transport to disposal	Yes
End-of-life	C3	Waste processing	Yes
End-of-life	C4	Waste disposal	Yes
Benefits	D	Energy exportation	Yes

The time frame of the assessment can be variable and not all the studies consider the whole life cycle (from cradle to grave); sometimes the analysis is performed from cradle to gate of the factory, sometimes from cradle to site, including impacts connected to transports, sometimes from cradle to cradle when the dismissing of a product coincides with a recycling process or from gate to gate when the only intermediate phase of work in the factory is considered. Table 12 shows the system boundaries, and the life cycle stages that are mandatory for carrying out the LCA of ARV demo projects.

The life span of the building is considered equal to 50 years. If a building component has a useful life that is lower than 50 years, its substitution should be taken into account by adding the related environmental impacts as a whole (e.g., without any partial replacement). The service life of a building, component, or material is defined as the period of time when its performance remains equal or exceeds the one declared in its technical sheets. The reference service life values reported in Table 13 can be used for LCA calculations if more specific values are not available. The following equation should be employed for the calculation of the number of replacements:

$$NR\ (j) = E\ [\ ReqSL\ /\ ESL(j) - 1]$$

where,

- E is the function that rounds up function ReqSL/ESL (j) to the higher integer value;
- ESL (j) is the estimated service life for product/component j;
- NR (j) is the number of replacements for product/component j;
- ReqSL is the required service life of the building (50 years).

***Table 13**: Building materials life spans.*

Material	Description	Life span (years)
Concrete	Load bearing structures	100
Steel	Load bearing structures	100
Timber	Load bearing structures	80
Roof covering	External layer of the roof	50
Wood	Wooden elements exposed to weather	20
Windows	All typologies	35
Internal partitions	Hollow brick blocks	50
EPS	External insulation coating	30
PV panel	Building services (BIPV, BAPV)	20
Heat pumps	Building services	20
Boilers	Building services	20

Module B5 shall consider all the impacts liked to the renovation of the building. If some of the building materials are directly reused on site, they should be considered as burden free (e.g., if the load bearing structure is not subjected to any kind of improvement intervention, its materials are free of burdens).

Module B6 shall include the energy used in the operational phase by the building systems for heating, cooling, lighting, domestic hot water, auxiliary energy (used for pumps, lifts, escalators, control, and automation).

The boundary of module B7 shall include the consumption of net fresh water (potable water) during the operation of the integrated building technical systems. The impacts related to modules B6 and B7 shall be separated in the final report.

Module D shall contain the environmental benefits linked to the exportation of the renewable energy produced into external energy grids, to the recycling, reusing, energy recovery of materials. The different benefits should be kept separated and grouped as follows:

- Benefits linked to energy exportation
- Benefit linked to the direct reuse of materials
- Benefits linked to the recycling of waste materials
- Benefits linked to energy recovery of waste materials
- Benefits linked to carbon sequestration capacities

Life Cycle Inventory

The Life Cycle Inventory analysis (LCI) regards the collection of data about the amount of materials and energy that characterize the inputs of the assessment. The inputs include energy flows and natural resources, and their quantification can be very time consuming because of the wide range of data to be collected and because of the necessity to analyze the flows in detail. A bottom-up approach is generally employed for the definition of the LCI in the LCA of buildings: transportations, materials and energy flows are accounted separately for each stage or activity characterizing the development of construction activities.

The cut-off criteria adopted for the creation of the LCI should be declared. Anyway, the material inputs that account for less than 1% of the total building mass can be considered negligible. In the case of energy retrofit or building refurbishments, the material and systems that are recovered from the existing construction are considered burden free: the inputs that should be considered are the ones linked to the new materials and energy flows that characterize the refurbishment and the demolition and end-of-life processes.

Representative data shall be selected for the definition of the LCI. The datasets selected in the life cycle databases employed should guarantee:

- The highest temporal relevance
- The highest geographical relevance
- The highest technological relevance

The Table 14 describes the requirements for data quality for the LCA analysis. Generally, a medium data quality should be guaranteed for the largest part of the inputs. Annual average monitored data should be considered for operational processes and the most updated emission factors and primary energy conversion factors for the country where the demo is located shall be employed.

***Table 14**. Data quality indicators.*

Quality index	**1 (high)**	**2 (medium)**	**3 (low)**
Temporal correlation	Less than 5 years	Less than 10 years	Unknown or more than 15 years
Geographical correlation	Data from area under study (e.g., country).	Data from area with similar production conditions (e.g., Europe).	Data from unknown area with different production conditions.
Technological correlation	Data from enterprises, processes and materials under study. Same technical characteristics (e.g., power, capacity, …).	Data from processes and materials under study but from different technology. Similar technical characteristics (e.g., power, capacity, …).	Data from related processes and materials but different technology. Different technical characteristics.

Two main methodologies can be adopted for the collection of the data for the compilation of the LCI regarding building materials and components: a **drawing-based** and a **computation-based** procedure. Since subtask 8.3.2 will evaluate building performance gaps (i.e., deviations between planned and actual building performance), it is required to clearly provide the source of the data, namely if they are obtained from design estimation, modelling, or from real documentation such as bill of quantities or delivery notes. The provision of both estimated and the actual values is required to evaluate building performance gaps.

The first procedure is characterized by a collection of the as-built drawings of the implemented project, from which it is possible to determine the dimensions, and the respective volumes, of the materials used in the construction of the building. The drawings should include the composition of walls and building components. The latter directly makes use of materials computations that can be derived from technical documents such as metric calculation, bill of materials, bill of quantities, price list, special specifications, etc. The procedure that should be adopted must rely on the original documentation of the materials and components of the building.

Concerning the recycled content or the reusability of the materials considered, standard literature values will be employed in the calculations if more detailed information is not provided by the demo groups. Sources of specific and more detailed information can be collected from environmental certifications, EPD, environmental labels, technical sheets. Table 15 reports the reference values that should be adopted for the most common building materials if more specific information is not available.

***Table 15**: Reference value for recycled content and reusability for some common building materials.*

Material	Reference content of recycled material (%), stages A1-A3	Reference end-of-life scenarios, stages C3-C4 (see Table 10 - D2.1)
Concrete	5%	Landfill
Bricks	10%	Landfill
Hollow bricks	5%	Landfill
Wood	95%	Recovery (energy)
Insulation EPS	30%	Recycling (mixed stream)
Insulation rock wool	15%	Recycling (mixed stream)
Insulation glass wool	60%	Recycling (mixed stream)
Plastics	30%	Recycling (mixed stream)
Structural steel	10%	Recycling (pure stream)
Non-structural steel	70%	Recycling (pure stream)

The expected structuring scheme for the LCI is a table resuming all the building materials, the heating, ventilation, and air-conditioning (HVAC) technologies and their main characterization parameters (density, thermal conductivity, dimensions, capacity power, content of recycled material, reusability potential, etc.). An explanatory structure to organize the data collected is displayed in Tables 16 and 17, for envelope materials and HVAC systems, respectively. This kind of information should be enriched with technical documentation: architectural and details drawings, technical sheets, Environmental Product Declarations (EPD), other labels, etc. Some notes should also be included to alert the user about the most relevant information related to the components reported.

Concerning the operational energy consumption and the renewable energy generation, monitored data should be employed in the LCA calculations. In the case of comparability purposes between ex-ante and ex-post performances in renovation interventions, it is necessary to use data referring to similar climatic conditions and operational schedules. For this reason it is recommended to use the following relations to make heating and cooling loads comparable:

$$HD_{c,ex-post} = \frac{HD_{m,ex-post}}{HDD_{ex-post}}(HDD_{ex-ante}) \quad \text{or} \quad HD_{c,ex-ante} = \frac{HD_{m,ex-ante}}{HDD_{ex-ante}}(HDD_{ex-post})$$

$$CD_{c,ex-post} = \frac{CD_{m,ex-post}}{CDD_{ex-post}}(CDD_{ex-ante}) \text{ or } CD_{c,ex-ante} = \frac{CD_{m,ex-ante}}{CDD_{ex-ante}}(CDD_{ex-post})$$

where

- HD_c and HD_m is the heating demand corrected and monitored,
- CD_c and CD_m is the cooling demand corrected and monitored,
- HDD and CDD are the heating and cooling degree days referred to the same period of the energy monitoring.

Alternatively, if operating schedules and monitoring conditions are very different, the monitoring data can be used for calibrating building energy models (e.g. in EnergyPlus (NREL and U.S. Department of Energy's (DOE), n.d.), TRNSYS (Thermal Energy System Specialists, n.d.), DOE-2 (James J. Hirsch & Associates et al., n.d.)or in other building energy simulation environments). The models should be calibrated on a monthly basis following the ASHRAE Guideline 14 (American Society of Heating, Refrigerating, and Air Conditioning Engineers, 2012). After the calibration of the models, the simulation outputs can then be used for the comparison.

***Table 16**: Example of LCI data structure for envelope materials.*

Material	Mass (kg)	Share of total building mass (%)	Density (kg/m³)	Thermal conductivity (W/mK)	Circularity & reusability	Relevant notes
Concrete	50000	50%	2400	1.00	% recycled & reusability	Structures (100 m²)
Bricks	20000	20%	800	0.30	% recycled & reusability	Infill walls (100 m²)
Wood	10000	10%	850	0.40	% recycled & reusability	Roof (100 m²)
Insulation EPS	5000	5%	20	0.035	% recycled & reusability	EPD available
Window 1 (glass)	…	…	…	…	% recycled & reusability	Double 4-16-4 low-e (dimension b x h)
Window 1 (frame)	…	…	…	…	% recycled & reusability	Wooden + PVC (thickness)

***Table 17**: Example of a rough LCI data structure for energy systems.*

System	Dimensions/ power/capacity	Technology	Technical sheet	Relevant notes
PV system	3 kW	Mono-Si	Yes	BIPV
Battery	12 kWh (weight: kg)	Li-Ion	Yes	Used component
Heat pump	6 kW_e	Air-to-water	Yes	Heating & cooling class A+++
Boiler	30 kW	Condensing, modulating	Yes	Gas methane
Inverter	…	…	…	…

Life Cycle Impact Assessment

Starting from the inputs of the LCI, the Life Cycle Impact Assessment (LCIA) calculates numerical indicators of environmental impact. The scope of the analysis defines, implicitly, the impact categories that need to be investigated. The typologies of these impacts can vary largely, and therefore the LCIA involves different impact categories: global warming, depletion of minerals and fossil fuels, photochemical oxidation, human toxicity, ozone depletion, eutrophication, water use, land use, acidification, ecotoxicity, etc. The impact indicators can be distinguished in midpoint and endpoint ones. Mid-point indicators, such as climate change and acidification, show a direct cause-effect chain or relation with a particular impact category. They look at the impact earlier along the cause-effect chain before the endpoint is reached. On the other hand, many impact categories (e.g., human health, depletion of resources or some ecosystem effects) have different stressors, thus some characterization and weighting factors should be employed to define an endpoint impact indicator. In this way, an endpoint method can describe the environmental impact at the end of the cause-effect chain.

The impacts that should be considered within ARV are the Global Warming Potential (GWP 100 years), Cumulative Energy Demand (CED – renewable and non-renewable part), and the ambient air pollution. The units of measure are the kg CO_2eq/m^{2}year for the GWP, the kWh/m^{2}year for the CED, and kg PM2.5/year, kg SO_x/m^{2}y, kg NOx/m^{2}y for ambient air pollution.

Biogenic carbon is excluded from the calculation or, if it is considered, its negative contribution in the determination of the GWP should be clearly declared in the final report (and deployed in stage D of the life cycle) so that it can be unbundled.

In case of renewable energy generation, the exported energy can be considered as a benefit (negative contribution) due to the avoided consumption of non-renewable energy sources. The imported energy should, instead, be modelled using national emission or conversion factors.

Results

The LCA results are usually displayed in a report underlining the contribution of the different life cycle stages that are indicated in Table 12 and Figure 9, grouped by category. The output may adopt an LCA calculation procedure, which is separated into five different life cycle stages groups:

- Upstream embodied impacts (A1-A3: from cradle-to-gate)
- Downstream embodied impacts (B4-B5)
- Operational impacts (B6-B7)
- End-of-life impacts (C1-C4)
- Benefits beyond the system boundaries (D), e.g., from exported energy, carbon sequestration or from the reuse, recycling, energy recovery of waste materials.

The contents of the LCA report should include:

1. A description of the building, where it is located and how it will be used.
2. The definition of the goal and scope of the analysis and the functional units adopted; the assumptions that are made and the boundaries of the analysis should be given in this section.
3. An overview of the main components of the building (e.g., structural elements, envelope, roof, basement, energy systems) with their supposed life span. The inclusion of the LCI is mandatory (see Tables 16-17).
4. A discussion about how design alternatives were evaluated including a plot with their operational non-renewable primary energy demand versus their total life cycle one (and their total GWP). The plot will include the baseline (in case of energy retrofits) and the reference scenario that is defined starting from the minimum energy requirements defined by the national law that transposes the EPBD (Directive 2010/31/EU (European Commission, 2018)).
5. A follow up/revision of the design results with updated detailed LCA calculation performed after the realization of the intervention and using monitored data. All the impact categories analyzed should be included with a differentiation among life cycle stages as suggested in the previous paragraph. Moreover, the KPIs should be calculated and a discussion on how the EIC are met should be provided.
6. A discussion about the limitations of the LCA study and a sensitivity analysis underling which are the variables that mostly affect the results (e.g., future-time variation of the electricity-to-emissions conversion factor, higher durability or service lives of the materials and systems installed, etc.).

5.1.2. LIFE-CYCLE GHG EMISSIONS IN A CPCC

Buildings are significant contributors to the life cycle emissions in a district but, at a metropolitan scale, different other sources of greenhouse gases can be detected: transportation, waste management, water use, streets construction, and public lighting. Carbon compensation strategies, such as biological carbon sequestration and renewable energy export, can also play a significant role in the GHG emissions balance of a CPCC. That is why the ARV project extends the environmental assessment of buildings to the neighborhood scale for the evaluation of climate change impacts.

Scope

The scope of the data collection is linked to the calculation of the following KPI:

- Life cycle GHG emissions in a CPPC

Methodology and recommendations

The “Life cycle GHG emissions in the CPPC” is basically calculated as the sum of different contributors:

- Buildings (embodied, operational, and end-of-life emissions)
- Mobility (embodied and operational emissions)
- Water consumptions
- Waste management
- Carbon compensation from renewable energy exportation
- Biological carbon sequestration in green areas such as trees and green roofs

The definition of the boundaries of the analysis is very important: the emissions that should be taken into account are the ones that can be allocated to the interventions that are the object of the project, namely to the people that are living or working in the buildings that are part of ARV.

Concerning the LCA of **buildings** the methodology to be adopted is already introduced in the previous sections.

The emissions linked to the **mobility** represent an important contribution that cannot be discarded. The interest of the project is posed only on the mobility for commuting and the calculation methodology defined in the deliverable 2.1 is centered on the use of statistical data about the annual km travelled, the transportation means ownership and habits of the people living or working in the constructions that are part of the CPCC addressed by ARV. Tables 18-19 contain some reference values that can be used in the evaluation of the GHG emissions attributable to mobility: some of the reference values currently proposed are referred only to Italy, but the use of more specific local information is encouraged. That is why some questions about mobility were integrated in the questionnaire 1 (see Appendix A).

The **water consumption** can be determined from utility bills. Alternatively, some reference water consumption numbers can be adopted: e.g. 220 liters/person/day for residential buildings. The factor that should be used for the determination of the GHG emissions linked to the tap water consumption is equal to 0.00032956 kg CO_2/liter (Wernet et al., 2016).

The calculation of the GHG mission linked to **waste management** implies the determination of the amount of municipal solid waste that is produced pro-capita. If more specific data are absent, a reference value of 490 kg/person year can be assumed for residential buildings. Considering only the amount of waste that is landfilled or incinerated, a reference value of 0.6 kg CO_2/kg can be adopted for the determination of the climate change impacts, this value includes the collection, transportation, and treatment of municipal solid waste in treatment facilities (Habib et al., 2013; Wernet et al., 2016).

The amount of the **renewable energy** produced and exported into external energy grids is obtained from the monitoring activities that are carried out by the project. It should be underlined that the energy that is exported into the national electricity grid or into the district heating network can be considered as a carbon compensation strategy only when it permits the substitution of the fossil fuels used in the electricity or heat generation. In this way, the total GHG saving depends on the carbon intensity of the grid where the electricity (or heat) is exported.

Finally, **green spaces** can play a role of carbon sinks. The calculation of the carbon sequestration capacity is based on the amount of trees that are planted with a carbon compensation scope by the CPCC promoted by ARV. There is a high variability in the carbon sequestration capacity of the trees that mainly depends on their age and typology. The annual average carbon removal capacity can be assumed equal to 40 kg CO_2/tree (Cox, 2012) if more detailed data are not available.

***Table 18**: Reference data for the determination of the operational GHG emissions of mobility.*

Item	Transportation data	GWP reference data	Source
External district	22 km/person/day	-	Norman et al. (Norman et al., 2006)
Inner district	6 km/person/day	-	Norman et al. (Norman et al., 2006)
Private car/scooter	70% (a_{vt})	0.23050 kg CO_2/ person*km	ISTAT, ecoinvent
Bus	5% (a_{vt})	0.10036 kg CO_2/person*km	ISTAT, ecoinvent
Metro/railways	10% (a_{vt})	0.045533 kg CO_2/person*km	ISTAT, ecoinvent
Foot/bike	15% (a_{vt})	0 g CO_2/km	ISTAT

***Table 19**: Reference data for the determination of the embodied carbon of mobility.*

Item	Reference data	Source
n. passengers per car	1.45 passengers/car	EEA
n. cars per inhabitant	0.670 cars/person (IT) 0.521 cars/person (SP) 0.503 cars/person (ND) 0.466 cars/person (DN) 0.560 cars/person (EU)	Eurostat
Small car (1324 kg)	9370 kg CO_2/unit	ecoinvent
Medium car (1524 kg)	10786 kg CO_2/unit	ecoinvent
Large car (1760 kg)	12457 kg CO_2/unit	ecoinvent
SUV (1997 kg)	14134 kg CO_2/unit	ecoinvent
Car maintenance	1 083 kg CO_2/unit	ecoinvent
Bus*	0.046 kg CO_2/km	ecoinvent
Bus maintenance	0.0053 kg CO_2/km	ecoinvent
Regional train/metro*	0.098 kg CO_2/km	ecoinvent
Train maintenance	0.011 kg CO_2/km	ecoinvent
Scooter	442 kg CO_2/unit	ecoinvent
Scooter maintenance	238 kg CO_2/unit	ecoinvent

*Bus: 65000 km/y - 12 years, train: 120000 km/y – 40 years

Outputs

The output of this activity consists of a report describing the calculation methodology adopted and containing the total GHG emissions (in kg CO_2 eq./year) attributable to buildings, mobility, and the equivalent CO_2 removals due to the export of energy into the external grids. The results should highlight the contribution of the different components in the whole life cycle GHG emissions of the CPPC: embodied and operational phases, as well as the different GHG sources and carbon compensation or removals actions, should be reported separately.

5.2. LIFE CYCLE COSTS

Life Cycle Cost (LCC) is a methodology that evaluates the total cost of an asset over its life cycle including initial planning and design costs, capital costs, maintenance costs, management and operating costs and the residual value of the asset at its end of life.

The LCA and LCC analyses have a lot of similitudes but also two main substantial differences: the LCC consider the cost of fabrication of a building or its market value, thus the acquisition price; the LCA considers the impacts linked to the fabrication process but not the socio-economic aspects (such as the cost of the human labor force, the administrative costs, the cost for insurances, etc.). The two methodologies should so be applied in combination to provide a more comprehensive evaluation that integrates economic and environmental analyses.

Normative references

The main reference guidelines and standards for the development of the LCC in the ARV project are:

1. Commission Delegated Regulation No. 244/2012
2. ISO 15686-1 Buildings and constructed assets - Service life planning: Part 1, General principles and framework
3. ISO 15686-2 Buildings and constructed assets - Service life planning: Part 2, Service life prediction procedures
4. ISO 15686-3 Buildings and constructed assets - Service life planning: Part 3, Performance audits and reviews
5. ISO 15686-5.2 Buildings and constructed assets - Service life planning: Part 5, Life-cycle costing
6. ISO 15686-6 Buildings and constructed assets - Service life planning: Part 6, Procedures for considering environmental impacts
7. ISO 15686-7 Buildings and constructed assets - Service life planning: Part 7, Performance evaluation for feedback of service life data from practice
8. ISO 15686-8 Buildings and constructed assets - Service life planning: Part 8, Reference service life and service-life estimation

Goal and scope definition

The LCC approach aims to overcome the logic of some builders that are only concerned about the minimization of the initial capital costs (land, design, and construction) of an asset bringing, sometimes, to a burden shifting on other life cycle cost components. For example, the support of solutions that require the smallest investment can cause a trade-off on higher operational costs: e.g., the application of a reduced insulation thicknesses results in a higher energy need for heating and cooling.

The goal and scopes of the analysis can be summarized by the following bullet points.

- Design Stage: quick selection of alternatives with the lowest/optimal life cycle cost
- Detailed post-realization assessment: verification of the performance targeted during the design stage through the calculation of ARV economic KPIs and comparison with a baseline building defined by legal requirements.
- Retrofit intervention evaluation: comparison of pre and post intervention life cycle costs and verification of the targeted objectives calculating the related KPIs.

The application of LCC helps the designers in the selection of the most cost-effective design alternative over a particular time frame, taking into consideration the building construction, operation, maintenance, replacement, and end-of life value.

In ARV, the application of LCC is connected with the determination of the following KPI:

- Global cost (see section 9.1 of Deliverable 2.1)

Methodological aspects

The main indicator that is proposed for the LCC analysis is the global cost as defined by the guidelines contained in the Commission Delegated Regulation No. 244/2012 (European Parliament and of the Council, 2021). This guidelines were developed to basically detail a reference methodology for member states for the identification of the minimum energy performance requirements of buildings, building elements and technical building systems based on cost-optimal levels as required by the Article 4(1) of Directive 2010/31/EU (Energy Performance of Buildings Directive, EPBD) (European Commission, 2018).

The aim of the procedure is firstly the determination of the total primary energy demand to fulfil the comfort standards in the indoor environment. After that, the financial level calculates the overall costs in the life cycle of the building (construction, use, maintenance, disposal) actualizing the annual cost to the starting year. The financial procedure is based on the definition of: C_i the initial cost, C_a the annual cost of the system j, R_{disc} the discount factor for every year (i), Val_F the final value, the global cost actualized to the starting year t_0, $C_g(t)$, can be calculated as follows.

$$C_g(t) = C_i + \sum_j \sum_i \left(C_{a,i} \cdot R_{disc}(i)\right) - Val_{F,t}(j)$$

The following list summarized the main cost components to be included in the LCC of a new building:

1. **Initial investment costs** including site acquisition costs, professional and authorization fees, construction of infrastructures and roads; in the case of energy retrofits interventions the construction costs refer to the cost sustained for the realization of the retrofitting interventions.
2. **Maintenance costs** that are intended as the cost to maintain the functional performance of the asset and that include periodic inspections, cleaning, periodic maintenance and replacement activities of the asset components, unscheduled replacements, retrofitting interventions.
3. **Operation costs** that include energy (specifically for heating, cooling, air conditioning, lighting, lifts, and appliances), water uses, rent and insurances. When using the Global Cost approach, the costs related to building elements which have no influence on the energy performance of a building can be omitted from the calculations.
4. **Disposal costs** that include the cost for demolition and dismantling but also eventual incomes coming from the residual values of components or the terminal value of the scraps.

The LCC should be developed in analogy with the LCA following the same structure in life cycle stages that have already been individuated for the LCA. Table 20 reports the cost categories that should be considered in the LCC analysis in relation with the life cycle stages that are already defined in the section about the LCA.

Furthermore, by analogy with the LCA, the functional unit that should be adopted is the square meter of gross internal area, to normalize the results for the size of the building; and similarly, the life span that should be considered for the interventions is equal to 50 years. The Global Cost shall be reported in €/m^2 or in €/m^{2}y when calculated on yearly basis.

It is important to underline that in a LCC analysis the maintenance, operation and end-of-life costs should be actualized because they are incurred in a future time period. The discount factor is calculated starting from the discount rate that needs to be defined by the demo groups considering the local economic context. A sensitivity analysis can be performed considering at least two different discount rates, one of which must be considered equal to 3%.

__Table 20__. LCC cost assigned to each life cycle stage and temporal time frame.

Phase	Cost description	LCA stage	Time	Terms		
Production	Raw materials	A1	t_0	Only in the LCA		Total cost C_g
	Transport	A2				
	Manufacturing	A2				
Construction	Transport	A4	t_0	Investment/refurbishment cost C_i		
	Construction	A5/B5				
Use	Use of components	B1	t_1, …, 50	Operational cost C_{op}	Annual cost C_a	
	Operational costs *insurances, taxes, …*	B1				
	Maintenance	B2-B3		Maintenance cost C_m		
	Replacements	B4				
	Energy use *heating* *cooling* *ventilation* *DHW* *lighting* *appliances etc.*	B6		Energy cost C_e		
	Water use	B7		Optional		
End-of-life	Residual value	-	50	Final value Val_F		
	Demolition	C1		Disposal cost C_{disp}		
	Transport	C2				
	Recycling	C3				
	Disposal	C4				
Benefits	Benefits	D	t_1, …, 50	Energy gain G_{en}		

A straight-line depreciation of the initial investment or replacement cost of a given building element shall be used to calculate its residual value. The depreciation time is determined considering the service lifetime of a building or building element, as reported in its technical sheet.

Another procedure that can be followed is the one proposed by the ISO 15686 (ISO, 2017) for the determination of the Net Present Value (NPV).

$$\mathrm{NPV} = -\mathrm{I}_0 + \sum_{n=1}^{t} \frac{\mathrm{F}_t}{(1+\mathrm{k})^t}$$

where,

- F_t represents the cash flows obtained, for example, from the difference between the management costs of the current building and of the ones after the retrofit or from the financial flows deriving from energy exports. It can include the presence of eventual annualized fiscal detractions, and maintenance or substitution additional investments. Investment costs are considered as a negative contribution while financial benefits (e.g., exported energy financial flows, savings due to retrofitting, …) are positive.
- k is the discount rate used to actualize the cash flows.
- t is time expressed in years that has started since the moment of the initial investment.
- I_0 is the initial investment, i.e., the sum of all the costs sustained for the intervention. This value can be calculated using parametric costs or national price lists.

For further details please refer to the ISO 15686.

Results

The results of the LCC will be disseminated through a report. The relationship between the operational energy requirement of the design alternatives (or CO_2 emissions) and their related life cycle cost, should be optimized. The optimization should produce a plot with the operational non-renewable primary energy demand (or CO_2 emissions) versus the Global Cost of the case study. The plot should include the baseline (in case of energy retrofits) and the reference scenario that is defined starting from the minimum energy requirements defined by the national law that transposes the EPBD, 2010/31/EU (European Commission, 2018).

The output concerning this activity should contain:

1. The goal and scope definition and the functional unit adopted; the assumptions that are made (e.g. about energy prices, actualization factors, energy conversion factors, etc.) and the boundaries of the analysis.
2. A discussion about how the design alternatives were evaluated and on the LCC optimization methodology adopted. The plots summarizing the results of the analysis will be part of the discussion.
3. The verification of design expectations and calculation hypotheses after the realization of the intervention through the elaboration of monitored data (a comparison between ex-ante and ex-post scenarios is requested for retrofit interventions).
4. The Global Cost (and eventually the NPV) time profile with a sensitivity analysis to show the influence of the variations of the discount rate and of the increase in the costs of the energy vectors.

5.3. SOCIAL LIFE CYCLE ANALYSIS

Social Life Cycle Assessment (SLCA) is a methodology aiming at assessing the social impacts of products and services across their life cycle. In the context of ARV, SLCA provides information on social and socio-economic aspects for decision makers, in the perspective of improving the social performance of the activities involved in the project.

Normative references

The SLCA is still a non standardized method that remains in a "pre-science" phase and also the level of development of the methodology, the application and harmonization of the analysis are still in a preliminary stage. UNEP published some guidelines about Social Life Cycle Assessment defining the main methodological steps to follow and the body of knowledge to help stakeholders in the assessment of social and socio-economic impacts in the life cycles of products (UNEP, 2020, 2009).

The main goal of the analysis is to find some significant relationships between the life cycle of a product and the consequences generated by it to the people or to the society. These consequences can be positive or negative and can be evaluated in different ways: variation in the expected life of people, consequences on health and wellbeing, variations in the employment level, variations in the education level of a group of people, etc.

To understand the social impacts on a variety of social groups, it is crucial to select the stakeholders, i.e., the people who are directly affected by the product or service in analysis.

The structure of the analysis recalls the one established by the international standards for Environmental Management ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b). Therefore, it can be developed in four phases: goal and scope definition, (Social) Life Cycle Inventory (S-LCI), (Social) Life Cycle Impact Assessment (S-LCIA) and Interpretation. As for the environmental LCA, there is not a strict time evolution between the phases, but the methodology is iterative, which means that the analysis can be developed in several loops moving from more generic/potential results to more specific ones after the revision of the assumptions made in the previous parts.

Goal and scope definition

The goal of the analysis is to determine the social impacts of ARV demo case studies.
The main scopes of the analysis are:

- To support sustainable design of buildings;
- To assess the most relevant stages in the social value chain in terms of social impacts/hotspots;
- To examine potential social improvement options along the life cycle;
- To assess the social performances of the interventions after their realization;
- To communicate the social performance or social impacts of the ARV projects to the public;

The target audience includes the participants of the project, the evaluation bodies, and the social groups affected by the realization and functioning of the ARV projects. The analysis is for internal use, and it is not foreseen an external revision body. Eventually, the results can be disclosed to the public after the final evaluation of the project.

The demo projects are the objects of the evaluation and represent the functional unit of the analysis. The boundaries of the evaluation are the activities involved in the project and related to the design, realization and functioning of the case studies: the life cycle stages that can be distinguished are: design, realization/construction of the projects, functioning/use stage of the demos, and their end-of-life (dismantling of the interventions realized).

The stakeholders to be considered are the participants of ARV, both research and industrial entities (and workers), and the social groups (e.g., inhabitants, users, local communities, society, and other value chain actors are part of the group of stakeholders) that are directly affected by the realization and functioning of the demos. The function that the demo is called to provide should be clearly stated.

Life Cycle Inventory

The Life Cycle Inventory consists of a collection of information regarding social aspects connected with the demo's realization and functioning. Data on possible social drivers of impact are collected for each life cycle stage (extraction of raw materials, manufacturing, assembly, operation, and end-of-life).

The working conditions in the construction sites need to be monitored: freedom of association, child and forced labor, safety equipment and plans, salaries, working hours, discrimination. The origin of construction materials needs also to be considered to verify the respect of human rights in the countries where their manufacturing is carried out.

Healthy living/working conditions and comfort levels should be monitored during the real-life operation of the demo projects. The evaluation will involve the percentage of population with access to improved water sources and improved sanitation facilities, the quality of roads (unpaved, paved but scarcely maintained, paved with good maintenance), the protection of cultural heritage, local employment rate, and secure living conditions. Crime events in the area are obtained from reliable sources such as policy authorities or different press sources.

Life Cycle Impact Assessment

A list of social impacts were identified from the Guidelines for Social Life Cycle Assessment of Products (UNEP, 2009) and reported in Table 21. The UNEP/SETAC criteria can be integrated by the social aspects that are directly addressed by the ARV project and that are reported in Table 22.

Table 21*. List of social impacts and indicators indicated by UNEP/SETAC guidelines.*

Stakeholder	Subcategory	Indicator	Score range of variation
Workers	Freedom of association and collective bargaining	Presence or not	1 or -1
Workers	Child labor	Percentage of child labor (5-14 years)	1 (absence) or -1 (presence)
Workers	Fair salary	Comply with minimum regulation=0; does not comply=−1	-1, 0 (comply), 1 (above)
Workers	Working hours	Daily working hours >8 h=−1; ≤8 h=1	1 (≤8 h) or -1 (>8 h)
Workers	Forced labor	Proportion of population in modern slavery	-1 (>0%), 1 (0%)

Workers	Equal opportunities and discrimination	Social institutions and gender index (SIGI)	-1, 0, 1 (below, on, above EU average)
Workers	Health and Safety	Un-fatal and fatal occupational injuries per 100 workers	-1, 0 (national average), 1 (significantly lower)
Local community	Access to material resources	Percentage of population with access to improved water sources and improved sanitation facilities, quality of roads	-1 (below EU average), 0 (on EU average, scarce accessibility), 1 (above EU average)
Local community	Access to immaterial resources	Quality cultural/ educational background on energy and sustainability is provided to the local community	-1 (absence) or 1 (presence)
Local community	Cultural heritage	Protection=1; no change =0; damage=−1	-1 (damage), 0, 1 (protection)
Local community	Safe/healthy living conditions	Percentage of prescriptions about comfort and safety that are respected.	-1 (low), 0, 1 (all)
Local community	Community engagement	Index of transparency of policymaking	-1 (low), 0, 1 (high)
Local community	Local employment	Percentage of local workers and suppliers	-1 (<50%) to 1 (100%)
Local community	Secure living conditions	Number of crime events in the area	-1, 0, 1 (above, on city/regional average, significantly lower)
Society	Public commitment to sustainability issues	Obligation on public sustainability reporting	-1 (absent), 0 (scarce or generic), 1 (detailed on specific topics)
Society	Contribution to the economic development	Full-time equivalent employment hours	-1 (scarce) or 1 (very good)
Society	Technology development	Application of innovative patents	-1 (outdated), 0 , 1 (>1)
Society	Corruption	Incidents/press reports concerning fraud, corruption and violation of property rights.	-1, 0 (minor issues), 1 (absence)
Value chain actors	Fair competition	Illegal price-fixing reported by press or police authorities	-1, 0 (minor issues), 1 (absence)
Value chain actors	Social responsibility promotion	Spontaneous actions of involved enterprises in sustainability and circularity promotion or discrimination fight.	-1 (absence) or 1
Value chain actors	Supplier relationship	Different suppliers are considered to optimize the quality of products/services and purchasing costs.	-1 (scarce) or 1 (good)

Results

For the scope of the evaluation, the experts working on social sustainability aspects should assign an integer score to each criterium, based on the final performance achieved by each demo. The score system adopts integer numbers that range from -1 to 1 for each impact subcategory. Figure 11 shows and example regarding the subcategory “Fair salary”.

Score	Performance reference point
1	Salary above the decent wage
0	Salary corresponding to decent wage level for a specific geographical location
-1	Salary below the decent wage level

Figure 11. *Example of a reference point scale.*

Aggregation in midpoint (e.g., human rights, health, autonomy, safety, security and tranquility, equal opportunities, participation, and influence) or endpoint (e.g., human wellbeing) categories and weighting are intrinsic to the SLCA methodology. It is applied to aggregate indicators into social subcategories but also to produce a set of stakeholders' level performances, and aggregate subcategory results into a single overall score.

The aggregation that could be undertaken includes: (i) workers: health & safety, fair salary, working hours, discrimination, forced labor; (ii) building occupants: health & safety living conditions, community engagement; (iii) local communities: accessibility, local employment, secure living conditions; and (iv) society: technology development, public commitment to sustainability issues.

An overall social sustainability score is achieved by the aggregation and weighting of the impacts identified in Table 21. Some questionnaires will be submitted to a group of stakeholders or to SLCA experts to determine the weight to be applied to each subcategory score.

The overall score is calculated as follows:

$$SLCA_{tot} = \sum_{i=1}^{n} score_i * weight_i$$

where $score_i$ is the score obtained in the subcategory i and $weight_i$ the correspondent weight obtained from experts questioning.

The outcome should refer to all the life cycle phases of the ARV demo projects, namely design, realization, functioning, and end-of-life. The results should discuss which of the main critical areas are from a social sustainability point of view and which life cycle stage represents the most impactful one.

The report concerning this activity should contain the following contents:

1. A description of the procedure followed.
2. A discussion about the most relevant life cycle stages in the social value chain in terms of social impacts/hotspots
3. The potential social improvement options that can be adopted along the life cycle of the demo case studies.

Table 22. List of possible additional impacts and indicators related to the ARV project.

Stakeholder	Subcategory/KPI	Score/Motivation
Local community	Democratic process	-1: scarce meetings and interest from the local community 0: good participation and interest from the community 1: a very good active participation was achieved
Local community	Social inclusion	-1: scarce social inclusion (only few social groups participated) 0: good social inclusion 1: a very good social inclusion (all targets were involved)
Local community	Social engagement	-1: a lot of aspects about social engagement were not achieved 0: good social engagement 1: a very good social engagement was achieved
Local community	Social interaction and cohesion	-1: scarce social cohesion and senso of belonging 0: good social cohesion, positive sense of belonging 1: high social cohesion, pride and sense of place
Local community	Safety and security (similar to "secure living conditions")	-1: scarce perception of safety and security 0: good perception of safety and security 1: very good perception of safety and security
Local community	Energy and environmental consciousness	-1: scarce awareness about energy and environmental issues 0: good awareness about energy and environmental issues 1: very good awareness about energy and environmental issues
Local community	Affordability of energy	-1: energy expense is more than 10% of the residents' income 0: energy expense is less than 10%, absence of energy poverty 1: energy expense is less than 5%, absence of energy poverty
Local community	Affordability of housing	-1: housing expense is more than 40% of the residents' income 0: housing expense is less than 40%, 1: housing is very affordable
Local community	Access to sustainable mobility	-1: not adequate 0: adequate 1: very good
Local community	Access to services and amenities	-1: not adequate 0: adequate 1: very good

6. FUTURE DEVELOPMENTS

The contents of this documents will pave the way for the future developments of the activities of WP8 in the ARV project that will be developed in the following tasks:

- Task 8.2 - Static and dynamic data collection and monitoring
- Task 8.3 - Evaluation of the interventions and analysis of building performance gaps
- Task 8.4 - Assessment of environmental, social and economic impacts
- Task 8.5 - Multiple-benefits analysis and assessment

6.1. MULTIPLE BENEFITS ANALYSIS

The purpose of this section is to provide an overview of the multiple benefits analysis approach, which will be explored in greater detail within Task 8.5.

Scope and concept definition

Any project is expected to deliver some benefits to the community. Aside from the main ones defined in the project design phase, further collateral benefits may derive from the implementation and may strengthen the impacts.

Multiple benefits (MBs) are all positive impacts that can derive from a project, including those that are strictly linked to the main goals and those that are not intentionally pursued. Therefore, it is crucial to examine the different benefits in order to fully grasp the project potential through an assessment of all beneficial consequences that result from it. The dissemination of these positive impacts can help raise awareness of the project's relevance and, as a result, gain a greater approval from investors, end users, and other stakeholders.

Methodological aspects

Regarding the methodology, Table 23 illustrates the key phases that should be developed in order to deliver the most thorough analysis possible.

***Table 23**. List of possible additional impacts and indicators related to the ARV project.*

	STEPS	TOOLS	ACTORS	Potentially related WP/tasks
1	**Identify** already consolidated multiple benefits through literature review and similar projects screening	Scientific literature, similar projects' documents	Analyst	
2	**Integrate** tailored multiple benefits according to the project vision	Project's documents	Analyst	
3	**Group** multiple benefits in macro-categories	Scientific literature, Project's documents	Analyst, Partners	2
4	**Rank** multiple benefits according to their relevance to the project goals through stakeholders' engagement	Survey (MCDA) - online/in presence	Analyst, Stakeholders	2, 3
5	**Determine** the relevance of multiple benefits within each lifecycle phase of the project	e.g. *Framework for Dignity in the Built Environment* (developed by IHRB), MCDA	Analyst, (Stakeholders)	2
6	**Associate** one or more KPI to each multiple benefit identified	Scientific literature, Regulatory documents	Analyst, Partners	2, 8.1
7	**Calculate** KPIs	Scientific literature, Regulatory documents	Analyst	8.1
8	**Monitor** the trend of multiple benefits	Scientific literature, Regulatory documents, KPIs' calculation, Survey	Analyst, Partners	2, 8.1

The Multiple Benefits analysis should be conducted by an analyst in cooperation with demo leaders and local cluster members in order to create a comprehensive framework.

For what concerns the identification of MBs, the following stages are required:

- Review of the scientific literature on the topic
- Screening of conceptually similar projects
- In-depth study of the ARV project

The result of this initial phase should be a list of items that might then be divided into the macro-categories mentioned in Deliverable 2.1 (Salom et al., 2022):

- Economics
- Society
- Environment
- Energy
- Architecture
- Circularity

Thanks to this subdivision, it would be easier to appreciate the contribution made by each benefit. Moreover, the overall outcome should be similar to the one illustrated in Figure 12, which has been developed by Bisello (Bisello, 2020) as part of the European project SINFONIA.

Subsequently, the identified MBs should be screened in order to focus attention on the most important ones. This might be achieved by giving stakeholders a survey, and then creating a list of MBs associated with the ARV project depending on their choices. The Best-Worst Scaling methodology could be used for presenting the items and analysing the outcomes, but other approaches could also be adopted. The advantage of this methodology is that respondents are only required to select the best and worst possibilities from a list of subgroups of items extracted from the overall, which simplifies, speeds up, and improves accuracy.

The analysis should be further detailed by investigating in which phase of the lifecycle of the built environment each benefit is more relevant. This could be based, for instance, on the *Framework for dignity in the built environment* (IHRB, 2019), which associates principles of the respect of human rights with the lifecycle of an area. Following this schema, developed by the Institute of Human Rights and Businesses, the lifecycle of the district should be composed of the following phases:

- Land acquisition
- Planning and finance
- Design
- Construction
- Management and use
- Demolition and redevelopment

After determining which advantages are more pertinent to the project and in which phase of the lifecycle of the district they are more present, it would be possible to determine and calculate the related KPIs. It should finally be necessary to keep track of the how and whether the different benefits actually occur. The monitoring will be conducted through the calculation of the KPIs during the implementation of the project, paying particular attention to the phase in which the benefit is more relevant. In addition, a survey should be distributed to the stakeholders in order to be aware of their perspective about MBs trend and to test whether the perception of importance has changed from the beginning to the end of the project.

Work packages that might provide knowledge to the execution of each specified phase are reported. WPs 2 (methodology for the implementation and assessment of CPCC), 3 (community engagement) and task 8.1 (Development of monitoring, evaluation and impact assessment specifications and guidelines) may be implicated in identifying multiple benefits due to the affinity of the themes covered by them. Furthermore, collaboration with WP9 is desirable in order to incorporate the concept of multiple benefits in the development of business models that consider sustainability performances via non-financial aspects (ESG criteria).

More details regarding the methodology and its implementation will be described in Deliverable 8.7.

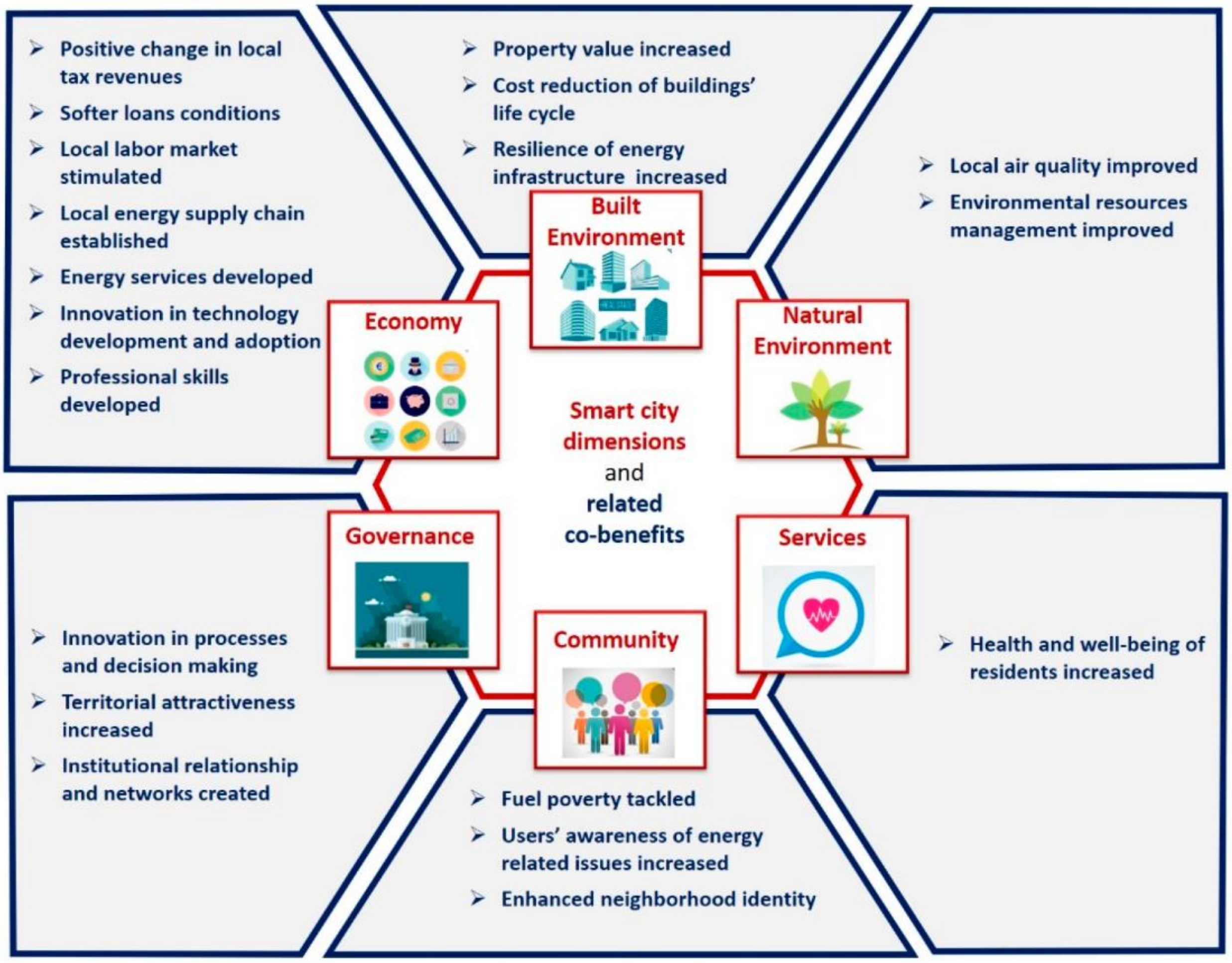


Figure 12*. Example of a reference point scale.*

6.2. OTHER FUTURE DEVELOPMENTS

The guidelines proposed in this document represent a completion of the assessment framework for the ARV project proposed in Deliverable 2.1. As the framework will be revised based on the feedback given by the demos as the project progresses, also the guidelines for the determination of the performance indicators can be updated. Moreover, after the first year of application and testing of the methodologies proposed, the lessons learned could contribute to the refinement of the guidelines. This continuous process of testing, validation and refinement will contribute to the improvement of the guidelines.

Concerning the monitoring aspects, this document provides only some preliminary suggestions about the monitoring devices, physical and network architectures of monitoring systems, functioning of the data collection processes (frequency of the measurements, local storage, backup systems), data-related protocols, data quality aspects and data saving and storage. All these topics will be deepened in the upcoming deliverables of WP8 related to Tasks 8.2.

The monitoring outcomes will also be fundamental for the evaluation of building performance gaps, namely the deviations between planned - or simulated - and the actual building performances. This topic will be addressed in Task 8.3 of WP8.

7. REFERENCES

Agency for Territorial Cohesion, 2018. Construction times for public works in Italy [WWW Document]. URL https://www.agenziacoesione.gov.it/news_istituzionali/tempi-di-realizzazione-delle-opere-pubbliche-online-il-rapporto-2018/ (accessed 2.20.22).

American Society of Heating, Refrigerating, and Air Conditioning Engineers, 2012. ASHRAE Standard 62.2.2012: Ventilation for Acceptable Indoor Air Quality. Atlanta, USA.

Bisello, A., 2020. Assessing Multiple Benefits of Housing Regeneration and Smart City Development: The European Project SINFONIA. Sustainability 12, 8038. https://doi.org/10.3390/su12198038

CEN, 2021. BS EN 15804:2012+A2:2019 Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products. Brussels, Belgium.

CEN, 2019. EN 16798-1:2019 Energy performance of buildings - Ventilation for buildings - Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics - Module M1-6. Brussels, Belgium.

CEN, 2014. EN 12341:2014. Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter. Brussels, Belgium.

CEN, 2011. EN 15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method. Brussels, Belgium.

Cox, H.M., 2012. A Sustainability Initiative to Quantify Carbon Sequestration by Campus Trees. Journal of Geography 111, 173–183. https://doi.org/10.1080/00221341.2011.628046

European Commission, 2018. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. Official Journal of the European Union L 156, 75–91.

European Commission, 2008. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. OJ, L 152, 1–44.

European Parliament and of the Council, 2021. Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. Official Journal of the European Union L 81, 18–36.

Global Health Observatory (WHO), 2021. Ambient (outdoor) air pollution.

Habib, K., Schmidt, J.H., Christensen, P., 2013. A historical perspective of Global Warming Potential from Municipal Solid Waste Management. Waste Management 33, 1926–1933. https://doi.org/10.1016/j.wasman.2013.04.016

Humphreys, M.A., 2005. Quantifying occupant comfort: are combined indices of the indoor environment practicable? Building Research & Information 33, 317–325. https://doi.org/10.1080/09613210500161950

IHRB, 2019. Principles for Dignity in the Built Environment: a roadmap for human rights [WWW Document]. URL https://www.ihrb.org/focus-areas/built-environment/ (accessed 5.12.22).

Institute for Air Quality Management, 2014. Guidance on the assessment of dust from demolition and construction. IAQM, London, UK.

International Electrotechnical Commission, 2017. IEC 60942:2017 Electroacoustics - Sound calibrators.

International Electrotechnical Commission, 2002. IEC 61672-1:2002 Sound level meters – Part 1: Specifications.

International Standardization Organization, 2017. ISO:1996-2:2017 Acoustics — Description, measurement and assessment of environmental noise — Part 2: Determination of sound pressure levels.

International Standardization Organization, 2016. ISO 1996-1:2016 Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures.

ISO, 2017. ISO 15686-5:2017 Buildings and constructed assets — Service life planning — Part 5: Life-cycle costing. Geneva, Switzerland.

ISO, 2006a. ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework. Geneva, Switzerland.

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

Italian Government, 1997. Decree of the President of Council of Ministers of 14 November 1997: "Determinazione dei valori limite delle sorgenti sonore" (in Italian). Gazzetta Ufficiale 280.

James J. Hirsch & Associates, Lawrence Berkeley National Laboratory, USDOE, n.d. DOE-2.2 [WWW Document]. URL https://www.doe2.com/ (accessed 5.10.22).

Norman, J., MacLean, H.L., Kennedy, C.A., 2006. Comparing High and Low Residential Density: Life-Cycle Analysis of Energy Use and Greenhouse Gas Emissions. J. Urban Plann. Dev. 132, 10–21. https://doi.org/10.1061/(ASCE)0733-9488(2006)132:1(10)

NREL, U.S. Department of Energy's (DOE), n.d. EnergyPlus 22.2.0 [WWW Document]. URL https://energyplus.net/ (accessed 5.10.22).

Salom, J., Maskova, I., Grazieschi, G., Woods, R., Schneider-Marin, P., Brudal, Ø., Vaz, D., van Dijkhuizen, M., Laterveer, R., Andresen, I., 2022. D.2.1 Assessment Framework for CPCC (No. 2.1).

Thermal Energy System Specialists, n.d. TRNSYS Transient System Simulation Tool [WWW Document]. URL https://www.trnsys.com/ (accessed 5.10.22).

UNEP, 2020. Guidelines for Social Life Cycle Assessment of Products 2020, Benoît Norris, C., Traverso, M., Neugebauer, S., Ekener, E., Schaubroeck, T., Russo Garrido, S., Berger, M., Valdivia, S., Lehmann, A., Finkbeiner, M., Arcese, G. ed.

UNEP, 2009. Guidelines for Social Life Cycle Assessment of Products 2009.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. Int J Life Cycle Assess 21, 1218–1230. https://doi.org/10.1007/s11367-016-1087-8

8. APPENDIX A – QUESTIONNARE 1

8.1. INTRODUCTION

You are being invited to participate in a research study about *social and architectural aspects.* This study is part of a project called ARV, which tries to create climate positive circular communities all over Europe. *The ARV project is funded by the European Union under the H2020 funding programme (Grant agreement ID: 101036723, DOI: 10.3030/101036723). Project website: https://greendeal-arv.eu/.*

There are no known risks if you decide to participate in this research study. There are no costs to you for participating in the study. The information you provide will be used for *statistical purposes related to the scopes of the project.*

This survey is *anonymous*. Do not write your name on the survey. In the case of web-based answers, we will not collect your IP address. No one will be able to identify you or your answers, and no one will know whether you participated in the study.

Your participation in this study is *voluntary*.

If you have any questions about the study, please contact *Name, mailing address, phone number of the local contact person.*

If you have any concerns about your rights in this study, please contact Ms Sladana Lazarevic of the Norwegian University of Science and Technology (NTNU) at email sladjana.lazarevic@ntnu.no.

8.2. METHODOLOGICAL ASPECTS

The people living in the neighborhood, including tenants or students, are the *reference population* of the survey.

The demo groups should identify a significant target population for the submission of the survey as well as a set of topics/questions they are interested in. The demos are responsible for the *correctness* of the overall methodology, for the submission of the survey and for the collection of the results.

The *submission procedure* should be preferably performed through digital instruments: the survey will be transposed in an online survey creator (e.g. SurveyMonkey, Microsoft Forms, Google Forms) eventually after the translation in the local language. A label (e.g. ARVQX_1.1_gi) is added at the beginning of every question in order to trace it after language translations. In the case of impossibility of a digital management, face-to-face interviews in the streets or in houses are allowed, but a responsible person should be identified for entering the answers in the online tool chosen. The questionnaire could also be filled in within the living labs under the help of the organizers.

The submission should be performed before and after the ARV interventions in the case of retrofits. Only people older than 19 should be involved.

8.3. THE QUESTIONNAIRE

General information

[ARVQX_1.1_gi] What is the neighbourhood you live in?
Open question

[ARVQX_1.2_gi] How old are you?
20-35, 36-50, 51-64, over 65

[ARVQX_1.3_gi] Which is your gender?
Male/female/other/not relevant

[ARVQX_1.4_gi] How long have you been living in this neighbourhood?
Open question

Social aspects

Democratic process

[ARVQX_1.1_dp] Were you involved in the planning/design processes of the neighbourhood where you live?
Yes/No

Social engagement

[ARVQX_1.1_se] To what extent were you involved in the planning/design process? Check what applies:
a. *I was informed of the design proposals/decisions made but I could not express my opinions*
b. *I was informed of the design proposals/decisions made and I could express my opinions.*
    b.1. My opinions were taken into account and to some extent implemented in the design. Yes/No
c. *I took an active role in the design process where I could make proposals/suggestions before these were made definitive.*
d. *I was not informed of the design proposals/decisions, and I could not express my opinions.*
e. *I was informed of the design proposals/decisions, but I was not interested in expressing my opinions.*

[ARVQX_1.2_se] Who informed you of the design proposal/decisions? Check what applies:
a. *A public authority (e.g. city council urban planning department), please specify:*
b. *A private actor (e.g. the owner of the land), please specify:*
c. *A neighbourhood association, please specify:*
d. *Neighbour or friend*
e. *Other, please specify:*

Demographic composition

[ARVQX_1.1_dc] Most of the people I socialize with have lived in this city/region for almost their whole life
Likert scale: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.2_dc] Most of the people I socialize with are of a similar age as mine
Likert scale: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.3_dc] Most of the people I socialize with are of a similar social background as mine (e.g. same educational level, same kind of job, same working sector, similar income, etc)
Likert scale: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.4_dc] I have much in common with the people of the neighbourhood.
Likert scale: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

Social interaction and cohesion

[ARVQX_1.1_si&c] There is a high turnover in the neighbourhood where I live (e.g. a high number of people renting/buying a house and leaving in few months/years)
Likert scale: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

How often and to what extent do you interact with the residents in your neighbourhood?
[ARVQX_1.2A_si&c] A: I barely know people in my neighbourhood
[ARVQX_1.2B_si&c] B: I know many people in my neighbourhood
[ARVQX_1.2C_si&c] C: I often interact with/talk to people in outdoor areas
[ARVQX_1.2D_si&c] D: I often invite people from the neighbourhood to my home
Likert scale: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.3_si&c] The people of my neighbourhood are important to me.
Likert scale: Not important, slightly important, moderately important, important, very much important

[ARVQX_1.4_si&c] How would you rank the social interaction that you have with your neighbourhoods?
Likert scale: Very bad (we hardly know each other and there are social conflicts) – bad (we have sporadic interactions in separated groups that are not very integrated and sometimes conflicting) – neutral (we have interactions in joint meetings/associations where it is difficult to come out with a joint decision but we have a civic culture and no social conflicts) – good (we have frequent interactions, we take joint decisions in neighbourhood associations and we have a good sense of belonging to the place where we live) – very good (we have frequent fruitful interactions, we take joint decisions in neighbourhood associations and we have a strong pride and sense of place)

Safety and security

[ARVQX_1.1_s&s] How safe do you feel in your neighbourhood:
Likert scale: Very bad – bad – neither bad nor good – good – very good

[ARVQX_1.2_s&s] Which are the main causes of unsafety in your neighbourhood:
Multiple choice: Firearms shooting or stabbings, robbery or theft (including pickpocketing on the street), drug, prostitution, assaults or rapes, street accidents are common (crossing the streets is unsafe, walking/biking in the streets is dangerous), damage to public lighting/ street furniture, damage to private vehicles and buildings, air pollution threaten my health, policemen are corrupted, institutions are untrusty, other (specify), not relevant.

[ARVQX_1.3_s&s] What makes your neighbourhood particularly safe?
Open question

Energy and environmental consciousness

[ARVQX_1.1_e&ec] The technologies implemented in this building/neighbourhood improve energy efficiency.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.2_e&ec] The passive design choices (building shape, amount and placement of windows, building layout, surfaces, material choices) in this building/neighbourhood improve energy efficiency.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.3_e&ec] Having shared energy management improves energy efficiency.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.4_e&ec] I am willing to invest from the housing community budget to information systems that track, display energy performance, and give recommendations on how to save energy.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.5_e&ec] Tracking energy consumption improves (would help improving) energy efficiency.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.6_e&ec] I am aware of my own energy consumption pattern and composition.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.7_e&ec] I know how much money I can save through energy efficiency.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.8_e&ec] I actively optimize my energy consumption and select appliances to reduce my cost of living.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.9_e&ec] I aim to live a more environmentally friendly lifestyle.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.10_e&ec] My friends, colleagues and family are strongly environmentally conscious and are vocal on environmental values.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.11_e&ec] I actively optimize my energy consumption and select appliances to reduce my carbon footprint.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

Affordability of energy/housing

[ARVQX_1.1_ae&h] How many adults and children live in your house/apartment including you?
Open question: Adults ___, Children ___

[ARVQX_1.2_ae&h] What is the approximate sum of net monthly income/allowances available to your household? (if you don't have an income, provide the monthly income of the person who is in charge of paying your rent/bills)
Open question[2]

[ARVQX_1.3_ae&h] What is the annual expense for energy bills of your family/house group?
Open question[3]

[ARVQX_1.4_ae&h] What is the monthly expense for housing (rents, mortgages, amortization…) of your family/house group?
Open question

[ARVQX_1.5_ae&h] What type of heating system do you use?
Open question

---

[2] Each demo can consider pre-defined ranges in function of the current wage levels in the country.
[3] Each demo can consider pre-defined ranges in function of the current energy prices in the country. The ranges individuated should be able to define a threshold of 10% in the ratio between the annual energy expenditure and the income/allowances available to the households.

[ARVQX_1.6_ae&h] My heating system is old and unable to provide adequate comfort conditions.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

[ARVQX_1.7A_ae&h] A: Do you know who your energy provider is?
Yes/No

[ARVQX_1.7B_ae&h] B: Have you considered to change your energy provider?
Yes/No

[ARVQX_1.7C_ae&h] C: If yes, why?
Multiple choice: Price (not competitive), energy carrier (I would like to switch to electrical energy or renewables), other reasons: write an answer

[ARVQX_1.8_ae&h] Which sentence do you agree with?
Multiple choice:
- *Sometimes it is difficult to pay utility bills for keeping my home adequately warm when necessary (I might go or I went into arrear at least once). Consequently, I reduce the setpoints or I switch the heating off for some hours even if comfort conditions are compromised.*
- *If I kept my house warm when necessary, the bills would represent a significant expense. Consequently, I reduce the setpoints or I switch the heating off for some hours without compromising comfort conditions too much.*
- *Keeping my house warm represents a not negligible expense but, for this reason, I don't need to reduce my indoor comfort conditions.*
- *I have no difficulties paying the energy bills to keep my house warm when necessary because my current energy bills are very affordable.*
- *I have no concerns about energy bills to keep my house warm.*

Access to sustainable mobility/services and amenities

[ARVQX_1.1_asm&s&a] How many km do you travel daily to go working and coming home?
Open question

[ARVQX_1.2_asm&s&a] What is your means of transportation?
Multiple choice: small car (Euro Car Segment A-B), medium car (Euro Car Segment C), SUV (Euro Car Segment J), large car (all remaining Euro Car Segments), bus, regional train/metro, scooter, bike, no one (on foot)

Do you agree with the following statements:
[ARVQX_1.3A1_asm&s&a] A1: I experience the overall quality of my neighbourhood as very good.
[ARVQX_1.3A2_asm&s&a] A2: I perceive the accessibility of public transport as very good.
[ARVQX_1.3A3_asm&s&a] A3: I perceive the accessibility of local services/amenities such as schools, kindergarten, health, services, grocery shops as very good.
[ARVQX_1.3A4_asm&s&a] A4: I perceive quality of the outdoor areas in the neighbourhood as very high.
[ARVQX_1.3A5_asm&s&a] A5: My home is close to my place of work.
[ARVQX_1.3A6_asm&s&a] A6: I am very satisfied with living in my neighbourhood.
Multiple choice: Strongly disagree, disagree, neither agree nor disagree, agree, strongly agree

Architectural quality aspects

Aesthetics and visual qualities

[ARVQX_1.1_avq] How much do you like the outside appearance of the building you live in?
Likert scale: Very bad – bad – neutral – good – very good

[ARVQX_1.2_avq] How much do you like the inside appearance of the building you live in?
Likert scale: Very bad – bad – neutral – good – very good

[ARVQX_1.3_avq] How much do you like the surroundings of the building you live in?
Likert scale: Very bad – bad – neutral – good – very good

[ARVQX_1.4_avq] Could you provide one aspect that you particularly like about the outside/inside appearance, or about the surroundings of the building you live in?
Open question

Flexibility and adaptability

[ARVQX_1.1_faa] Can you easily change the function of a room in your apartment? E.g. transforming it in a segregated studio for teleworking or adapting it to wheelchair mobility.
Yes/No

[ARVQX_1.2_faa] What are the main barriers that prohibit/hinder change?
Multiple choice: lack of physical space for living/manoeuvring, impossibility of wall demolitions, installation of additional service routes, absence of appropriate technologies, impossibility of separating a room from the apartment, absence of acoustic treatment, costs of the interventions.

[ARVQX_1.3_faa] Can you easily change the floor layout of your apartment (e.g., make one bigger out of two smaller rooms and vice versa)?
Yes/No

[ARVQX_1.4_faa] Is the location of the building services (heating, cooling, ventilation, warm / cold water) known to you?
Yes/No

[ARVQX_1.5_faa] If yes: Are the services centrally located or on the periphery of the apartment?
Multiple choice: on the periphery, centrally.

[ARVQX_1.6_faa] How high are the ceilings in your apartment?
Multiple choice: Low, Normal, High, specify the height in meters if you know it: ___________

Accessibility

[ARVQX_1.1_acc] My apartment is accessible for persons with disabilities in …. (check what applies)
Multiple choice: walking, seeing, hearing, others.

Indoor Air Quality

[ARVQX_1.1_iaq] Do you think your home provides environmental comfort in terms of air quality?
Yes/No

[ARVQX_1.2_iaq] In general, how do you rate the quality of the indoor air?
Likert scale: Very Satisfied (adequate fresh air is introduced, good ventilation system), Satisfied, Neutral Dissatisfied, Very Dissatisfied (the air is too polluted).

Sufficiency and adequacy of space

[ARVQX_1.1_s&asp] How would you rate your apartment in terms of size?
Likert scale: too small - small - just right - large - very large

[ARVQX_1.2_s&asp] Is there a particular room / area in your apartment that you feel is a very good / very bad space for its use? If so, why? (E.g., the kitchen has great daylight and is very well organized for daily cooking / eating)
Open question

Solar and Daylight Access

[ARVQX_1.1_s&da] Are you satisfied about the quantity (e.g. enough hours per day, enough days per year) of natural lighting in your living spaces? (Excluding technical rooms, corridors, or distribution areas.)
Yes/No

[ARVQX_1.2_s&da] Do you need artificial lighting during the daylight hours to carry out your home tasks?
Yes/No

[ARVQX_1.3_s&da] Are you experiencing undesired glare effects? (Glare is considered as an unpleasant bright or a too strong light.)
Yes/No

Acoustic comfort

How loud is the noise in your home?
[ARVQX_1.1A_ac] A: from outside
[ARVQX_1.1B_ac] B: from adjacent rooms/apartments
[ARVQX_1.1C_ac] C: from service equipment
Likert scale: Very loud (e.g. heavy traffic, rock concert) – Moderately loud (e.g. noisy office, hairdryer) – Slightly loud noise with low annoyance (e.g. dishwasher, radio) – Slightly loud with no annoyance (e.g. rainfall, computer, refrigerator) – Not loud at all (e.g. less than a whisper)

[ARVQX_1.2_ac] How do you assess the quality of the sound environment that is in your living space? (Bad sound qualities are reverberation, echo, difficulty to distinguish single words/sounds.)
Likert scale: Very poor, poor, acceptable, good, very good

Outdoor comfort

[ARVQX_1.1_oc] Do you like spending time outdoors in your neighbourhood?
Yes/No

[ARVQX_1.2_oc] Is there an outdoor area associated with the building you live in (garden, park, entrance area)?
Yes/No; if yes, please specify.

[ARVQX_1.3_oc] The entrance area leading up to the building (outside) is particularly
Multiple choice: hot in the summer, cool in the summer, warm in the winter, cold in the winter, windy, calm, noisy, quiet, dark, bright, dusty, clean, other, please specify:

Thermal comfort

[ARVQX_1.1_tc] Are you experiencing cold air drafts from windows even when they are closed?
Yes/No

[ARVQX_1.2_tc] Are you experiencing summer overheating problems?
Yes/No

[ARVQX_1.3A_tc] A: Do you have access to and the possibility to operate shading systems?
Yes/No

[ARVQX_1.3B_tc] B: What kind of the shading system?
External (louvres, overhangs), internal (curtains, venetian blinds), integrated in the window

9. APPENDIX B – QUESTIONNARE 2

9.1. INTRODUCTION

You are being invited to participate in a research study about *noise and dust generation during construction works.* This study is part of a project called ARV, which tries to create climate positive circular communities all over Europe. *The ARV project is funded by the European Union under the H2020 funding programme (Grant agreement ID: 101036723, DOI: 10.3030/101036723). Project website: https://greendeal-arv.eu/.*

There are no known risks if you decide to participate in this research study. There are no costs to you for participating in the study. The information you provide will be used for *statistical purposes related to the scopes of the project.*

This survey is *anonymous*. Do not write your name on the survey. In the case of web-based answers, we will not collect your IP address. No one will be able to identify you or your answers, and no one will know whether you participated in the study.

Your participation in this study is *voluntary*.

If you have any questions about the study, please contact *Name, mailing address, phone number of the local contact person.*

If you have any concerns about your rights in this study, please contact Ms Sladana Lazarevic of the Norwegian University of Science and Technology (NTNU) at email sladjana.lazarevic@ntnu.no.

9.2. METHODOLOGICAL ASPECTS

The people living in the neighborhood, the workers of the construction site and the habitual users of the public spaces that are located in the proximity of the area are the *reference population* of the survey.

The demo groups should individuate a significant target population for the submission of the survey as well as a set of topics they are interested in. The demos are so responsible for the *correctness* of the overall methodology, for the submission of the survey and for the collection of the results.

The *submission procedure* should be preferably performed through digital instruments: the survey will be transposed in an online survey creator (e.g. SurveyMonkey, Microsoft Forms, Google Forms) eventually after the translation in the local language. A label (e.g. ARVQX_2.1_gi) is added at the beginning of every question in order to trace it after language translations. It is fundamental that the questionnaire is submitted to the target people while construction works are ongoing, preferably through a tablet and without influencing the soundscape of the area (e.g. speaking). In the case of impossibility of a digital management, a manual submission in paper form in the streets or in houses is allowed, but a responsible person should be individuated for the transposition of the answers in the online tool chosen.

9.3. THE QUESTIONNAIRE

General information

[ARVQX_2.1_gi] How old are you?
0-19, 20-35, 36-50, 51-64, over 65

[ARVQX_2.2_gi] Which is your gender?
Male/female/other

[ARVQX_2.3_gi] Are you a resident at, a worker in or a visitor of the study site?
Open question

[ARVQX_2.4_gi] How often do you visit this place on average?
Multiple choice: Always (almost every day), Often (at least three times a week), Sometimes (at least 4 times a month), Sometimes on the weekend, Rarely (once a month or less).

for residents only:

[ARVQX_2.5A_gi] A: Do you live in your apartment during the construction work?
Yes/No

[ARVQX_2.5B_gi] B: If no, for how long do you have to move house?
No. of months

On a scale of 1-5 (agree):
[ARVQX_2.6A_gi] A: The renovation will benefit the neighbourhood very much.
[ARVQX_2.6B_gi] B: The information I received before the renovation process was very good.
[ARVQX_2.6C_gi] C: I expect the renovation to increase my/my family`s quality of life.
[ARVQX_2.6D_gi] E: The information I receive about the ongoing renovation is very good.
Likert scale: Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree.

Dust during construction works

[ARVQX_2.1_ddcw] Please, list some dusty activities that characterize traditional construction works (N.B. in traditional construction sites all the activities of excavation, wall erection, roof building, plumbing installation, electrical wiring, finishing and flooring are realized directly in site without being prefabricated in a factory).
Open question

[ARVQX_2.2_ddcw] Are you experiencing them in this construction site?
Likert scale: Never – Rarely – Sometimes – Often – Always.

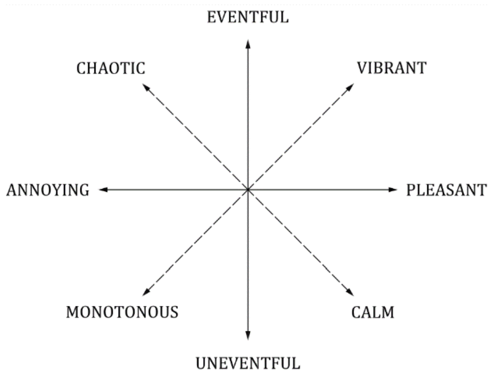
[ARVQX_2.3_ddcw] In your opinion, how are the dust levels generated by the present construction site compared to dust levels generated by traditional construction works?
Likert scale: much more dust (more than +30%) – significantly more dust (+30%) – same level – significantly less (-30%) – much less (more than -30%).

[ARVQX_2.4_ddcw] Which actions could improve your dust exposure in your house/living place while the construction is ongoing?
Open question

Noise during construction works

[ARVQX_2.1_ndcw] Please list sound sources you noticed in descending order starting with the most noticeable sound source.
Answers in a scale of importance/loudness (max 8)

For each of the 8 scales below, to what extent do you agree or disagree that the present surrounding sound environment is…
[ARVQX_2.2A_ndcw] A: eventful
[ARVQX_2.2B_ndcw] B: exciting/vibrant
[ARVQX_2.2C_ndcw] C: pleasant
[ARVQX_2.2D_ndcw] D: calm
[ARVQX_2.2E_ndcw] E: uneventful
[ARVQX_2.2F_ndcw] F: monotonous
[ARVQX_2.2G_ndcw] G: annoying
[ARVQX_2.2H_ndcw] H: chaotic
Likert scale: Strongly agree, Agree, Neither agree nor disagree, Disagree, Strongly disagree.



[ARVQX_2.3_ndcw] Overall, how would you describe the present surrounding sound environment?
Likert scale: Very good, Good, Neither good nor bad, Bad, Very bad

[ARVQX_2.4_ndcw] Overall, to what extent is the present surrounding sound environment appropriate to the present place?
Likert scale: Not at all, Slightly, Moderately, Very, Perfectly

[ARVQX_2.5_ndcw] Please, list activities at traditional construction sites that generate noise.
Open question

[ARVQX_2.6_ndcw] Which of these activities have you experienced at this construction site?
Open question

[ARVQX_2.7_ndcw] In your opinion, how much of the noise generated by the present construction site is lower than the one generated by a traditional construction activity?
Likert scale: much more noisy (>+30%) – significantly more noisy (+30%) – same level – significantly less (-30%) – much less (more than -30%).

[ARVQX_2.8_ndcw] How do you rate the level of noise disturbance of the construction activity on your daily life?
Likert scale: 1 (very much disturbed) – 2 (moderately disturbed) – 3 (neutral) – 4 (slightly disturbed) - 5 (not at all disturbed)

[ARVQX_2.9_ndcw] Which actions can improve your sound experience in your house/living place while the construction is ongoing?
Open question

10. APPENDIX C – QUESTIONNARE 3

10.1. INTRODUCTION

You are being invited to participate in a research study about *social and architectural aspects.* This study is part of a project called ARV, which tries to create climate positive circular communities all over Europe. *The ARV project is funded by the European Union under the H2020 funding programme (Grant agreement ID: 101036723, DOI: 10.3030/101036723). Project website: https://greendeal-arv.eu/.*

There are no known risks if you decide to participate in this research study. There are no costs to you for participating in the study. The information you provide will be used for *statistical purposes related to the scopes of the project.*

This survey is *anonymous*. Do not write your name on the survey. In the case of web-based answers, we will not collect your IP address. No one will be able to identify you or your answers, and no one will know whether you participated in the study.

Your participation in this study is *voluntary*.

If you have any questions about the study, please contact *Name, mailing address, phone number of the local contact person.*

If you have any concerns about your rights in this study, please contact Ms Sladana Lazarevic of the Norwegian University of Science and Technology (NTNU) at email sladjana.lazarevic@ntnu.no.

10.2. METHODOLOGICAL ASPECTS

The *reference population* of the survey is composed by the design team members, the technical consultants, the developers, the constructors and all the experts who were involved in the realization of the ARV interventions.

The demo groups should individuate a significant target population for the submission of the survey as well as a set of topics they are interested in. The demos are so responsible for the *correctness* of the overall methodology, for the submission of the survey and for the collection of the results.

The *submission procedure* should be preferably performed through digital instruments: the survey will be transposed in an online survey creator (e.g. SurveyMonkey, Microsoft Forms, Google Forms) eventually after the translation in the local language. A label (e.g. ARVQX_3.1_gi) is added at the beginning of every question in order to trace it after language translations. In the case of impossibility of a digital management, a manual submission in paper form is allowed, but a responsible person should be individuated for the transposition of the answers in the online tool chosen.

The survey should be submitted after the conclusion of the construction activities.

10.3. THE QUESTIONNAIRE

General information

[ARVQX_3.1_gi] What is your role in the ARV project (e.g. architect, engineer, consultant, member of the construction company, member of the local association, …)
Open question

Social aspects

Democratic process/Social engagement

[ARVQX_3.1_dp] Which stakeholders were involved in the design process? Check what applies.
Multiple choice: Land owner, Design teams, Technical consultants, Developers, Construction companies, Sub-contractors, Public authorities, End-users, Local civil associations, Others: please specify

[ARVQX_3.2_se] To what extent end-users, local citizens, and/or their representatives (e.g. local associations) were involved in the design process? Check what applies and please specify in few words the procedures followed:
Multiple choice:

a) *They were informed of the design strategies and solutions through vis-à-vis meetings.*
b) *They were informed of the design strategies and solutions through public consultation (e.g. through official channels of local public authorities).*
c) *They participated in meetings and workshops with the design team and expressed their opinions, which were, to a certain extent, integrated in the design development process.*
d) *They actively participated in meetings/workshops with the design teams before the design strategies were made definite, and their inputs were integrated in the design solutions.*
e) *They expressed they opinions through public channels (e.g. through official channels of local public authorities).*
f) *They were not informed of the design strategies/solutions.*

If either questions 3c or 3d were answered, to what extent did the received inputs change the followings:

[ARVQX_3.3A_se] A: The initial design concept and main features.
Please specify

[ARVQX_3.3B_se] B: The time for design development and finalization.
Please specify

Affordability of energy/housing

[ARVQX_3.1A_ae&h] A: Did the design team calculate an expected reduction of annual energy expenditure of the residents in the retrofitted buildings?
Yes/No

[ARVQX_3.1B_ae&h] B: Can you provide an estimation of the reduction in the annual energy expenditure that can be experienced by the residents of the retrofitted buildings?
Multiple choice: No reduction, 1-10%, 10-20%, 20-30%, 30-40%, >40%

[ARVQX_3.1C_ae&h] C: Was this estimation revised (increased/decreased) during the design process? Check what applies:
Multiple choice: It was increased, It was decreased, No changes, If the first two answers do not apply, please explain the reasons.

[ARVQX_3.2A_ae&h] A: Did the design team apply Life Cycle Cost (LCC) or Life Cycle Analysis (LCA) methodologies to identify an optimal solution from a financial and environmental point of view?
Yes both, only LCA, only LCC, No

[ARVQX_3.2B_ae&h] B: If yes, can you provide an estimation of the reduction in the Life Cycle Cost (e.g. investment + operational energy costs) of the building 50 years after the intervention compared to the ex-ante situation or to the common practice?
Multiple choice: no reduction, 1-10%, 10-20%, 20-30%, 30-40%, >40%

[ARVQX_3.2C_ae&h] C: Was this estimation revised (increased/decreased) during the design process? Check what applies:
Multiple choice: It was increased, It was decreased, No changes, If the first two answers do not apply, please explain the reasons.

[ARVQX_3.2D_ae&h] D: If LCA was applied, can you provide an estimation of the reduction in the Life Cycle Emissions (e.g. embodied + operational energy emissions) of the building 50 years after the intervention compared to the ex-ante situation or to the common practice?
Multiple choice: no reduction, 1-10%, 10-20%, 20-30%, 30-40%, >40%

[ARVQX_3.2E_ae&h] E: Was this estimation revised (increased/decreased) during the design process? Check what applies:
Multiple choice: It was increased, It was decreased, No changes, If the first two answers do not apply, please explain the reasons.

Architectural quality aspects

Aesthetics and visual qualities

[ARVQX_3.1_avq] Please describe the architectural concept/idea of the project in one sentence.
Open question

[ARVQX_3.2A_avq] Did this concept change throughout the design process?
Yes/No

[ARVQX_3.2B_avq] If yes, why?
Open question

[ARVQX_3.3_avq] In your opinion, was the concept successfully executed?
Yes/No

For new constructions:

[ARVQX_3.4A_avq] A: Considering plan/prospect composition, it is possible to detect a clear proportion rule in the distribution of the architectural elements (e.g. geometric proportions, symmetry, modular repetition, ….).
Yes/No, please explain.

[ARVQX_3.4B_avq] B: The overall appearance of the building is very good.
Yes/No, please explain the reason behind your answer.

[ARVQX_3.4C1_avq] C1: There is a clear material concept for the structure of the building.
Yes/No, please specify.

[ARVQX_3.4C2_avq] C2: There is a clear material, surface and colour concept for the exterior of the building.
Yes/No, please specify.

[ARVQX_3.4C3_avq] C3: There is a clear material, surface and colour concept for the interior of the building.
Yes/No, please specify.

[ARVQX_3.4D_avq] D: Architectural details and structural connections are deeply studied from a technical, technological and aesthetical perspective (e.g. can be made visible and not hide).
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

[ARVQX_3.4E_avq] E: Visual connections with the external landscape or with the internal environment (e.g. through an atrium, double height spaces, transparent elements, etc.) are searched.
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

[ARVQX_3.4F_avq] F: There is an adequate coherence (volumes, façade patterns, colours) between the new/renovated building and the surrounding built environment.
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

For renovations:

[ARVQX_3.5A_avq] A: There is an adequate coherence (volumes, façade patterns, colours) between the new/renovated building and the surrounding built environment.
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

[ARVQX_3.5B_avq] B: The intervention blends in the surrounding natural/urban environment.
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

[ARVQX_3.5C1_avq] C1: The reconstruction of historical appearance is differentiated through contrast (new additions in contrast to the original appearance of the building)
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

[ARVQX_3.5C2_avq] C2: The reconstruction of historical appearance is differentiated through interpretation (new additions are blended by interpretation of the historical building, e.g. similar façade patterns, size, shape, and rhythm of openings, etc.)
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

[ARVQX_3.5C3_avq] C3: The reconstruction of historical appearance follows as much as possible the original design (same colours, materials, openings shapes, size, and number)
Likert scale: Strongly Agree, Agree, Undecided, Disagree, Strongly Disagree

Flexibility and adaptability

[ARVQX_3.1_faa] Did the design consider the adoption of structural systems that support layout changes?
Yes/No
Please briefly discuss.

[ARVQX_3.2_faa] Did the design consider greater ceiling heights (e.g. > 3m) for service routes?
Yes/No

[ARVQX_3.3_faa] Did you consider a plant or equipment room located externally to the building with a complete/separated access?
Yes/No

[ARVQX_3.4_faa] Is it possible to segregate a new space within the residential/working units that has adequate dimensions, light and services to support teleworking?
Yes/No
Please briefly discuss.

[ARVQX_3.5A_faa] A: Are the building services (water, heating, ventilation, if applicable) routed centrally or in separate shafts?
Please briefly discuss.

[ARVQX_3.5B_faa] B: How many shafts per apartment?
Open question

[ARVQX_3.6_faa] Is it possible to use a room in the building/apartment with different purposes throughout the day (e.g. partitioning large rooms with temporary screens to host different functions/uses)?
Yes/No
Please briefly discuss

Sufficiency and adequacy of space

[ARVQX_3.1_s&asp] Are the surfaces of the single rooms larger than the minimum law requirements?
Yes/No

[ARVQX_3.2_s&asp] Are the spaces designed to host specific functions?
Please describe briefly

[ARVQX_3.3_s&asp] If so, specify which ones and give reasons.
Open question

Solar and Daylight Access

[ARVQX_3.1_s&da] Did the design team address daylight strategies that exceeded the minimum requirements set in the building code? (e.g. increase of daylight availability, glare control strategies, overheating control strategies, etc)
Yes/No
Please briefly describe how

[ARVQX_3.2A_s&da] A: Did the design team use additional lighting and visual comfort metrics than daylight factor? (e.g. discomfort glare index, discomfort glare probability, visual comfort probability, illuminance uniformity, daylight autonomy, useful daylight illuminance, continuous daylight autonomy, etc)
Yes/No
Please briefly describe how

[ARVQX_3.3B_s&da] B: To what extent were the above metrics calculated?
Multiple choice: Significant rooms, multiple rooms, whole building

[ARVQX_3.4_s&da] Did the design of lighting systems provide the possibility of a users' control in dimming the intensity of artificial illumination?
Yes/No
Please briefly describe how

[ARVQX_3.5_s&da] Did the design of lighting systems foresee the installation of efficient lamps (e.g. efficiency > 120 lm/W) with adequate Colour Temperature (e.g. ≤3500K) and high Colour Rendering Index (e.g >80)?
Yes/No
Please briefly discuss

Accessibility

[ARVQX_3.1_acc] the design consider pram or wheelchair mobility to access the residential/working units and for internal manoeuvres?
Yes/No
Please briefly discuss

[ARVQX_3.2_acc] Did the design consider people with disabilities other than mobility (e.g., vision or hearing disabilities, unusually tall or short persons)?
Yes/No
Please briefly discuss

Acoustic comfort

[ARVQX_3.1_ac] Did the design consider the passive acoustic requirements of building components (e.g. façade sound insulation - $D_{2m,nT,w}$, airborne sound insulation - R'_w, impact sound insulation - $L'_{n,w}$, service equipment noise - $L_{Aeq,nT}$ or $L_{AFmax,nT}$, sound absorption in rooms and reverberation times – T_{60})?
Yes/No
Please briefly describe how

Outdoor comfort

[ARVQX_3.1_oc] Was there a design concept for the outdoor areas? If so, which of the following human comfort parameters were considered?
Multiple choice: sun, shade, wind, noise.

[ARVQX_3.2_oc] Did you consider the building's ability to shield the surrounding areas from wind and / or sun? If so, did this influence the design of the building's geometry?
Yes/No.
Please briefly describe how

11. APPENDIX D – PRELIMINARY PLANS FOR THE APPLICATION OF THE GUIDELINES PROPOSED IN THE DEMONSTRATION PROJECTS

An overview of the preliminary plans for implementing the guidelines for monitoring, evaluating, and assessing the impact of ARV demonstration projects can be found in this appendix. This overview can be considered as a follow-up of the preliminary plans for the application of the assessment framework the that have already been reported in the Appendix D of Deliverable 2.1.

11.1. DEMONSTRATION PROJECT IN SPAIN

Table D.1 recaps the demo actions that affect the proposed KPIs; the related guidelines for the evaluation of the KPIs were discussed and agreed with the Palma demo group.

Table D.1. *Preliminary plan for the application of the assessment framework and related guidelines to the Llevant demo project.*

Category	KPI	Level (Mandatory/ Optional)	Relevance	Demo actions impacting the KPIs	Type of buildings/ Comments
Energy	**Non-renewable Primary Life Cycle Energy in the Built Environment**	**Mandatory**	x	Large-scale renovation	Renovated residential and non-residential buildings
				Deployment of renewable energy using available private and public roofs in the area	New and renovated residential and non-residential buildings
				Use of innovative local materials	New Social Housing buildings
	Renewable Energy Ratio	**Mandatory**	x	Deployment of renewable energy using available private and public roofs in the area	Available optimal private and public roofs in the area
	Grid Delivered Factor	Optional	x	Implementation of CEC	Mainly public buildings
	Net Energy/Net Power	**Mandatory**	x	All actions	
	Flexibility Index	**Mandatory**	x	Optimization of the operation of heat pumps for DHW	New residential buildings
Environment	**Life-cycle GHG Emissions in CPCC**	**Mandatory**	x	All actions	Emissions will be accessed from buildings and water consumption
	Air Pollution from the Energy Consumption	**Mandatory**	x	Large scale retrofitting actions	Renovated residential and non-residential buildings
	Dust during Retrofitting	**Mandatory**	x	New social housing and large scale retrofitting	Residential buildings

	Noise during Retrofitting	**Mandatory**	x	New social housing and large scale retrofitting	Residential buildings
Society	Democratic Process	Optional	x	*Es Laboratori as a Living Lab*	Residential buildings. **The name of "LivingLab" has been changed to "Es Laboratori" because it sounds more engaging for the local target group.*
	Social Inclusion	**Mandatory**	x	Es Laboratori as a Living Lab	Residential buildings
	Social Engagement	**Mandatory**	x	Es Laboratori as a Living Lab	Residential buildings
	Demographic Composition	Optional			
	Social Interaction and Cohesion	**Mandatory**	x	Es Laboratori as a Living Lab	Residential buildings
	Safety and Security	Optional			Residential buildings
	Energy & Environmental Consciousness	**Mandatory**	x	Es Laboratori as a Living Lab	Residential buildings
	Affordability of Energy	Optional	x	Es Laboratori and Large scale retrofitting actions	Renovated residential building
	Affordability of Housing	Optional			
	Access to Sustainable Mobility	Optional			
	Access to Services and Amenities	Optional			
Architecture	**Aesthetics and Visual Qualities**	**Mandatory**	x	Renovation of a flagship heritage protected office building. New Social Housing.	New and renovated residential and non-residential buildings
	Flexibility and Adaptability	Optional			
	Sufficiency and Adequacy of Space	Optional			
	Solar and Daylight Access	**Mandatory**	x	New social housing	New buildings
	Accessibility	**Mandatory**	x	Large scale renovation and New high efficiency Residential Multifamily Buildings	New buildings and renovated buildings
	Indoor Air Quality	**Mandatory**	x	Optimal use of comfort-driven ventilation system in social housing	New social housing
	Thermal Comfort	**Mandatory**	x	New social housing and large scale retrofitting	New buildings and renovated buildings
	Overheating Risk	**Mandatory**	x	New social housing and large scale retrofitting	New buildings and renovated buildings
	Acoustic Comfort	**Mandatory**	x	New social housing and large scale retrofitting	New buildings and renovated buildings
	Outdoor Comfort	**Mandatory**	x	New social housing and large scale retrofitting	New buildings and renovated buildings
Circularity	**Materials from Cycled Sources**	**Mandatory**	x	Use of innovative local materials	New social housing
	Reusability	Optional			

Economics	**Global Cost**	**<u>Mandatory</u>**	**x**	Large scale renovation, CEC	Renovated buildings and creation of CEC
	Energy Renovation Rate	**<u>Mandatory</u>**	**x**	Large scale renovation	Renovated buildings
	Number of Jobs Created	Optional	x	All actions	
	Construction Time Reduction	**<u>Mandatory</u>**	**x**	Large scale renovation New social housing	Renovated buildings New buildings

11.2. DEMONSTRATION PROJECT IN ITALY

Table D.2 recaps the demo actions that affect the proposed KPIs; the related guidelines for the evaluation of the KPIs were discussed and agreed with the Trento demo group.

Table D.2. *Preliminary plan for the application of the assessment framework and related guidelines to the Trento demo project.*

Category	KPI	Level (Mandatory/ Optional)	Relevance	Demo actions impacting the KPIs	Type of buildings/ Comments
Energy	**Non-renewable Primary Life Cycle Energy in the Built Environment**	**Mandatory**	x	A catalogue of Integrated Circular Design solutions for building refurbishment with 50% of energy reduction and positive energy new construction	Renovated residential and non-residential buildings
				Building envelopes with active (BAPV/BIPV) and passive elements. Using geothermal potential	New and renovated residential and non-residential buildings
				Wood prefabrication, local supply chain. Circular economy-based design process	New and renovated residential and non-residential buildings
	Renewable Energy Ratio	**Mandatory**	x	Building envelopes with active (BAPV/BIPV) and passive elements. Using geothermal potential	New and renovated residential and non-residential buildings
	Grid Delivered Factor	Optional			
	Net Energy/Net Power	**Mandatory**	x	All actions	
	Flexibility Index	**Mandatory**	x		
Environment	**Life-cycle GHG Emissions in CPCC**	**Mandatory**	x	Summer cooling by heat pumps and green roof sample for cooling of heat islands and local rainwater management (rain gardens, greenery)	New and renovated residential and non-residential buildings
	Air Pollution from the Energy Consumption	**Mandatory**	x	Local RES production	New and renovated residential and non-residential buildings
	Dust during Retrofitting	**Mandatory**	x		
	Noise during Retrofitting	**Mandatory**	x		
Society	Democratic Process	Optional			
	Social Inclusion	**Mandatory**	x	Involvement of different local stakeholders in common visits, workshops, events	

	Social Engagement	**Mandatory**	x		
	Demographic Composition	Optional			
	Social Interaction and Cohesion	**Mandatory**	x		
	Safety and Security	Optional			
	Energy & Environmental Consciousness	**Mandatory**	x		
	Affordability of Energy	Optional			
	Affordability of Housing	Optional			
	Access to Sustainable Mobility	Optional			
	Access to Services and Amenities	Optional			
Architecture	**Aesthetics and Visual Qualities**	**Mandatory**	x	Architectural and aesthetic integration of BIPV/BAPV solutions	
	Flexibility and Adaptability	Optional			
	Sufficiency and Adequacy of Space	Optional			
	Solar and Daylight Access	**Mandatory**	x		
	Accessibility	**Mandatory**	x		
	Indoor Air Quality	**Mandatory**	x	Natural and mechanical ventilation concepts	
	Thermal Comfort	**Mandatory**	x		
	Overheating Risk	**Mandatory**	x		
	Acoustic Comfort	**Mandatory**	x		
	Outdoor Comfort	**Mandatory**	x		
Circularity	**Materials from Cycled Sources**	**Mandatory**	x	Wood prefabrication, local supply chain. Circular economy-based design process	Renovated residential buildings and new non-residential buildings
	Reusability	Optional			
Economics	**Global Cost**	**Mandatory**	x	One-stop-shop platform business model connected to Italian national incentives for refurbishment	
	Energy Renovation Rate	**Mandatory**	x		
	Number of Jobs Created	Optional			
	Construction Time Reduction	**Mandatory**	x	Definition of standard modules (shape and dimension) with some flexibility (dimension, materials, layers)	

11.3. DEMONSTRATION PROJECT IN THE NETHERLANDS

Table D.3 recaps the demo actions that affect the proposed KPIs; the related guidelines for the evaluation of the KPIs were discussed and agreed with the Utrecht demo group.

Table D.3. *Preliminary plan for the application of the assessment framework and related guidelines to the Overvecht-Noord district and the Kanaleneiland-Zuid district.*

Category	KPI	Level (Mandatory/ Optional)	Relevance	Demo actions impacting the KPIs	Type of buildings/ Comments
Energy	**Non-renewable Primary Life Cycle Energy in the Built Environment**	**Mandatory**	x	Design and implementation of RES and storage solutions for buildings/neighbourhoods' electricity/thermal needs	Renovated residential buildings
				Plug-and-play BIPV/BAPV solutions	Renovated residential buildings
				Circular hub for optimized construction	Renovated residential buildings
	Renewable Energy Ratio	**Mandatory**	x	Plug-and-play BIPV/BAPV solutions	Renovated residential buildings
	Grid Delivered Factor	Optional			
	Net Energy/Net Power	**Mandatory**	x	Deployment of solutions for forecasting (city weather, solar, load)	
	Flexibility Index	**Mandatory**	x	Smart building control optimisation	
Environment	**Life-cycle GHG Emissions in CPCC**	**Mandatory**	x	One-piece flow optimized construction workflow	Renovated residential buildings
	Air Pollution from the Energy Consumption	**Mandatory**	x	Plug-and-play BIPV/BAPV solutions	Renovated residential buildings
	Dust during Retrofitting	**Mandatory**	x	Prefabrication of modular building components	Renovated residential buildings
	Noise during Retrofitting	**Mandatory**	x	Prefabrication of modular building components	Renovated residential buildings
Society	Democratic Process	Optional			
	Social Inclusion	**Mandatory**	x	Social renovation with housing tenants	

	Social Engagement	**<u>Mandatory</u>**	x	Human Capital program Bouw=Wouw!. Physical Hub in district	
	Demographic Composition	Optional			
	Social Interaction and Cohesion	**<u>Mandatory</u>**	x		
	Safety and Security	Optional			
	Energy & Environmental Consciousness	**<u>Mandatory</u>**	x	Energy coaching of residents to reduce energy poverty	
	Affordability of Energy	Optional			
	Affordability of Housing	Optional			
	Access to Sustainable Mobility	Optional			
	Access to Services and Amenities	Optional			
Architecture	**Aesthetics and Visual Qualities**	**<u>Mandatory</u>**	x	Architectural and aesthetic plug-and-play BIPV/BAPV solutions	
	Flexibility and Adaptability	Optional			
	Sufficiency and Adequacy of Space	Optional			
	Solar and Daylight Access	**<u>Mandatory</u>**	x		
	Accessibility	**<u>Mandatory</u>**	x		
	Indoor Air Quality	**<u>Mandatory</u>**	x	Renovation concepts with mechanical ventilation solutions	
	Thermal Comfort	**<u>Mandatory</u>**	x	Inside-Out system design for retrofitting	
	Overheating Risk	**<u>Mandatory</u>**	x	Inside-Out system design for retrofitting	
	Acoustic Comfort	**<u>Mandatory</u>**	x		
	Outdoor Comfort	**<u>Mandatory</u>**	x		

Circularity	**Materials from Cycled Sources**	**Mandatory**	**x**	Circular hub for optimized construction	Renovated residential buildings
	Reusability	Optional	x	Circular hub for optimized construction	Renovated residential buildings
Economics	**Global Cost**	**Mandatory**	**x**	Innovative business models	
	Energy Renovation Rate	**Mandatory**	**x**		
	Number of Jobs Created	Optional			
	Construction Time Reduction	**Mandatory**	**x**	Inside-Out system design for retrofitting. Zero-engineering of construction process	Renovated non-residential buildings

11.4. DEMONSTRATION PROJECT IN CZECH REPUBLIC

Table D.4 recaps the demo actions that affect the proposed KPIs; the related guidelines for the evaluation of the KPIs were discussed and agreed with the Karvina demo group.

Table D.4. *Preliminary plan for the application of the assessment framework and related guidelines to the Karviná Mizerov Health Centre.*

Category	KPI	Level (Mandatory/ Optional)	Relevance	Demo actions impacting the KPIs	Type of buildings/ Comments
Energy	**Non-renewable Primary Life Cycle Energy in the Built Environment**	**Mandatory**	x	nZEB design	Renovated non-residential building
				Deployment of integrated RES and storage systems (BIPV, BAPV, PV-T, heat pump and energy storage)	Renovated non-residential building
	Renewable Energy Ratio	**Mandatory**	x	Deployment of RES (BIPV, BAPV, PV-T)	Renovated non-residential building
	Grid Delivered Factor	Optional			
	Net Energy/Net Power	**Mandatory**	x	All actions related to RES	Renovated non-residential building
	Flexibility Index	**Mandatory**	x	Forecasting of electricity and heat load profiles, deployment of energy storages (second-life energy storage and heat/cold storage tank	Renovated non-residential building
Environment	**Life-cycle GHG Emissions in CPCC**	**Mandatory**	x	LCA of HVAC systems with focus on carbon footprint. Small-scale pilots of climate change resilient solutions – use of heat pumps for summer cooling	Renovated non-residential building
	Air Pollution from the Energy Consumption	**Mandatory**	x	Local RES production from PV, PV-T	Renovated non-residential building
	Dust during Retrofitting	**Mandatory**	x		Renovated non-residential building
	Noise during Retrofitting	**Mandatory**	x		Renovated non-residential building
Society	Democratic Process	Optional			
	Social Inclusion	**Mandatory**	x	Deployment of Living Lab	Renovated non-residential building

	Social Engagement	**Mandatory**	x	Creation of Living Lab (workshops, public activities), stakeholders engagement	Renovated non-residential building
	Demographic Composition	Optional			
	Social Interaction and Cohesion	**Mandatory**	x	Deployment of Living Lab	Renovated non-residential building
	Safety and Security	Optional			
	Energy & Environmental Consciousness	**Mandatory**	x	Deployment of Living Lab	Renovated non-residential building
	Affordability of Energy	Optional			
	Affordability of Housing	Optional			
	Access to Sustainable Mobility	Optional			
	Access to Services and Amenities	Optional			
Architecture	**Aesthetics and Visual Qualities**	**Mandatory**	x	Keeping architectural aesthetics of the BIPV, deployment of the digital twin,	Renovated non-residential building
	Flexibility and Adaptability	Optional			
	Sufficiency and Adequacy of Space	Optional			
	Solar and Daylight Access	**Mandatory**	x		Renovated non-residential building
	Accessibility	**Mandatory**	x		Renovated non-residential building
	Indoor Air Quality	**Mandatory**	x	IAQ monitoring platform, small scale pilot of HVAC system	Renovated non-residential building
	Thermal Comfort	**Mandatory**	x	Innovative cooling solutions	Renovated non-residential building
	Overheating Risk	**Mandatory**	x		Renovated non-residential building
	Acoustic Comfort	**Mandatory**	x		Renovated non-residential building
	Outdoor Comfort	**Mandatory**	x	Green roof sample	Renovated non-residential building
Circularity	**Materials from Cycled Sources**	**Mandatory**	x	Green roof sample - application of recycled and/or secondary materials, second-life energy storage	Renovated non-residential building
	Reusability	Optional			

Economics	**Global Cost**	**<u>Mandatory</u>**	**x**		Renovated non-residential building
	Energy Renovation Rate	**<u>Mandatory</u>**	**x**		Renovated non-residential building
	Number of Jobs Created	Optional			
	Construction Time Reduction	**<u>Mandatory</u>**	**x**	Installation of swappable façade elements with integrated RES	Renovated non-residential building

11.5. DEMONSTRATION PROJECT IN DENMARK

Table D.5 recaps the demo actions that affect the proposed KPIs; the related guidelines for the evaluation of the KPIs were discussed and agreed with the Sønderborg demo group.

Table D.5. *Preliminary plan for the application of the assessment framework and related guidelines to the SAB Department 22: Kløvermarken/Hvedemarken.*

Category	**KPI**	**Level (Mandatory/ Optional)**	**Relevance**	**Demo actions impacting the KPIs**	**Type of buildings/ Comments**
Energy	**Non-renewable Primary Life Cycle Energy in the Built Environment**	**Mandatory**	x	Demonstration and monitoring existing building integrated PV panels in combination with battery solutions	Three floors apartment buildings. 432 apartments in 19 buildings.
	Renewable Energy Ratio	**Mandatory**	x	Demonstration and monitoring existing BIPV panels in combination with battery solutions	Three floors apartment buildings. 432 apartments in 19 buildings.
	Grid Delivered Factor	Optional			
	Net Energy/Net Power	**Mandatory**	x	All actions	
	Flexibility Index	**Mandatory**	x	Intelligent and flexible management of the district heating network	District heating network in the neighborhood of Demo project
Environment	**Life-cycle GHG Emissions in CPCC**	**Mandatory**	x	Focusing on low carbon intensive technical components used in the buildings	
	Air Pollution from the Energy Consumption	**Mandatory**	x	PV panels and battery solutions. District heating. Supply from wind turbines.	
	Dust during Retrofitting	**Mandatory**	***No****		**No building construction work, only inside technical solutions*
	Noise during Retrofitting	**Mandatory**	***No****		**No building construction work, only inside technical solutions*
Society	Democratic Process	Optional	x		Social housing associations
	Social Inclusion	**Mandatory**	x		Social housing associations
	Social Engagement	**Mandatory**	x	Information activities for tenants	
	Demographic Composition	Optional			
	Social Interaction and Cohesion	**Mandatory**	x	Activities for tenants	
	Safety and Security	Optional			

	Energy & Environmental Consciousness	**Mandatory**	**x**	Green Ambassadors will be appointed among the tenants	
	Affordability of Energy	Optional			
	Affordability of Housing	Optional			
	Access to Sustainable Mobility	Optional			
	Access to Services and Amenities	Optional			
Architecture	**Aesthetics and Visual Qualities**	**Mandatory**	***No****		**No architectural changes on buildings or environment.*
	Flexibility and Adaptability	Optional			
	Sufficiency and Adequacy of Space	Optional			
	Solar and Daylight Access	**Mandatory**	***No****		**No changes of the existing buildings*
	Accessibility	**Mandatory**	***No****		**No changes of the existing buildings*
	Indoor Air Quality	**Mandatory**	***No****		**No changes of the indoor air climate*
	Thermal Comfort	**Mandatory**	**x**	New technical heating components	
	Overheating Risk	**Mandatory**	**x**	New technical heating components	
	Acoustic Comfort	**Mandatory**	***No****		*No changes of acoustic*
	Outdoor Comfort	**Mandatory**	***No****		*No changes of outdoor conditions*
Circularity	**Materials from Cycled Sources**	**Mandatory**	***No****		*Not used for technical installations*
	Reusability	Optional			
Economics	**Global Cost**	**Mandatory**	**x**		
	Energy Renovation Rate	**Mandatory**	**x**		
	Number of Jobs Created	Optional			
	Construction Time Reduction	**Mandatory**	***No****		*No building construction work as such*

11.6. DEMONSTRATION PROJECT IN NORWAY

Table D.6 recaps the demo actions that affect the proposed KPIs; the related guidelines for the evaluation of the KPIs were discussed and agreed with the Oslo demo group.

***Table D.6**. Preliminary plan for the application of the assessment framework and related guidelines to the Voldsløkka School and Cultural area.*

Category	KPI	Level (Mandatory/ Optional)	Relevance demo	Demo actions impacting the KPIs	Type of buildings/ Comments
Energy	**Non-renewable Primary Life Cycle Energy in the Built Environment**	**Mandatory**	x	Low-temperature thermal heating and high temperature thermal cooling Low Exergy (LowEx) HVAC system	The school building
				Renewable energy generation using innovative BIPV and BAPV	The school building
	Renewable Energy Ratio	**Mandatory**	x	Renewable energy generation using innovative BIPV and BAPV	The school building
	Grid Delivered Factor	Optional			
	Net Energy/Net Power	**Mandatory**	x	All actions	The school building
	Flexibility Index	**Mandatory**	x	Models for energy generation forecasting and control of the LowEx system	New and renovated non-residential buildings. The school building
Environment	**Life-cycle GHG Emissions in CPCC**	**Mandatory**	x	Climate adapted design by an innovative open surface water solution. Digital design for optimum life cycle performance. Application of low-carbon concrete. Climate adapted design: green schoolyard where vegetation and surface water management are used.	The whole complex
	Air Pollution from the Energy Consumption	**Mandatory**	x	Electric- and bio-based fuels construction machinery will be used	Monitoring will be performed on the Sportshall construction site. Commencement of construction activities yet to be decided
	Dust during Retrofitting	**Mandatory**	x	Electric- and bio-based fuels construction machinery will be used	Monitoring will be performed on the Sportshall construction site. Commencement of construction activities yet to be decided

	Noise during Retrofitting	**Mandatory**	x	Electric- and bio-based fuels construction machinery will be used	Monitoring will be performed on the Sportshall construction site. Commencement of construction activities yet to be decided
Society	Democratic Process	Optional	x	Social Renovation	
Society	**Social Inclusion**	**Mandatory**	x	The development of VR and AR applications are targeted toward several distinct stakeholders and citizen user groups	
Society	**Social Engagement**	**Mandatory**	x	Raising climate awareness through education and local community engagement	
Society	Demographic Composition	Optional			
Society	**Social Interaction and Cohesion**	**Mandatory**	x		
Society	Safety and Security	Optional			
Society	**Energy & Environmental Consciousness**	**Mandatory**	x	Raising climate awareness through education and local community engagement. Energy coaching of occupants	These activities will be part of the Living Labs actions (WP3) and will involve the school students and the cultural hall users
Society	Affordability of Energy	Optional			
Society	Affordability of Housing	Optional			
Society	Access to Sustainable Mobility	Optional			
Society	Access to Services and Amenities	Optional			
Architecture	**Aesthetics and Visual Qualities**	**Mandatory**	x		Questionnaire 3 can be applied to the school and cultural hall site
Architecture	Flexibility and Adaptability	Optional			
Architecture	Sufficiency and Adequacy of Space	Optional			

	Solar and Daylight Access	**<u>Mandatory</u>**	**x**		Monitoring can be performed in representative rooms of the schools and the cultural centre
	Accessibility	**<u>Mandatory</u>**	**x**		
	Indoor Air Quality	**<u>Mandatory</u>**	**x**	Climate adapted design	Monitoring can be performed in representative rooms of the schools and cultural centre
	Thermal Comfort	**<u>Mandatory</u>**	**x**	Climate adapted design	Air temperature and RH profiles can be monitored in representative rooms of the school and the cultural centre
	Overheating Risk	**<u>Mandatory</u>**	***No****		*This is not relevant for the Norwegian demo*
	Acoustic Comfort	**<u>Mandatory</u>**	**x**		Monitoring can be performed in representative rooms of the schools and cultural centre
	Outdoor Comfort	**<u>Mandatory</u>**	**x**		
Circularity	**Materials from Cycled Sources**	**<u>Mandatory</u>**	**x**	Circular renovation design strategies	New and renovated non-residential building
	Reusability	Optional		Circular renovation design strategies	
Economics	**Global Cost**	**<u>Mandatory</u>**	**x**		The whole project
	Energy Renovation Rate	**<u>Mandatory</u>**	***No****		**Not relevant for the Norwegian demo (school/cultural centre) since it is difficult to find comparable examples*
	Number of Jobs Created	Optional			
	Construction Time Reduction	**<u>Mandatory</u>**	**x**	On-site monitoring with devices and/or evaluations based on visits/reports	The school building

12. APPENDIX E – GLOSSARY OF TERMS

Table A.1: Abbreviations used in the report.

Abbreviation	Description
ARV	Name of the EU H2020 project (ID: 101036723; doi: 10.3030/101036723)
BIPV	Building Integrated Photovoltaics
CDD	Cooling Degree Days (°C)
CED	Cumulative Energy Demand (kWh/MJ). Reference : Weidema et al. (ecoinvent)
CPCC	Climate Positive Circular Communities
EIC	Expected Impacts of the Call
GWP	IPCC Global Warming Potential (kg CO_2eq.), 2013
HDD	Heating Degree Days (°C)
IEQ	Indoor Environmental Quality
KPIs	Key Performance Indicators. Reference: D2.1 of ARV.
MBs	Multiple benefits
LCA	Life Cycle Assessment
LCC	Life Cycle Costs
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NPV	Net Present Value
SLCA	Social Life Cycle Assessment
TSP	Total Suspended Particles
PENR	The concept of primary energy attempts to provide a single metric for all forms of energy that are supplied to a building. It can be defined as the natural energy that has not been subjected to any human engineered conversion process. The Primary non-Renewable Energy consumption [kWh] is the non-renewable part that composes the total primary energy consumption of a building.
PER	The Primary Renewable Energy consumption [kWh] is the renewable part that composes the total primary energy consumption of a building.
Exported energy	It is the energy [kWh] produced by local distributed renewable energy systems that is exported into an external utility grid (e.g. national electric grid, district heating grid) and measured by a bidirectional power/energy meter.
Imported energy	It is the energy [kWh] that is imported from an external utility grid (e.g. national electric grid, district heating grid) measured by a bidirectional power/energy meter.
Renewable energy generation	It is the energy [kWh] that is produced by local distributed renewable energy systems.
Final energy consumption	It is the energy [kWhf] delivered for end consumption that is measured by the power/energy meter of a single consumer. It can be characterized by different energy carriers: electricity, natural gas, GPL, oil, petrol, coal, ….

Thermal energy requirement	It is the heating/cooling sensible or latent energy requirement [kWht] to maintain the targeted comfort conditions of indoor spaces.
Primary energy conversion factor	It is the coefficient [kWhp/kWhf], defined by national authorities, to convert a final energy carrier into primary energy.
Emission factor	It is the coefficient [kg CO_2eq/kWhf], defined by national authorities, to convert a final energy carrier into kg of CO_2eq emissions.
Upstream embodied energy	It is the primary energy requirement [kWh] linked to the extraction of raw materials, transportation to the manufacturing site and to the manufacturing process. (stages A1-A3: cradle-to-gate analysis).
Downstream embodied energy	It is the primary energy requirement [kWh] due to the replacement or refurbishment of building components/materials (stages B4-B5).

13. ACKNOWLEDGEMENTS AND DISCLAIMER

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101036723.

14. PARTNER LOGOS

WWW.GREENDEAL-ARV.EU