ARV
CLIMATE POSITIVE CIRCULAR COMMUNITIES

# D2.1 ASSESSMENT FRAMEWORK FOR CPCC

## WP 2 FRAMEWORK AND TOOLS FOR EFFECTIVE IMPLEMENTATION AND ASSESSMENT OF CPCC

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*30.09.2022*

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

# PROJECT INFORMATION

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|---|---|
| **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 |

[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.*

# DOCUMENT INFORMATION

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|---|---|---|---|---|
| **Deliverable Number and Title** | **D.2.1 Assessment Framework for CPCC** | | | |
| **Due Month** | Month 9 (September 2022) | | | |
| **Work Package Number and Title** | WP 2. Framework and Tools for Effective Implementation and Assessment of CPCC | | | |
| **Task number and Title** | Task 2.2 Assessment Framework for Climate Positive Circular Communities | | | |
| **Dissemination Level** | PU = Public, fully open | | | |
| **Date of Delivery** | 30.09.2022 | | | |
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| **Status** | Final DRAFT version V.05 (Pending European Commission approval) | | | |
| **Revision Log** | Version | Author | Main changes | Date |
| | V.01 | I. Maskova at al. | First draft | 15.07.2022 |
| | V.02 | I. Maskova at al. | Second draft after internal review | 26.08.2022 |
| | V.03 | I. Maskova at al. | Final draft after review by WP and Demo leaders | 09.09.2022 |
| | V.04 | I. Andresen, NTNU | Quality review | 17.09.2022 |
| | V.05 | I. Maskova at al. | Final version | 23.09.2022 |

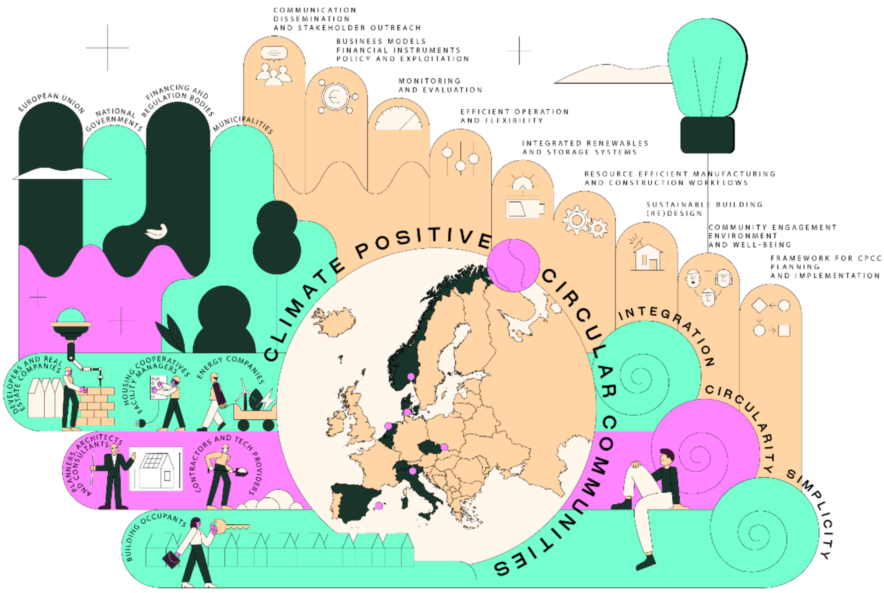
# ABOUT THE ARV PROJECT

The vision of the ARV project is to contribute to 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, 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 multi-stakeholder co-creation and use of innovative digital tools. **Circularity** in ARV means a systematic way of addressing circular economy through 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.



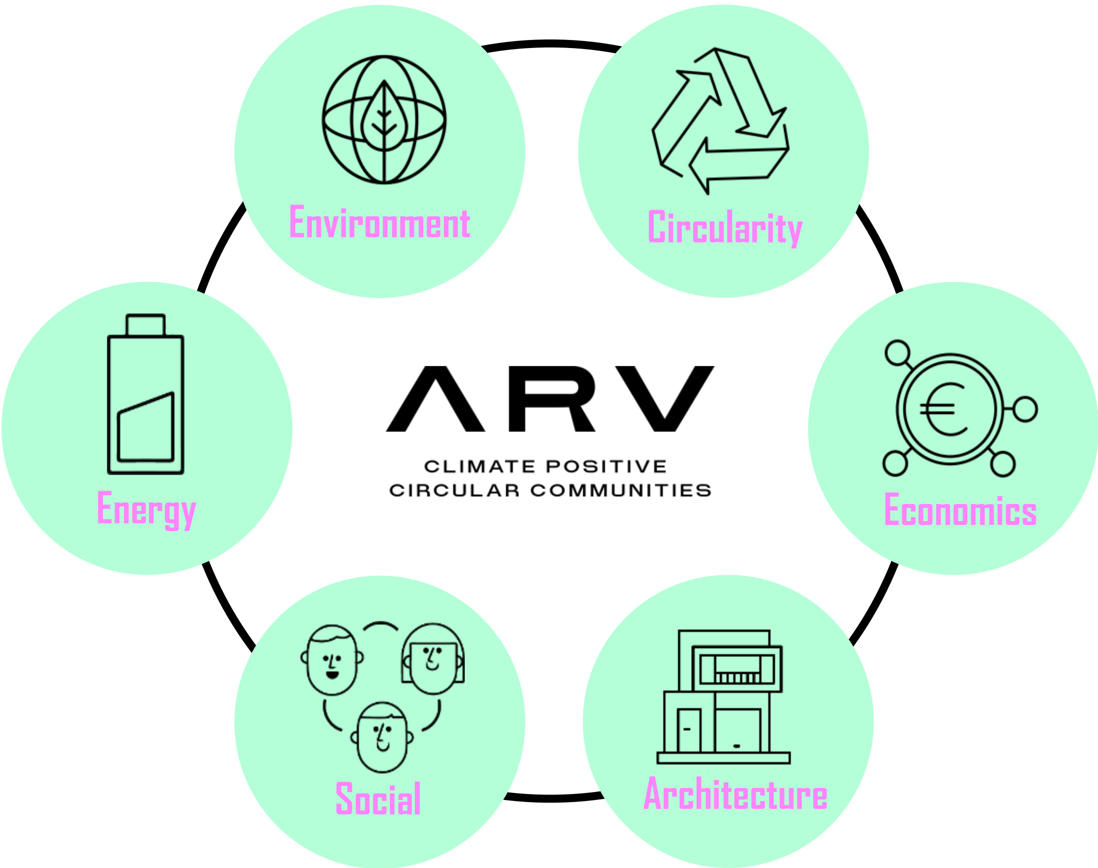

The ARV project is an Innovation Action that has received funding under the Green Deal Call LC-GD-4-1-2020 - Building and renovating in an energy and resource efficient way. The project started in January 2022 and has a project period of 4 years, until December 2025. The project is coordinated by the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

# EXECUTIVE SUMMARY

The main objective of this report is to provide an assessment framework for the effective design and successful implementation and evaluation of Climate Positive Circular Communities (CPCCs). A Climate Positive Circular Community (**CPCC)** is an urban area, which aims to net zero greenhouse gas emissions, enable energy flexibility, and promotes a circular economy and social sustainability. The CPCC concept focuses strongly on the **interaction** and **integration between new and regenerated buildings, users,** and **energy systems, facilitated by ICT to provide attractive, resilient, and affordable solutions** for citizens**.** Transformation of the built environment could give a major contribution towards carbon-neutrality and acting at community scale would contribute to accelerate it.

The proposed assessment framework goes beyond the traditional sustainability assessment of buildings, to highlight the importance of a neighbourhood-based approach in a life cycle perspective taking into account architectural qualities and circularity aspects. Several on-going initiatives at both European and international level are focusing on the neighbourhood and district levels, such as Positive Energy Districts and Sustainable Plus Energy Neighbourhoods. The ARV assessment framework includes indicators from established and emerging EU methodologies that aim to assess the performance of sustainable buildings, neighbourhoods, and cities, adding a number of carefully selected KPIs to characterize the multidimensional perspectives of CPCC.

The ARV assessment framework focuses on the energy, environmental, economic, well-being and social impacts of CPCC implementation, emphasising circularity and architectural qualities. Hence, the main categories of Key Performance Indicators (KPIs) selected for the ARV assessment framework are: energy, environment, social, architecture, circularity, and economics.



The proposed KPIs are presented by explaining the motivation for the selection, the definition, and the unit, as well as the calculation method used for each KPI and considering aspects at both building and community level. The assessment of some indicators is sometimes difficult to calculate due to their qualitative nature. Therefore, some supporting indicators have been selected to provide a qualitative assessment of progress in the neighbourhoods. For instance, the citizen-centred approach applied by Living Labs for social indicators has a multiple methods approach where both quantitative and qualitative methods can be applied to evaluate social sustainability and the interactions between social, architectural, and environmental qualities.


The assessment framework provides a common starting point for the ARV project, which brings together key stakeholders from the demo sites and the consortium's expert partners to jointly develop, define and apply a comprehensive framework. A continuous testing process during the implementation of actions in the different communities across Europe (Norway, Czech Republic, Denmark, Italy, Netherlands, and Spain) will result in a proven, validated, and consistent framework at the end of the project pursuing the harmonization and standardisation at EU level.

Finally, this evaluation framework aims to provide a coherent guideline for the evaluation of urban regeneration projects targeting sustainable communities in order to assess the multidimensional impacts of a neighbourhood-based approach along the life cycle.

# TABLE OF CONTENTS

# 1. INTRODUCTION

The ARV assessment framework provides an overview of the defined Key Performance Indicators (KPIs), taking into account a multidimensional perspective, to characterise the impacts of Climate Circular Positive Communities (CPCCs) along its life cycle. The proposed assessment framework aims to go beyond the traditional sustainability development assessment of buildings based mainly on environmental, economic, and social impacts and highlights the importance of the community-based approach.

A Climate Positive Circular Community (**CPCC)** is an urban area, which aims to achieve net zero greenhouse gas emissions, enables energy flexibility, and promotes a circular economy and social sustainability. The CPCC concept focuses strongly on the **interaction** and **integration between new and regenerated buildings, users,** and **energy systems, facilitated by ICT to provide attractive, resilient, and affordable solutions** for citizens**.**

The main KPIs categories selected for the ARV assessment framework are energy, environment, circularity, economics, social, and architecture, taking into account aspects at both building and neighbourhood levels.

This document consists of the following sections:

After the introduction and objectives, the context section provides an overview of ongoing EU initiatives addressing climate change and energy transition in the built environment. The background section provides an overview of considered existing assessment frameworks used to assess sustainable buildings, neighbourhoods, and cities, along with the Expected Impacts of the Call[2] (EICs). It then presents the working definition of the CPCC in line with Positive Energy District (PED) concepts. The context and background section concludes with an explanation of the methodological approach used to develop the ARV assessment framework. KPIs categories sections introduce the proposed indicators by explaining the motivation for selection, the definition and unit, and the calculation method used for each KPI. The paper concludes with an application of an assessment framework to ARV demo projects and an explanation of future updates.

[2] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/lc-gd-4-1-2020

# 2. OBJECTIVES

The main objective of this report is to provide an **assessment framework for efficient design** and **successful implementation of Climate Positive Circular Communities (CPCC)**. It defines a set of Key Performance Indicators (KPIs) which aims to support the **promotion, implementation,** and **replicability** of **CPCCs**.

The framework assesses the multidimensional aspects of CPCC such as **energy, environmental, economic** and **social** impacts while emphasizing specific aspects of the concept such as **circularity** and **architectural quality.**

The assessment framework provides a common starting point for the ARV project, which bring together key stakeholders from the demo sites and the consortium's expert partners to jointly develop and define a comprehensive framework. The task does not finish with this document, but will accompany the development of the demo projects to monitor how the framework is implemented and used in the demos. This will be done in annual workshops and through follow-up questionnaires in cooperation with the demo's implementers and the Work Package (WP) responsible for providing monitoring guidelines and the evaluation of impact assessment. A continuous process will result in a proven, validated, and consistent framework at the end of the project.

The proposed framework aims to provide background and scientific knowledge to the on-going international activities that pursue the harmonization of characterizing climate neutral neighbourhoods, which are named differently depending on the analysis perspective: Zero Emission Neighbourhoods, Positive Energy Districts, Smart Cities, NetZeroCities, etc. Particular attention was paid to the inclusion of social and architectural quality aspects, as it was assumed that citizens should be at the centre of any urban intervention, in line with the New European Bauhaus Initiative.

# 3. BACKGROUND

## 3.1. EU INITIATIVES FOR SUSTAINABLE NEIGHBOURHOODS

Today, the global energy system is on a path of radical transformation, driven by the need to meet the ambitious climate goals of the Paris Agreement [1]. The European Green Deal [2] and the Mission on Climate-neutral and Smart Cities [3] have set ambitious energy and climate targets in Europe to reduce greenhouse gas (GHG) emissions, energy vulnerability, and increasing the reuse and recycling of materials. The brand new EU initiative NetZeroCities (NZC) [4] has been designed to help cities overcome the obstacles they face in achieving climate neutrality by 2030 by developing and promoting a methodology for planning and implementing net zero cities. The European Commission has also launched the New European Bauhaus initiative, which provides a forum where Europeans can come together to exchange ideas on climate-friendly architecture [5].

In this context, the built environment could make a major contribution to the transformation of the EU energy sector towards carbon-neutrality, as the building stock is responsible for about 40% of total EU energy consumption and about 36% of GHG emissions [6]. Therefore, buildings should be embedded in the energy system and the need for their integration into the system must be highlighted by EU objectives and policies. By incorporating renewable energy systems (RES), energy storage and heat recovery systems, buildings can become net zero-energy or even energy positive, while reducing energy consumption and associated emissions.

It is essential to go beyond the concept of individual buildings and adopt a neighbourhood and community approach, which enables multiple synergies that can contribute to decarbonising the building stock in a profitable way, while also incorporating the collective social potential of energy solutions [7]. In the Renovation Wave strategy [8], the European Commission has recognized the role of buildings as active and contributing parts of the energy system, rather than just passive and energy consuming parts. The strategy highlights the importance of neighbourhoods' spatial dimension by "placing an integrated, participatory and neighbourhood-based approach at the heart of the Renovation Wave". The Renovation Wave strategy also states that "synergies for renovation become evident when scaled up to district and community approaches. Aggregating projects at this level may lead to zero-energy or even positive energy districts".

In this context, the Positive Energy Districts (PED) concept is currently considered as one of the pioneering strategies to lead cities towards carbon neutrality and is considered to be one of the three pillars of Driving Urban Transition (DUT) [9]. A PED is an "energy-efficient and energy-flexible urban area or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy" [10]. A PED requires integration of different systems, interaction between buildings and users, and other mobility, Information and Communication Technologies (ICT) and energy systems. In parallel, several ongoing concepts are closely related to the concept of PED, such as Zero Emission Neighbourhood (ZEN) [11] and Sustainable Plus Energy Neighbourhood (SPEN) [12].

Although various studies and practical experiences of PEDs focus on newly built neighbourhoods, there is an urgent need to start the process of transforming existing neighbourhoods in a sustainable and carbon neutral direction. **Figure 1** summarises various ongoing policy initiatives around CPCCs [7]. This marks an opportunity to change course from the individual building scale to a community-oriented approach, and to extend the scope from only focusing on the energy in operational phase to a wider lifecycle perspective.

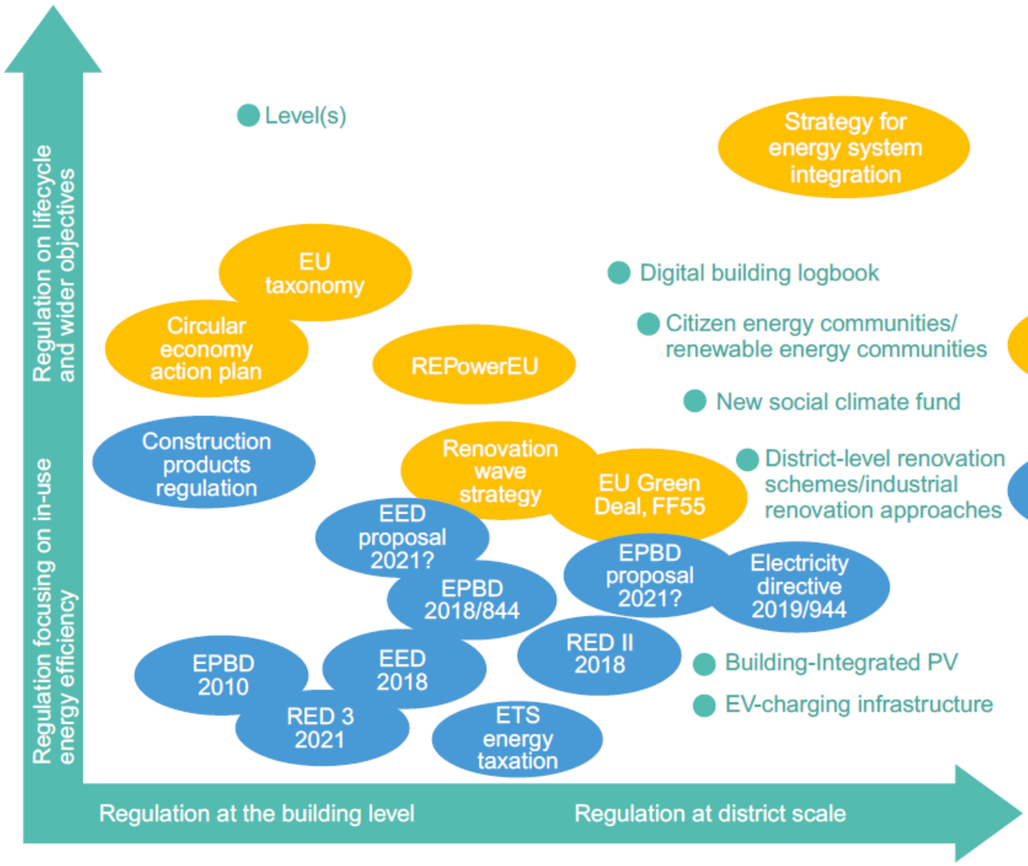



***Figure 1.*** *PEDs in the wider policy context. Adopted from [7].*

## 3.2. BACKGROUND

The ARV assessment framework is consistent with a number of EU and international directives and policies that call for decarbonisation, sustainability, affordability, resource efficiency, and resilience in the built environment and beyond. In particular, the assessment framework considers the revised Energy Performance of Buildings Directive (EPBD) [13], the Renovation Wave [8], the New European Bauhaus [5], Clean Energy for all Europeans [14], and the Paris Agreement [1]. In addition, it considers the new framework that is being developed in relation to the Sustainable Development Goals (SDGs) [15], with a specific focus on:

- SDG 7 (Affordable and Clean Energy);
- SDG 8 (Decent Work and Economic Growth);
- SDG 9 (Industry, Innovation and Infrastructure);
- SDG 11 (Sustainable Cities and Communities);
- SDG 12 (Responsible Consumption and Production);
- SDG 13 (Climate Action);
- SDG 17 (Partnerships to achieve the Goal).

To conclude, the ARV assessment framework takes into account approaches of already established methodologies at the European level that aim to assess the performance of sustainable buildings, neighbourhoods and cities, while covering all the Expected Impacts of the Call (EICs) resulting from the implementation of CPCC.

**Table 1** summarises the main methodologies considered in the assessment framework. In particular, it explains when the methodology was developed and describes which objective and which KPIs categories it covers, the total number of indicators applied, and whether the methodology is applicable at the building, district, or city levels.

***Table 1.*** *EU established methodologies considered for ARV´s assessment framework.*

| Methodology (year) | Objective | Categories (number of indicators) | Level |
|---|---|---|---|
| **SCIS (2018):** EU Smart Cities Information System [16] | To develop indicators to measure technical and economic aspects of energy, mobility, and ICT related measures in European funded demonstration projects. | Technical (3); Environmental (3); Economic (5); For ICT related technologies (7); For mobility related technologies (9).<br><br>***In total: 27 indicators.*** | Building<br>Set of Buildings<br>Energy Supply Units<br>Set of Energy Supply Units<br>Neighbourhood<br>City |
| **syn.ikia (2020):** Methodology Framework for Plus Energy Buildings and Neighbourhoods [12] | To provide a joint framework for the evaluation of the performance of positive energy buildings and neighbourhoods. | Energy and Environmental (9); Economic (11); Indoor Environmental Quality (IEQ) (8); Social (14); Smartness and Flexibility (2).<br><br>***In total: 44 indicators.*** | Building and Neighbourhood |
| **BUILD UPON² Framework (2021):** Capturing the benefits of building renovation [17] | To track and monitor holistically the impact of energy renovation at municipality level and to better link local and national initiatives. | Environmental (4); Social (4); Economic (5).<br><br>***In total: 13 indicators.*** | Building<br>City |
| **Level(s) (2021):** A common EU framework of core sustainability indicators for office and residential buildings [18] | To provide a common EU framework of core indicators for assessing the sustainability of office and residential buildings. | GHG and air pollutant emissions along a building's life cycle (2); Resource efficient and circular material life cycles (4); Efficient use of water resources (1); Healthy and comfortable spaces (4); Adaptation and resilience to climate change (3); Optimised life cycle cost (LCC) and value (2).<br><br>***In total: 16 indicators.*** | Building |

**Table 2** provides an overview of ARV´s Expected Impacts of the Call (EIC) as required by the EU as a funding institution. The proposed assessment framework directly addresses and goes beyond all the core EICs.

*__Table 2.__ Overview of ARV's Expected Impacts (EICs).*

| Expected Impact of the ARV actions |
|---|
| **EIC1** – Trigger primary energy savings |
| **EIC2** – Trigger investments in sustainable energy |
| **EIC3** - Demonstrate sites that go beyond nearly-zero energy building performance |
| **EIC4** – Demonstrate high energy performance (nearly zero-energy level within the meaning of Directive 2010/31/EU for retrofitted/positive-energy level buildings for new constructions) |
| **EIC5** - Reduce GHG emissions towards zero for the total life cycle compared to the current situation shown through cradle-to-cradle LCA |
| **EIC6** – Reduce embodied energy in buildings by 50% without concessions with respect to energy consumption and comfort |
| **EIC7** - Reduce air pollutants towards zero (in kg/year) for the total life cycle compared to current situation shown through cradle-to-cradle LCA |
| **EIC8** - Demonstrate high potential for replicability using new or existing innovation clusters incorporating the whole value chain |
| **EIC9** - Shorten construction/retrofitting time and cost by at least 30%, in order to allow market uptake and social affordability |
| **EIC10** – Improve final IEQ by at least 30% and reduce dust and noise during retrofitting by at least 30%, leading to higher rate of users' satisfaction, demonstrated according to the relevant CEN standard (or equivalent) |

## 3.3. CLIMATE POSITIVE CIRCULAR COMMUNITIES

Due to the importance of the community-based approach for climate and energy transition goals, the Climate Positive Circular Communities needs to be integrated into EU buildings policy. Several different conceptual definitions are currently under development in various initiatives, and have not yet been finalised. These concepts are often differentiated according to their size, system boundaries, social significance, and other aspects.

The ARV project's definition of CPCC is aligned with the concepts of PED, SPEN, ZEN and EU circular economy principles. **Table 3** explains when these concepts were developed and their definitions.

*Table 3. Energy and sustainable neighbourhood concepts developed in the last years.*

| Concept (year) | Definition |
|---|---|
| **PED (2018):** Positive Energy District [10] | Energy-efficient and energy-flexible urban area or groups of connected buildings, which produce net-zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. Integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems while securing the energy supply and a good life for all in line with social, economic, and environmental sustainability. |
| **ZEN (2018):** Zero Emission Neighbourhood [19] | A group of interconnected buildings with associated infrastructure, located within a confined geographical area. A ZEN aims to reduce its direct and indirect GHG emissions towards zero over the analysis period, in line with a chosen ambition level with respect to which life cycle modules and building and infrastructure elements to include. |
| **SPEN (2020):** Sustainable Plus Energy Neighbourhood [12] | A group of interconnected buildings with associated infrastructure, located within both a confined geographical area and a virtual boundary. A SPEN aims to reduce its direct and indirect energy use towards zero over adopted complete year and an increased use and production of renewable energy according to a normalization factor. The SPEN framework includes a strong focus on cost efficiency, indoor environmental quality, occupant satisfaction, social factors (co-use, shared services and infrastructure), and power performance (peak shaving, flexibility, and self-consumption). |

The CPCC concept considers multidimensional aspects based on the classical dimensions of sustainable development (**Figure 2**), with a specific focus on circularity.

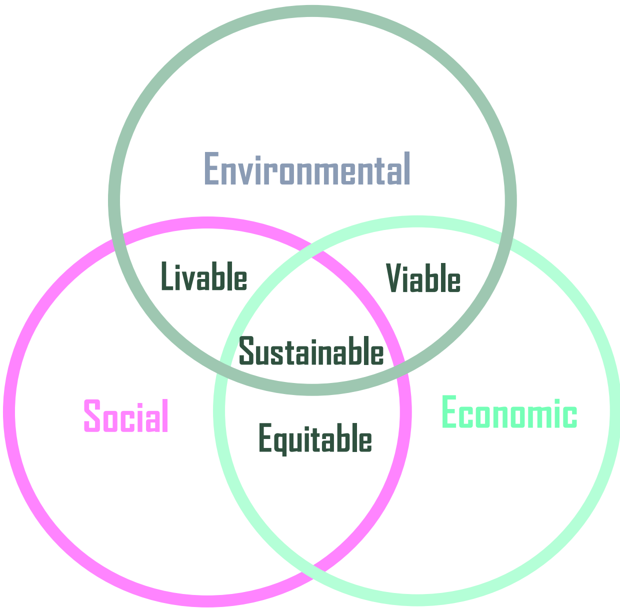



***Figure 2.*** *Classic Dimensions of Sustainable Development* [20].

Based on these concepts, there is a need to create a definition of CPCC that clarifies the boundaries of the built environment and includes aspects related to renewable energy use, energy communities, mobility, density, and social cohesion. The working definition of CPCCs is as follows, but will be further refined based on the findings of the ARV project and through interaction with other Horizon 2020 (H2020) projects and EU policy initiatives.

A **C**limate **P**ositive **C**ircular **C**ommunity (**CPCC)** is an urban area, which aims to achieve **net zero greenhouse gas emissions**, enables **energy flexibility**, and promotes a **circular economy** and **social sustainability**.

The CPCC concept focuses strongly on the **interaction** and **integration between new and regenerated buildings, users,** and **energy systems, facilitated by ICT to provide attractive, resilient, and affordable solutions** for citizens**.**

A CPCC can be an urban area or a city district, and consists of several interconnected buildings with associated infrastructure such as grids and technologies for the generation, storage, and exchange of electricity and heat (**Figure 3**).

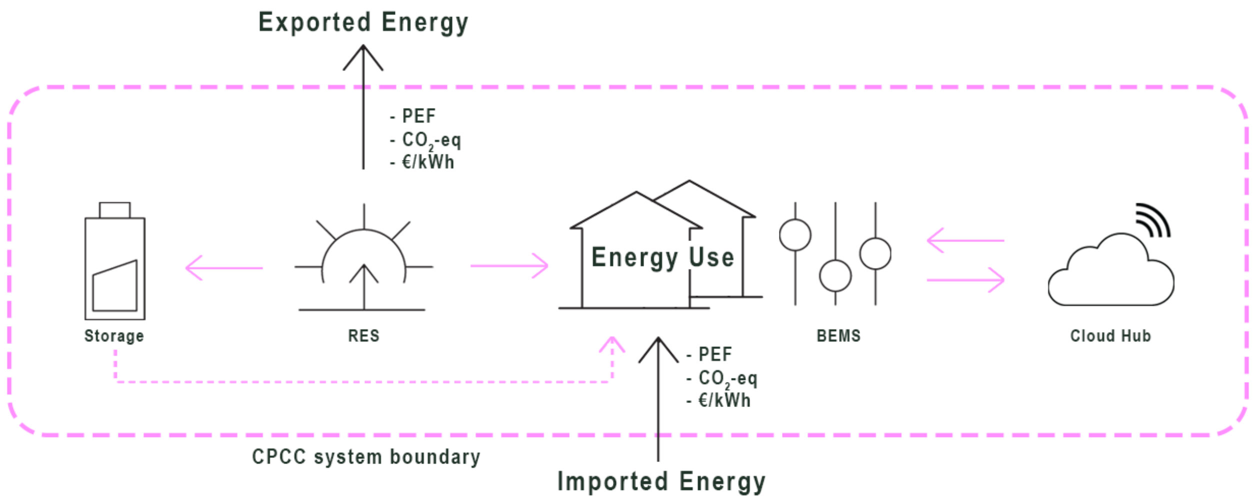



***Figure 3.*** *The main elements of a CPCC (storage, energy generation, energy use, energy management), and the energy flows within and in/out of the CPCC, managed by the ARV digital cloud hub.*

## 3.4. METHODOLOGY

The first phase of the CPCC assessment framework definition was based on desktop research, which is described in the background section. From the analysis of existing assessment systems, it can be concluded that the most widely used approach for assessing the sustainability of a building is a multi-criteria approach taking into account the three dimensions of building sustainability: environmental aspects (mostly represented by indicators such as GHG emissions and energy consumption), economic aspects (e.g., capital and operational costs) and social requirements (e.g., energy affordability), in line with the triple bottom line framework.

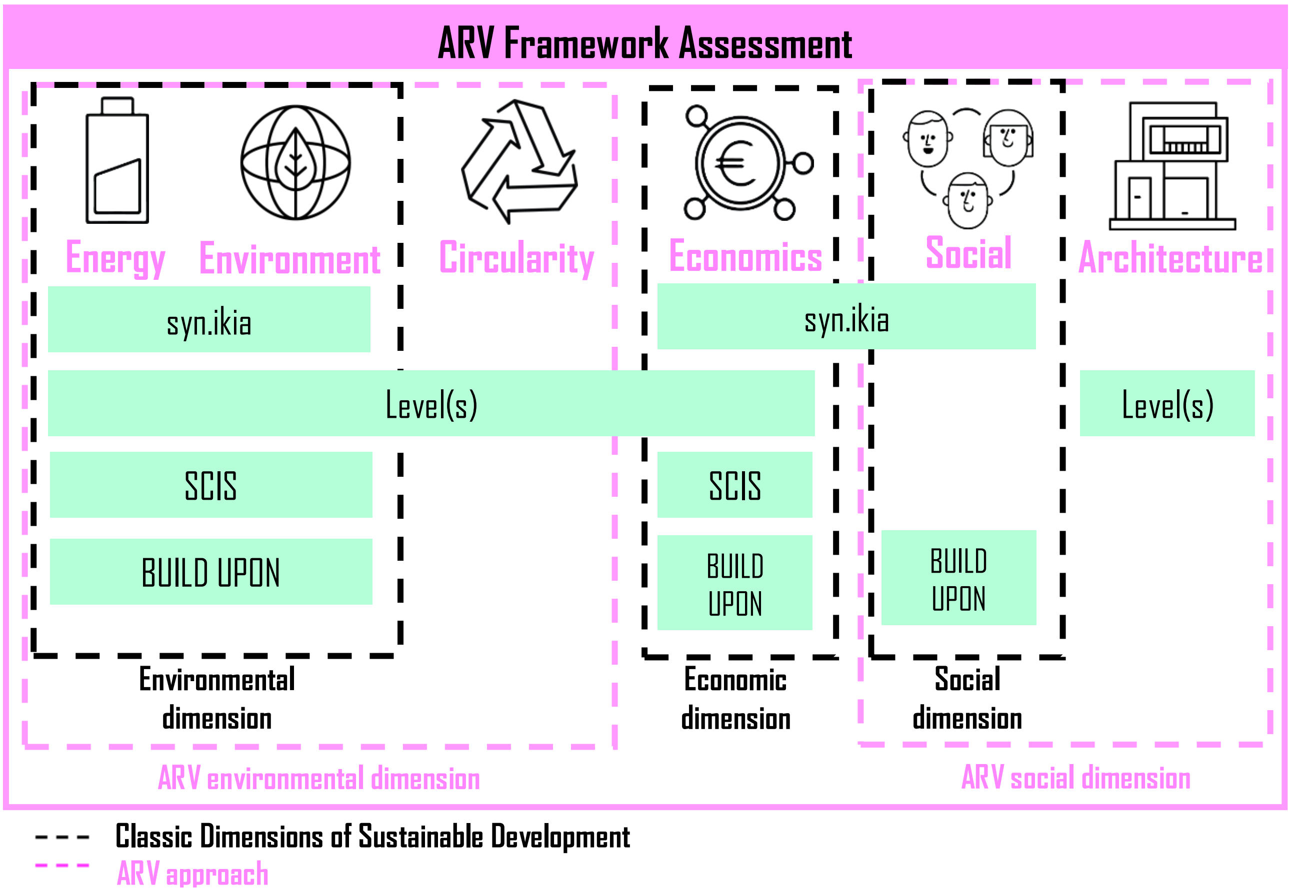
However, achieving all the ambitions of the ARV project requires a multidisciplinary approach that includes a number of additional features. As was highlighted in the previous section, successful innovations of CPCCs are based on the application of the following three conceptual pillars: integration, circularity, and simplicity. Specifically, the successful innovations and solution in a CPCC should be based on the application of the following concepts:

- **Integration** means dealing with several aspects in combination. For example, it is not sufficient to build a highly energy-efficient building if it is not affordable due to high costs, or if a good indoor climate is not guaranteed. Architectural quality, affordability, and people's well-being are therefore important indicators that need to be taken into account.

- **The circularity** pillar aims at durability, flexibility, adaptability, reuse, and recycling, which includes the increased use of local materials.
- **Simplicity** means to make solutions that are easy to understand and use for all stakeholders. In particular, ARV focuses on **resource-efficient, integrated** construction and renovation processes through smart industrialisation and prefabrication, leading to a reduction in air pollutants, dust, and noise during retrofitting, as well as construction time and costs.

**Figure 4** demonstrates how the ARV assessment framework combines categories from established methodologies, classical dimensions of sustainable development and additional categories to meet the EICs of the call and goals of the project.

***Figure 4.*** *The categories of ARV´s assessment framework and their relationship with EU established methodologies.*




In addition, the assessment framework aims to propose specific KPIs to support and evaluate CPCC implementation along the life cycle.

**Figure 5** demonstrates the life cycle approach integrated in the ARV assessment framework based on Level(s) life cycle stages. **Table 4** explains correlation between nomenclature used in formulas for the proposed ARV KPIs and the Level(s) life cycle stages.

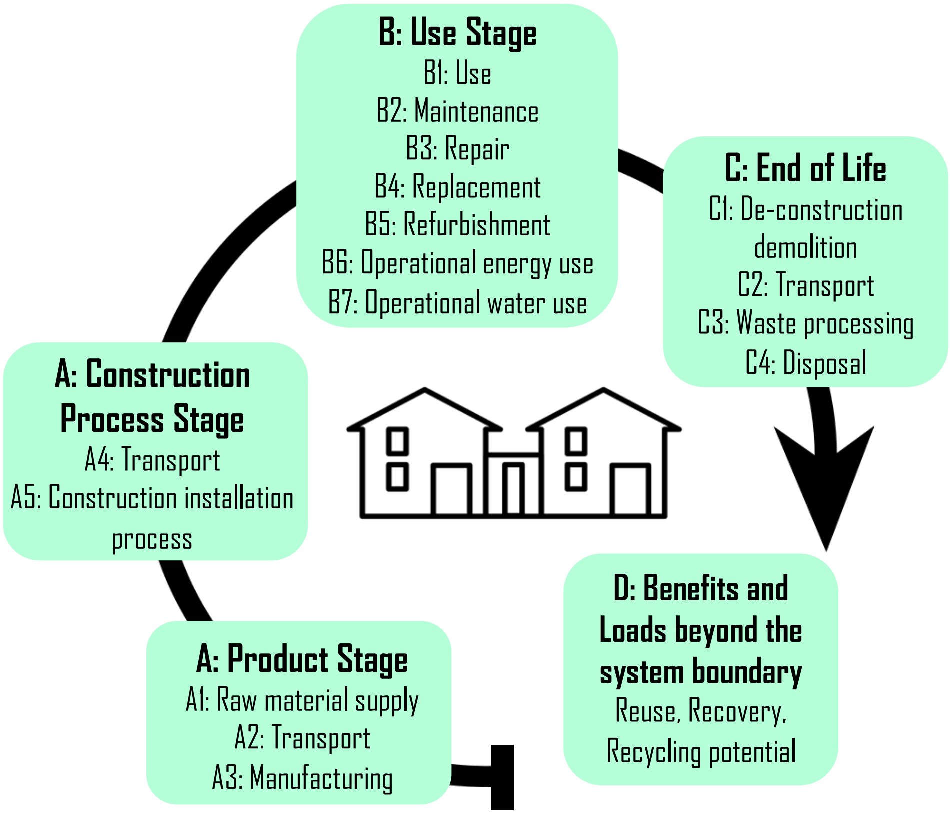



***Figure 5***. *Life cycle approach integrated in the ARV´s assessment framework. Adopted from Level(s)* [18].

***Table 4.*** *Correlation between nomenclature used in formulas for ARV KPIs and Level(s) stages.*

| Nomenclature used in sub-indices for KPIs | Description | Level(s) stage |
|---|---|---|
| $\boldsymbol{P}$ | Product stage | A: Product Stage |
| $\boldsymbol{P_i}$ | *Initial* product stage | A: Product Stage |
| $\boldsymbol{P_r}$ | *Recurring* product stage | A: Product Stage |
| $\boldsymbol{C}$ | Construction stage | A: Construction Process Stage |
| $\boldsymbol{U}$ | Use stage | B: Use Stage |
| $\boldsymbol{EoL}$ | End-of-life stage | C: End of Life |
| $\boldsymbol{D}$ | De-construction demolition of the building | C1: De-construction demolition |
| $\boldsymbol{T}$ | Transporting waste materials | C2: Transport |

Based on these concepts, the initial set of KPIs was developed in close cooperation with Work Package 8 in ARV, which includes the task of defining the monitoring procedures for the KPIs calculations and to ensure that the KPIs required for the impact assessment calculations are in place. Additional collaboration with other WP leaders was organised, focusing on the KPIs related to the activities of each WP. As the next step, bi-weekly expert discussions were organised for a core group of experts in WP 2, leading to two workshops (Month 4 and Month 6) for all project participants. The main objective of the first workshop (Month 4) was to introduce an initial set of KPIs. In addition, a joint survey was distributed to the WPs and demo leaders before the workshop to assess the relevance of the proposed indicators. Based on the survey results and the feedback received after a workshop, the initial selection of KPIs was revised. The aim of the second workshop (Month 6) was to present a final selection of KPIs and to understand their relevance for each demo site. The following aspects were covered at the second workshop:

- Will the demo project have an impact on this indicator?
- If not, is this indicator still important to consider from a community/urban perspective?
- If the indicator is worth considering, is the baseline easy to establish?
- If ARV has an impact, ARV Ambition level needs to be defined. Is it possible?
- Is the indicator measurable, at least partially (spatial/temporal)?
- Can the indicator be easily transferred to the community level?

Feedback from the second workshop was used to agree on the final selection of KPIs. **Figure 6** summarises the final selection of KPIs, which cover the following categories: Energy, Environment, Social, Architecture, Circularity, and Economics.

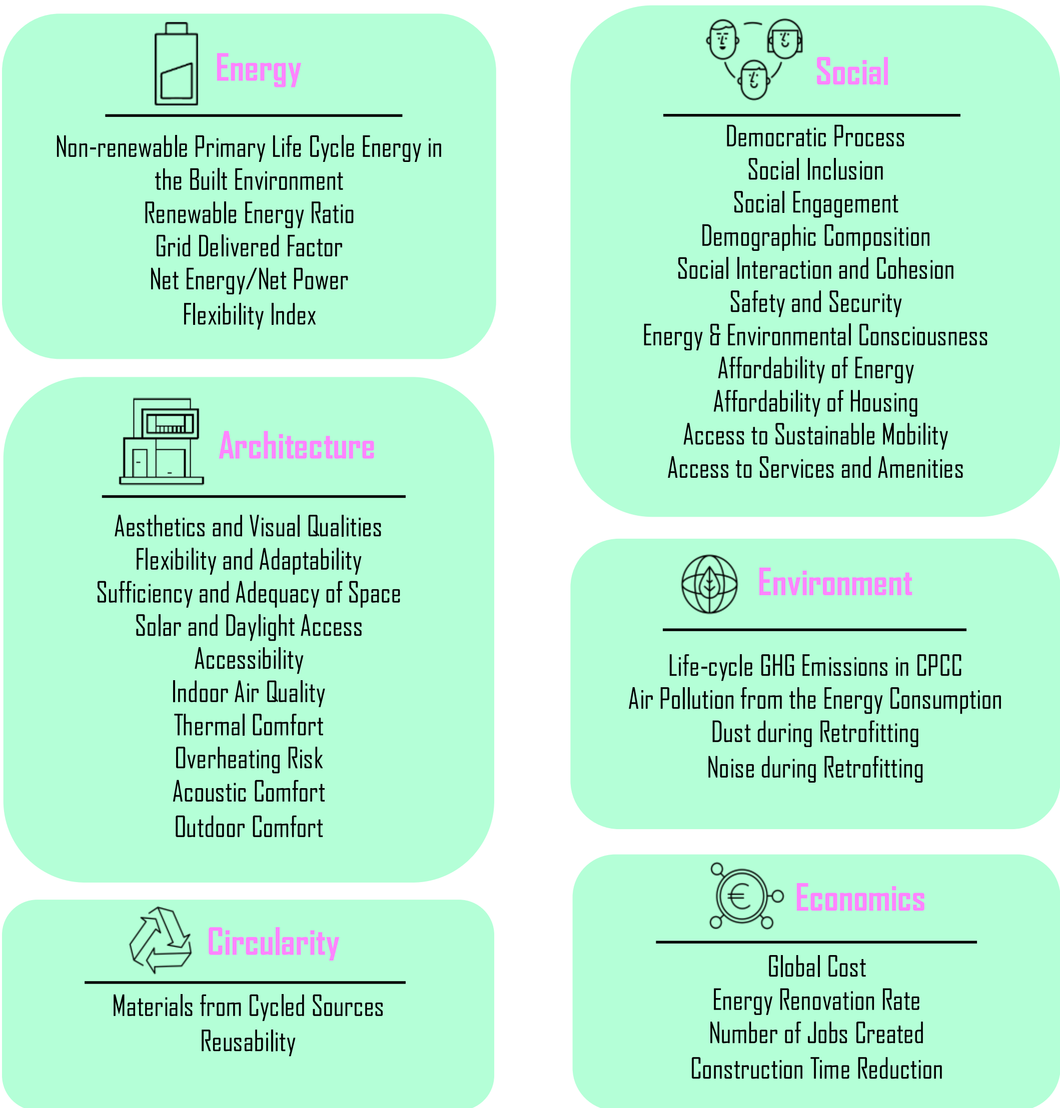



***Figure 6.*** *ARV assessment framework.*

# 4. ENERGY KPIS

## 4.1. NON-RENEWABLE PRIMARY LIFE CYCLE ENERGY IN THE BUILT ENVIRONMENT

***Motivation:***
The conceptual approach to overall energy performance (**Figure 7**) adopted for the assessment framework considers the following aspects for the built environment:

- The Life Cycle Energy (LCE) approach is considered (not only energy in the use stage), which underlines the importance of assessing energy at all stages of a building's life cycle.
- All energy uses (EPB and non-EBP) are considered for energy consumption.
- Non-renewable primary LCE in the built environment can be aggregated at CPCC level as a sum of non-renewable primary LCE for different types of buildings, e.g.: new residential and non-residential buildings, renovated residential and non-residential buildings, and other types of buildings (e.g. non-renovated).

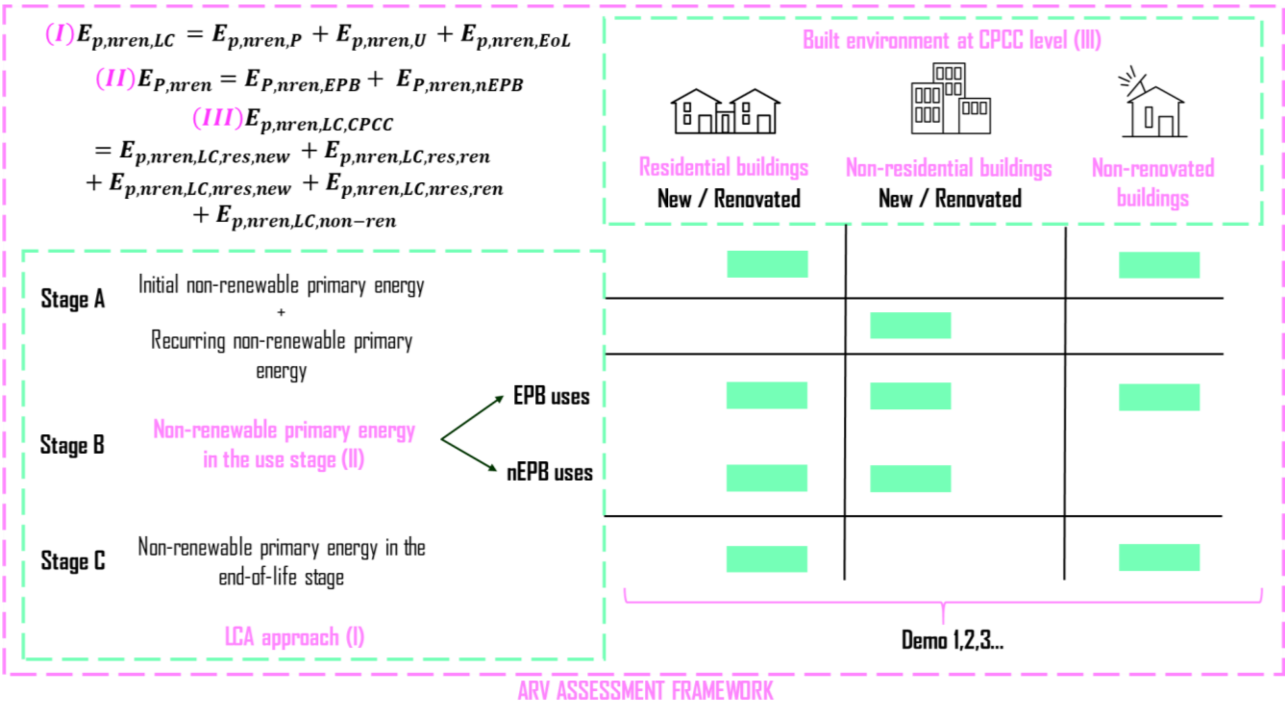



***Figure 7.*** *The conceptual approach to LCE assessment in CPCC.*

***Description:***
This indicator takes into consideration all types of energy used and generated by the system, as well as exported, and the exchange with the energy networks for all buildings within the CPCC during the life cycle. The temporal boundaries of this indicator include the energy use of the following phases: product and construction stages, use stage, and end-of-life stage. The physical boundary is based on the geographical limits of the urban area and considers generation systems in the urban spaces and regional specificities by means of weighting factors. The considered lifespan of the buildings to compute the energy balance is set to 50 years based on the reference study period in the Level(s) framework [21].

***Unit:***
$kWh/m^2y$.

***Calculation:***
Calculation method is adopted from LCE approach for individual buildings [22] and applied to the CPCC level:

$$\boldsymbol{E_{p,nren,LC,CPCC}} = \boldsymbol{E_{p,nren,LC,res,new}} + \boldsymbol{E_{p,nren,LC,res,ren}} + \boldsymbol{E_{p,nren,LC,nres,new}} + \boldsymbol{E_{p,nren,LC,nres,ren}} + \boldsymbol{E_{p,nren,LC,non-ren}}$$

Where:

$\boldsymbol{E_{p,nren,LC,CPCC}}$ - non-renewable primary LCE in the built environment [kWh/m$^2$y];
$\boldsymbol{E_{p,nren,LC,res,new}}$ - non-renewable primary LCE in new residential buildings [kWh/m$^2$y];
$\boldsymbol{E_{p,nren,LC,res,ren}}$ - non-renewable primary LCE in renovated residential buildings [kWh/m$^2$y];
$\boldsymbol{E_{p,nren,LC,nres,new}}$ - non-renewable primary LCE in new non-residential buildings [kWh/m$^2$y];
$\boldsymbol{E_{p,nren,LC,nres,ren}}$ - non-renewable primary LCE in renovated non-residential buildings [kWh/m$^2$y];
$\boldsymbol{E_{p,nren,LC,non-ren}}$ - non-renewable primary LCE in non-renovated buildings [kWh/m$^2$y].

The proposed approach of considering CPCC as the sum of different building types can be applied to other relevant KPIs in this deliverable.

The non-renewable primary LCE for an individual building can be calculated using the following formula:

$$\boldsymbol{E_{p,nren,LC}} = \boldsymbol{E_{p,nren,P}} + \boldsymbol{E_{p,nren,U}} + \boldsymbol{E_{p,nren,EoL}}$$

Where:

$\boldsymbol{E_{p,nren,LC}}$ - non-renewable primary LCE [kWh/m$^2$y];
$\boldsymbol{E_{p,nren,P}}$ – non-renewable primary energy in a product stage [kWh/m$^2$y];;
$\boldsymbol{E_{p,nren,U}}$ – non-renewable primary energy in use stage [kWh/m$^2$y];
$\boldsymbol{E_{p,nren,EoL}}$ – non-renewable primary energy in the end-of-life stage [kWh/m$^2$y].

The non-renewable primary energy in product stage is divided into initial non-renewable primary energy in product stage and recurring non-renewable primary energy in product stage.

$$\boldsymbol{E_{p,nren,P}} = \boldsymbol{E_{p,nren,Pi}} + \boldsymbol{E_{p,nren,Pr}}$$

The initial non-renewable primary energy in the product stage is the energy incurred for initial construction of the building. It can be calculated using the following formula:

$$\boldsymbol{E_{p,nren,Pi}} = \frac{\sum_i \boldsymbol{m_i} \cdot \boldsymbol{M_i}}{\boldsymbol{S} \cdot \boldsymbol{L}} + \frac{\boldsymbol{E_{p,nren,C}}}{\boldsymbol{L}}$$

Where:

$\boldsymbol{E_{p,nren,Pi}}$ - the initial non-renewable primary energy in a product stage [kWh/m$^2$y];
$\boldsymbol{m_i}$ - quantity of building material *i* [kg];
$\boldsymbol{M_i}$ - energy content of material *i* per unit quantity [kWh/kg];
$\boldsymbol{S}$ – useful floor area of the building [m$^2$];
$\boldsymbol{L}$ - reference study period [y];
$\boldsymbol{E_{p,nren,C}}$ - non-renewable primary energy for a construction stage [kWh/m$^2$].

The recurring non-renewable primary energy in product stage is the sum of the energy embodied in the material used in the retrofitting and maintenance and can be expressed as:

$$E_{p,nren,Pr} = \frac{\sum_i m_i \cdot M_i \cdot \left[\left(\frac{L}{L_{mi}}\right) - 1\right]}{S \cdot L}$$

Where:

$E_{p,nren,Pr}$ - recurring non-renewable primary energy in a product stage [kWh/m$^2$y];
$m_i$ - quantity of building material *i* [kg];
$M_i$ - energy content of material *i* per unit quantity [kWh/kg];
$L$ - reference study period [y];
$L_{mi}$ - life span of the material *i* [y];
$S$ – useful floor area of the building [m$^2$].

The non-renewable primary energy in the use stage can be calculated as follows:

$$E_{P,nren,U} = \sum_i E_{p,nren,del,i} - \sum_i E_{p,nren,exp,i}$$
$$= \sum_i \int P_{del,i}(t) \cdot w_{del,nren,i}(t) \cdot dt - \sum_i \int P_{exp,i}(t) \cdot w_{exp,nren,i}(t) \cdot dt$$

Where:

$E_{p,nren,U}$ - the non-renewable primary energy in the use stage [kWh/m$^2$y];

$E_{p,nren,del,i}$ - delivered non-renewable primary energy per energy carrier *i* [kWh/m$^2$y];

$E_{p,nren,exp,i}$- exported non-renewable primary energy per energy carrier *i* [kWh/m$^2$y];

$P_{del,i_i}$ - the delivered power on site or nearby for energy carrier *i* [kW/m$^2$];

$w_{del,nren,i}$ - the non-renewable primary energy factor for the delivered energy for energy carrier *i* [-];

$P_{exp,i}$ - the exported power on site or nearby for energy carrier *i* [kW/m$^2$];

$w_{exp,nren,i}$ - the non-renewable primary energy factor of the exported energy for energy carrier *i* [-].

The calculation method for non-renewable primary energy is adopted from the syn.ikia project [12].

In this indicator, all energy uses (EPB and non-EPB) are considered. ISO 52000-1[13] defines heating, cooling, domestic hot water (DHW), ventilation, and lighting (optional to country regulations for non-residential) as EPB (Energy Performance Building) uses, and appliances, plug-loads, and electric vehicles (EV) consumption as non-EPB uses.

$$E_{p,nren,U} = E_{p,nren,EPB} + E_{p,nren,nEPB}$$

Finally, non-renewable primary energy in the end-of-life stage is the energy required to demolish the building and transport the waste material, and can be expressed as follows:

$$E_{p,nren,EoL} = E_{p,nren,D} + E_{p,nren,T}$$

Where:

$E_{p,nren,EoL}$ - non-renewable primary energy in the end-of-life stage [kWh/m$^2$y];
$E_{p,nren,D}$ - non-renewable primary energy incurred for de-construction demolition of the building [kWh/m$^2$y];
$E_{p,nren,T}$ - non-renewable primary energy used for transporting waste materials [kWh/m$^2$y].

## 4.2. RENEWABLE ENERGY RATIO (RER)

***Motivation:***
A CPCC aims to achieve an annual net zero energy and GHG emissions balance. This can be achieved by working towards an annual local surplus of renewable energy production by using local renewable energy generation, e.g. building integrated photovoltaics (BIPV) and building applied photovoltaics (BAPV). Therefore, it is important to monitor the share of renewable energy in the total energy consumption.

***Description:***
Renewable Energy Ratio (RER) is the percentage of energy from renewable sources in the total primary energy consumption.

***Unit:***
Dimensionless.

***Calculation:***

$$\boldsymbol{RER} = \frac{\boldsymbol{E_{p,ren}}}{\boldsymbol{E_{p,tot}}}$$

Where:

$\boldsymbol{RER}$ – Renewable Energy Ratio [-];

$\boldsymbol{E_{p,ren}}$ - renewable primary energy consumption [kWh/m$^2$ y];

$\boldsymbol{E_{p,tot}}$ - total primary energy consumption [kWh/m$^2$ y].

## 4.3. GRID DELIVERED FACTOR

***Motivation:***
The grid delivered factor is intended to evaluate the proportion of energy delivered from the grid in the total energy used by the system. This indicator is used to assess the quality of the energy system and its control, and allows a fairer comparison of the different systems compared to the load cover factor and supply cover factor [23].
The load cover factor (use matching fraction) and supply cover factor (production matching fraction) are the matching factors presented in ISO 52000-1 [24]. These factors are mainly used to analyse mismatch between renewable electricity produced on-site and electricity load in the buildings, and are proposed in this framework as complementary indicators.

***Description:***
Grid delivered factor or grid purchase ratio [23] is the ratio between the energy delivered from the grid and the total energy used by the system. Grid delivered factor should be computed in terms of final energy and is commonly used for electricity as energy carrier, but can be extended to other energy carriers as for example thermal energy from a district heating and cooling system.

***Unit:***
Dimensionless.

***Calculation:***

$$\gamma_{grid} = \frac{E_{del,grid}}{E_{used,tot}} = \frac{\int max\left[P_{used}(t) - P_{prod}(t), 0\right] \cdot dt}{\int P_{used}(t) \cdot dt}$$

Where:

$\gamma_{grid}$ – grid delivered factor [-];

$E_{del,grid}$ – delivered energy form the grid [kWh];

$E_{used,tot}$ – total energy used by the system [kWh];

$P_{prod}$ - on-site produced power [kW];

$P_{used}$ – on-site used power [kW].

## 4.4. NET ENERGY/NET POWER

***Motivation:***
The visual representation of net energy/power can be a useful tool in the decision-making process, as it helps to visualise the interaction between the CPCC and the grid as well as the differences between alternative solutions for energy carriers or system solutions for a neighbourhood.

***Description:***
Net energy or net power is the sum of delivered and exported energy per energy carrier in each of the calculation time steps, where negative values represent energy/power exported to the grid, whereas positive values demonstrate energy/power delivered from the grid. The conceptual approach to energy performance assessment adopted for the assessment framework considers all energy uses (EPB and non-EBP); therefore, the duration curve can be presented as follows (**Figure 8**).

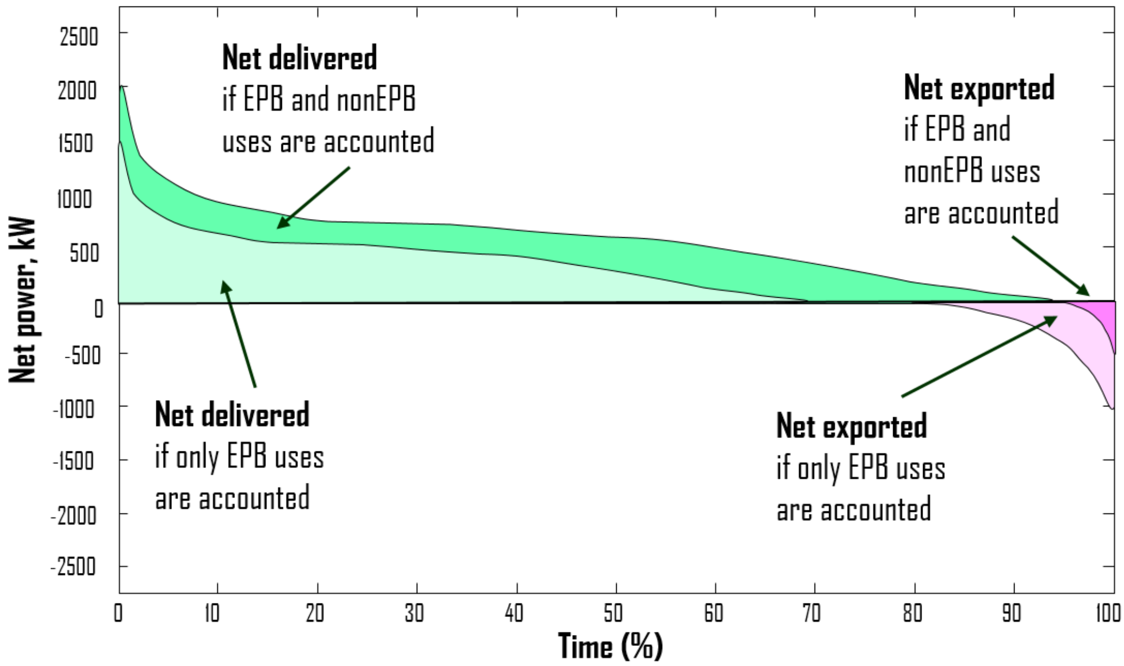



***Figure 8.*** *Net energy duration curve considering EPB and non-EPB uses* [25].

***Unit:***
kWh (energy) or kW (power).

***Calculation:***

$$E_{net,i} = \int P_{net,i}(t) \cdot dt = \int [P_{del,i}(t) - P_{exp,i}(t)] \cdot dt$$

Where:

$E_{net,i}$ - net energy per energy carrier *i* [kWh];

$P_{net,i}$ - net power per energy carrier *i* [kW];

$P_{del,i}$ - the delivered power on site or nearby for energy carrier *i* [kW];

$P_{exp,i}$ - the exported power on site or nearby for energy carrier *i* [kW].

## 4.5. FLEXIBILITY INDEX

***Motivation:***
The Flexibility Index (FI) aims to ensure high energy efficiency through the use of smart home services and controls, smart building components, and smart user engagement systems. Therefore, the consideration of FI in the assessment framework can be used as a measure of a building's smartness.

***Description:***
FI is the fraction of the cost saved by a penalty-aware operational strategy (flexible) compared to a penalty-restrained operation strategy (baseline). This can be illustrated by the comparison between accumulated penalty of the baseline and the flexible scenario in **Figure 9**.

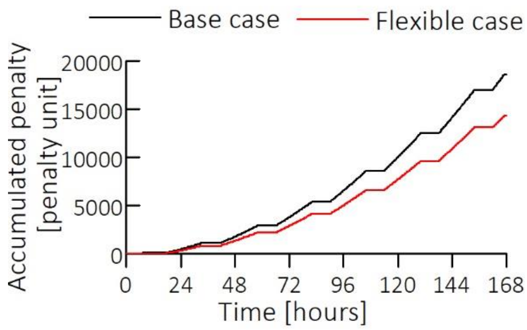



***Figure 9****. Comparison between accumulated penalty of the baseline and the flexible scenario. Source: IREC.*

***Unit:***
Dimensionless.

***Calculation:***

$$FI = 1 - \frac{C_1}{C_0}$$

Where:

$FI$ - fractional savings [-];
$C_1$ - cost of running the system using energy flexibility [penalty unit];
$C_0$ - cost of running the system without using energy flexibility [penalty unit].

# 5. ENVIRONMENTAL KPIS

## 5.1. LIFE-CYCLE GHG EMISSIONS IN CPCC

***Motivation:***

To evaluate the impact of GHG emissions from the built environment, LCA studies have traditionally been used to assess the impacts of buildings, mobility, and energy systems separately. Recently, however, several studies have been published that conduct integrated analyses at the neighbourhood, district, and city levels [26]. Linking buildings, mobility, and energy systems in the context of communities through the goal of creating CPCCs, provides a unique opportunity to contribute to climate change mitigation. At the same time, other potential sources of GHG emissions such as water consumption and waste generation should not be neglected in GHG analysis at the CPCC level [27][28]. A full analysis can help in the assessment of which variables have the greatest impact on the carbon footprint in order to minimise emissions by applying carbon sequestration/saving measures (water conservation, green areas and roofs, deployment of RES, and other) and setting climate change policies (or mitigation interventions).

The emissions and mitigation measures that should be taken into account for the assessment framework are the ones that can be allocated to the interventions that are the object of the CPCC. GHG emissions sources that are considered in the framework are:

- Emissions in product stage (buildings, mobility, energy and city infrastructures).
- Emissions in the use stage (buildings, mobility).
- Emissions in the end-of-life stage (buildings).
- Emissions from water consumption.
- Emissions from waste management.

Emission offset measures that are considered in the framework:

- Emissions offsets by on-site generation of surplus renewable energy in community infrastructures, beyond the ones already integrated in buildings.
- Biological carbon sequestration in green areas such as trees and green roofs.

The considered sources of GHG emissions and their mitigation at CPCC level are illustrated in **Figure 10.**

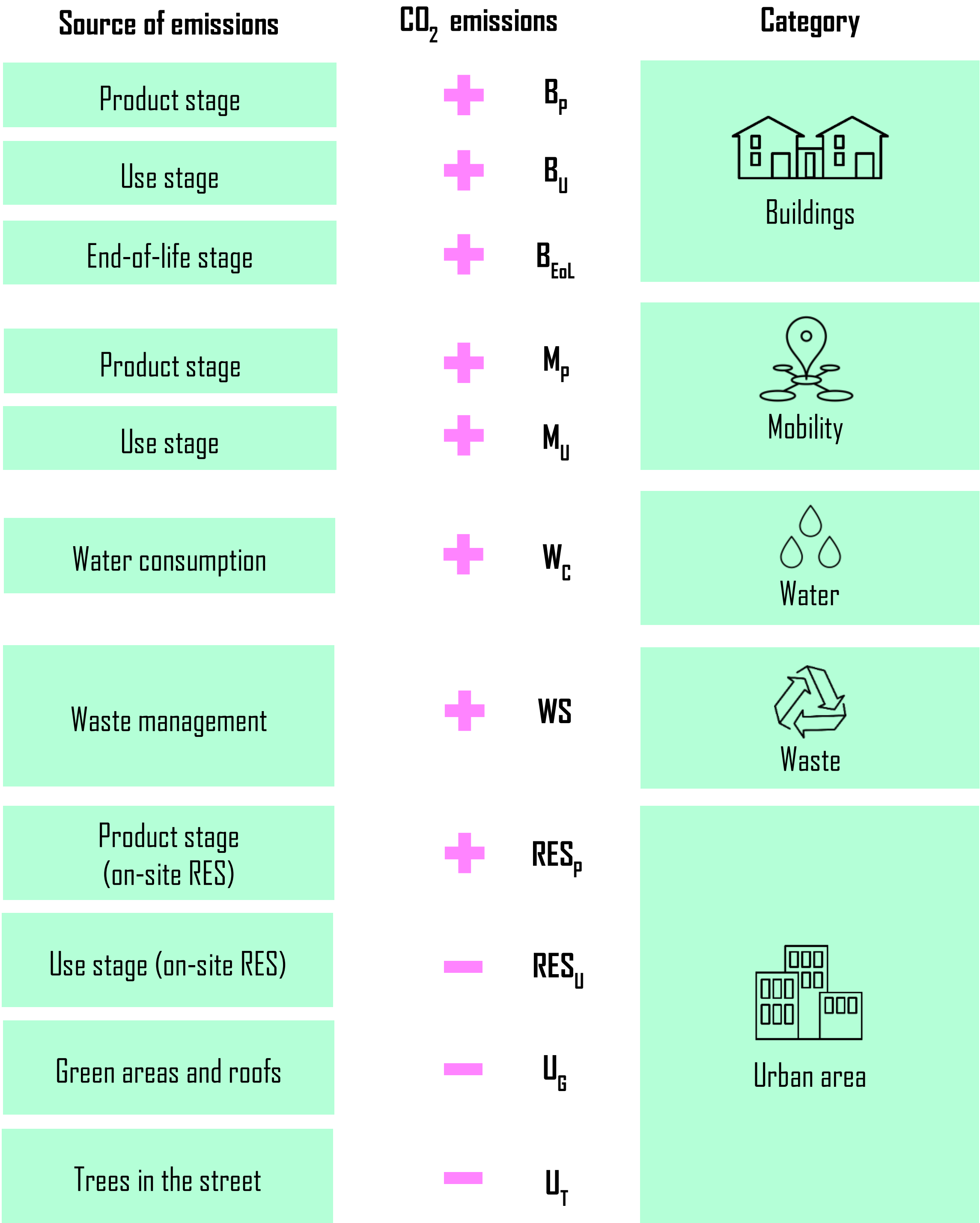



***Figure 10.*** *Sources of GHG emissions and their mitigation at CPCC level.*

***Description:***
The total life cycle GHG emissions of the CPCC are the balance between the total GHG generated emissions and the total life cycle GHG offsets in the lifespan of an urban area.

***Unit:***
kg $CO_2$eq/y.

***Calculation:***

$$GHG_{CPCC} = B_P + B_U + B_{EoL} + M_P + M_U + W_C + WS + RES_P - RES_U - U_G - U_T$$

Where:

$GHG_{CPCC}$ - total life-cycle GHG emissions in CPCC [kg $CO_2$eq/y];
$B_P$ - emissions in product stage (buildings) [kg $CO_2$eq/y];
$B_U$ - emissions in the use stage (buildings) [kg $CO_2$eq/y];
$B_{EoL}$ - emissions in the end-of-life stage (buildings) [kg $CO_2$eq/y];
$M_P$ - emissions in product stage (mobility) [kg $CO_2$eq/y]; *(optional)*
$M_U$ - emissions in the use stage (mobility) [kg $CO_2$eq/y];
$W_C$ - emissions from water consumption, deducting the avoided emissions from rainwater collection and grey water reuse [kg $CO_2$eq/y]; *(optional)*
$WS$ - emissions from waste management [kg $CO_2$eq/y]; *(optional)*
$RES_P$ – emissions in product stage (on-site RES) [kg $CO_2$eq/y];
$RES_U$ – emissions offsets in the use stage (on-site RES) [kg $CO_2$eq/y];
$U_G$ – emissions offsets from green areas and green roofs [kg $CO_2$eq/y];
$U_T$ – emissions offsets from trees in the street [kg $CO_2$eq/y].

The total life cycle GHG emissions and offsets included in the formula are intended to demonstrate the overall GHG footprint of CPCC. However, the mandatory components should be determined by each project based on its objectives. Some of them are marked as optional.

The GHG emissions in the product stage are divided into initial GHG emissions in the product stage and recurring GHG emissions in the product stage.

$$B_P = B_{Pi} + B_{Pr}$$

Where:

$B_P$ – emissions in the product stage [kg $CO_2$eq/y];
$B_{Pi}$ – initial emissions in the product stage [kg $CO_2$eq/y];
$B_{Pr}$ – recurring GHG emissions in the product stage [kg $CO_2$eq/y].

The initial GHG emissions in the product stage are incurred for the initial construction of the building. It can be calculated using the following formula:

$$B_{Pi} = \frac{\sum_i m_i \cdot w_{mat_i} + B_C}{L}$$

Where:

$B_{Pi}$ – initial emissions in the product stage [kg $CO_2$eq/y];
$m_i$ – quantity of building material *i* [kg];
$w_{mat_i}$ – emission content of material *i* per unit quantity [kg $CO_2$eq/kg];
$L$ – reference study period [y];
$B_C$ – emissions in a construction stage (negligible for construction works based on prefabrication) [kg $CO_2$eq].

The recurring GHG emissions in the product stage is the sum of the emissions embodied in the materials used in the renovation and maintenance, and can be expressed as:

$$B_{Pr} = \frac{\sum_i m_i \cdot w_{mat_i} \cdot \left[\left(\frac{L}{L_{mi}}\right) - 1\right]}{L}$$

Where:

$B_{Pr}$ – recurring emissions in a product stage [kg $CO_2$eq/y];
$m_i$ – quantity of building material *i* [kg];
$w_{mat_i}$ – emission content of material *i* per unit quantity [kg $CO_2$eq/kg];
$L$ – reference study period [y];
$L_{mi}$ – life span of the material *i* [y].

The GHG emissions in the use stage can be calculated as follows:

$$B_U = \sum_i B_{E_{p,nren,del,i}} - \sum_i B_{E_{p,nren,exp,i}} = \sum_i \int P_{del,i}(t) \cdot w_{CO_2,del,i}(t) \cdot dt - \sum_i \int P_{exp,i}(t) \cdot w_{CO_2,exp,i}(t) \cdot dt$$

Where:

$B_U$ – emissions in the use stage [kg $CO_2$eq/y];
$B_{E_{p,nren,del,i}}$ – emissions from delivered non-renewable primary energy per energy carrier *i* [kg $CO_2$eq/y];
$B_{E_{p,nren,exp,i}}$ – emissions from exported non-renewable primary energy per energy carrier *i* [kg $CO_2$eq/y];
$P_{del,i}$ – delivered power for energy carrier *i* into object of assessment [kW];
$w_{CO_2,del,i}$ – emission coefficient for delivered energy carrier *i* [kg $CO_2$eq/kWh];
$P_{exp,i}$ – exported power for energy carrier *i* out of object of assessment [kW];
$w_{CO_2,exp,i}$- emission coefficient for exported energy carrier *i* [kg $CO_2$eq/kWh].

The GHG emissions in the end-of-life stage are emissions resulting from demolition of the building and transportation of the waste material and can be expressed as follows:

$$B_{EoL} = \frac{B_D + B_T}{L}$$

Where:

$B_{EoL}$ - emissions in the end-of-life stage [kg $CO_2$eq/y];
$B_D$ - emissions from de-construction demolition of the building [kg $CO_2$eq];
$B_T$ - emissions from transporting waste materials [kg $CO_2$eq];
$L$ – reference study period [y].

The total GHG emissions from mobility operation in the use stage can be computed by:

$$M_U = \sum_i w_{vehicle_i} \cdot L_{tot_i}$$

Where:

$M_U$ - emissions in use stage (mobility) [kg $CO_2$eq/y];
$w_{vehicle_i}$ - emissions per km driven by vehicle type *i* [kg $CO_2$eq/km];
$L_{tot_i}$ - average annual trip run by vehicle type *i* [km/y].

$$L_{tot_i} = \alpha_i \cdot L_{daily} \cdot p_i \cdot d$$

$L_{tot_i}$- average annual trip run by vehicle type *i* [km/y];
$\alpha_i$ - share of the different vehicle type *i* [%];
$L_{daily}$ - total daily travel length for commuting [km/person/day];
$p_i$ - total number of people travelling by vehicle type *i* in CPCC [person];
$d$ - total travelling days in a year [day/y].

The total GHG emissions from mobility materials*:*

$$M_P = \frac{\sum_i cpp \cdot p \cdot \alpha_i \cdot w_{private\ car_i}}{L} + \sum_i w_{public\ transport_i} \cdot L_{tot\ public\ transport_i}$$

Where:

$M_P$ **-** emissions in product stage (mobility) [kg $CO_2$eq/y];
$cpp$ - number of cars per inhabitant [unit/person];
$p$ - total number of car owners in the CPPC [person];
$\alpha_i$ - share of the different car type *i* in the total number of private vehicles [%];
$w_{private\ car_i}$ - embodied carbon for each type of private car $i$ [kg $CO_2$eq/unit];
$L$ - reference study period [y];
$w_{public\ transport_i}$ - embodied carbon for each type of public transport $i$ [kg $CO_2$eq/km];
$L_{tot\ public\ transport_i}$- average annual trip run by public transport type *i* [km/y].

Reference data for the determination of the GHG emissions from mobility operation in the product and the use stage can be found in **Table B.1** and **Table B.2** (Appendix B – GHG Emissions in Mobility).

The total GHG emissions from water consumption is computed based on the amount of water consumption. It can be determined from utility bills, however, if this information is not available, this indicator can be computed considering total number of inhabitants and estimated amount of water per person:

$$W_C = V_C \cdot w_{water} = l \cdot p \cdot w_{water}$$

Where:

$W_C$ – emissions from water consumption [kg $CO_2$eq/y];
$V_C$ – amount of water consumption [l/y];
$l$ – amount of water consumption per person [l/person·y];
$p$ – total number of inhabitants [person];
$w_{water}$ – emission coefficient for water consumption [kg $CO_2$eq/l].

The total GHG emissions from waste management:

$$WS = y \cdot p \cdot w_{waste}$$

Where:

$WS$ – emissions from waste management [kg $CO_2$eq/y];
$y$ – amount of waste generated per inhabitant [kg/person·y];
$p$ – total number of inhabitants [person];
$w_{waste}$ – emission coefficient for waste management [kg $CO_2$eq/kg].

The total GHG emissions from on-site RES, e.g. a PV system, in the product stage can be computed with the following formula:

$$RES_P = \frac{\sum_i C_{PV,i} \cdot w_{PV_i} \cdot (1 + r)}{L}$$

Where:

$RES_P$ - total GHG emissions from on-site RES in the product stage [kg $CO_2$eq/y];
$w_{PV_i}$ - PV material GHG intensity [kg $CO_2$eq/kW];
$r$ - number of replacements over the reference study period;
$C_{PV}$ - installed PV capacity according to the PV type *i* [kW];
$L$ - reference study period [y].

If GHG emissions offsets measures are adopted, their positive impacts on the reduction of total GHG emissions can also be considered.

The total GHG emissions offsets from on-site RES, e.g. a PV system, in the use stage:

$$RES_U = E_{prod,PV} \cdot w_{CO_2,elect}$$

Where:

$RES_U$ - emissions offsets from on-site RES, e.g. a PV system, in the use stage [kg $CO_2$eq/y];
$E_{prod,PV}$ – electricity production from PV system [kWh/y]
$w_{CO_2,elect}$ - emission coefficient for electricity [kg $CO_2$eq/kWh].

To assess the GHG emissions offsets from carbon sinks (green areas and roofs) the surfaces of green areas and roofs should be multiplied by a corresponding GHG emission absorption factors:

$$U_G = \sum_i S_{G_i} \cdot w_{G_i}$$

Where:

$U_G$ - emissions offsets by green surface area [kg $CO_2$eq/y];
$S_{G_i}$ - total green surface area *i* [$m^2$];
$w_{G_i}$ - emission absorption factor for green surface area *i* [kg $CO_2$eq/ $m^2$ y].

The total GHG emissions offsets from trees in the street:

$$U_T = \sum_i N_{tree_i} \cdot w_{tree_i}$$

Where:

$U_T$ - emissions offsets by trees in the street [kg $CO_2$eq/y];
$N_{tree_i}$ – number of trees of type *i* [unit];
$w_{tree_i}$ – emission absorption factor for type of tree *i* [kg $CO_2$eq/unit·y].

There are other GHG emissions offsets measures, e.g. development of sustainable mobility (establishment of bicycle lanes, creation of traffic-free zones in pedestrian-only areas, improvement of public transport). Calculation methods for such emissions offsets measures should be developed on a case-by-case basis.

## 5.2. AIR POLLUTION FROM THE ENERGY CONSUMPTION

***Motivation:***

Air pollutants have a significant impact on human health and the environment. Therefore, reducing air pollution is an important step towards vibrant and sustainable neighbourhoods.

Air pollution can be assessed at different stages, e.g., energy production, transport, processing, and operation (**Figure 11**). However, using Life Cycle Assessment (LCA) to assess air pollutants may not be a viable option because of the complexity of accessing data at different stages of a cycle [29]. Therefore, only air pollutants generated in the building operation phase will be calculated as they directly affect human health and the environment in the neighbourhood due to combustion of fossil fuels.

Air pollutants relevant to the combustion process that affect human health are small particles (namely, $PM_{2.5}$), nitrogen oxides ($NO_x$) and sulphur dioxide ($SO_2$):

- $PM_{2.5}$ is closely associated with heart and lung diseases. In addition, $PM_{2.5}$ is the main component of smog, which affects crop cultivation.
- $NO_x$ is associated with the formation of smog and thus with respiratory problems and other human diseases. It also has a negative impact on agriculture, as smog reduces sunlight.
- $SO_2$ has local and regional impacts: it is linked to heart and lung diseases and causes acidification that affects forests, lakes, and buildings.

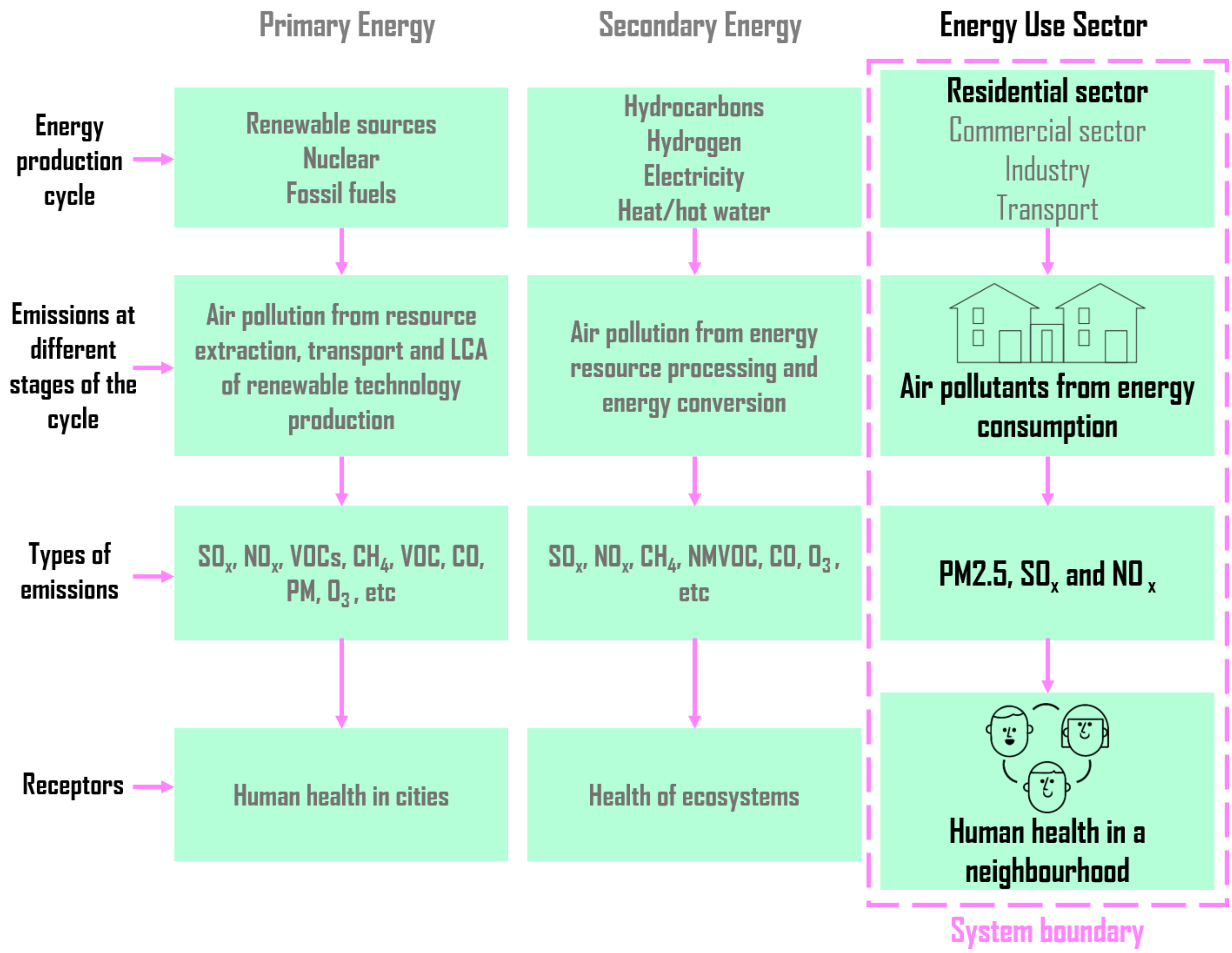



***Figure 11**. Air pollutants in the total life cycle (adopted from [29]) and a system boundary for the framework assessment.*

***Description:***
Air pollution from energy consumption is an indicator that measures the total annual amount of air pollution produced by combustion processes.

***Unit:***
kg/m$^2$ y.

***Calculation:***
Annual air pollution of each pollutant can be calculated using the following equation (adopted from [31]):

$$\boldsymbol{AP_i} = \sum_{j,k} \boldsymbol{EF_{i,j,k}} \cdot \boldsymbol{E_{P,nren,j,k}}$$

Where:

$\boldsymbol{AP_i}$ - annual air pollution of pollutant *i* [kg/m$^2$ y];
$\boldsymbol{EF_{i,j,k}}$ - default emission factor of pollutant *i* for source type *j* and fuel *k* [kg/kWh];
$\boldsymbol{E_{P,nren,j,k}}$ - annual consumption of fuel *k* in source type *j* [kWh/m$^2$y].

The emission factor of a pollutant represents the mass of a particular pollutant that is emitted per unit of energy delivered (or of heat produced) by a given source type (e.g., conventional boiler) and fuel (e.g., natural gas). **Table C.1** (Appendix C – Emission Factors for Air Pollutants per Energy Carrier) reports the emission factors for different energy carriers. Given factors correspond to conventional boilers below 50 kW, emission factors related to other technologies will be evaluated case by case.

Air pollution from electricity consumption is not considered by this indicator, as electricity is not generated on site and therefore air pollution from electricity generation is not directly related to the neighbourhood. However, in case electricity needs to be considered in the calculation, emission factors for low-voltage electricity generation could be found in **Table C.2** (Appendix C – Emission Factors for Air Pollutants per Energy Carrier).

## 5.3. DUST DURING RETROFITTING

***Motivation:***
At a construction site, there are several routine tasks that may produce high levels of dust, e.g., cutting blocks or tiles, demolition works, aggregates transportation, 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.

This indicator aims to evaluate dust reduction due to implementation of light construction works mainly through dry assembly processes and prefabrication which leads to reduced production and spread of dust at the construction site.

***Description:***
The evaluation of dust generated by the construction works is performed using a hybrid method that merges qualitative and quantitative approaches. The qualitative assessment is based on the submission of a survey to a target group connected to the project; the quantitative evaluation is performed using a dust sensor. The indicator adopted for the qualitative evaluation is the percentage of respondents confirming that the dust generated by the construction activities in place is significantly lower than the one characterizing a traditional construction site. The quantitative assessment is performed measuring the dust concentration ($PM_{2.5}$, $PM_{10}$, total suspended particulate (TSP)) in a representative location.

***Unit:***
Qualitative assessment: % of respondents.
Quantitative assessment: µg/m$^3$ of $PM_{2.5}$, $PM_{10}$, TSP.

***Calculation:***
Concerning the qualitative assessment, the evaluation should be carried out through a questionnaire that should be submitted to a significant sample of people. The questionnaire should contain, for example, the following questions:

- Please, list some dusty activities that characterize traditional construction works (open question).
- Are you experiencing them in this construction site? 5 levels Likert scale: Never – Rarely – Sometimes – Often – Always.
- In your opinion, how much lower are the dust levels generated by the present construction site compared to dust levels generated by a traditional construction activity? 5 levels Likert scale: much more dust (more than +30%) – significantly more dust (+30%) – same level – significantly less (-30%) – much less (more than -30%).

The target is considered met if a majority of the respondents agree that the dust generated by the construction works is significantly lower (-30%) compared to traditional ones.

An alternative version of a questionnaire can be used. In that case, the survey is submitted to the demo target group and to people related to another traditional construction site. The ARV target is considered met if the comparison of the statistical mode measurement of the responses given by the two groups confirms that the construction methodologies supported by the project are capable to significantly reduce dust levels compared to traditional ones:

- How much did you experience dust nuisance? 5 levels Likert scale: very dusty – dusty – as expected – low dusty – little or no dusty.

The quantitative measuring campaign is optional but can be useful to further support the findings obtained from the questionnaire. It should be performed with a device that is able to monitor TSP in ambient air, the $PM_{10}$ or the $PM_{2.5}$. The results gathered will be compared with literature reference values.

## 5.4. NOISE DURING RETROFITTING

***Motivation:***
The purpose of this KPI is to assess whether the renovation and construction activities are carried out with the least possible nuisance for a target group connected to the project.

The noise control is a challenging task. The traditional approach to noise control is focused on the reduction of the sound pressure levels that are experienced by the receivers. The strategies to accomplish this objective can act on the noise source, on the means of transmission (noise barriers) or on the receiver (by means of personal protective equipment or by absorbing and reflecting materials). However, the reduction of the sound pressure levels of environmental noise is not always a feasible and practicable solution since noise annoyance depends only in part on the physical noise itself.

***Description:***

The evaluation of noise generated by the construction works is performed using a hybrid method that merges qualitative and quantitative approaches. The qualitative assessment is based on the submission of a survey to the target group; the quantitative evaluation is performed using a phonometer or binaural head meters. The indicator adopted for the qualitative evaluation is the percentage of respondents confirming that the noise generated by the construction activities in place is significantly lower than the one characterizing a traditional construction site. The quantitative assessment is performed measuring the environmental noise.

***Unit:***

Qualitative assessment: % of respondents.

Quantitative assessment: equivalent continuous A-weighted sound pressure level ($L_{Aeq,T}$) and the unit of measure is the dBA.

***Calculation:***

Concerning the qualitative assessment, the questionnaire should be submitted to a significant sample of people and should contain, for example, the following questions:

1. Which noises/sounds do you discern? (Answers in a scale of importance/loudness)
2. How do you evaluate the soundscape of this area? (Eventful, exciting, pleasant, calm, uneventful, monotonous, annoying, chaotic (based on ISO/TS 12913-2:2018 - Method A))
3. Please, list some noisy activities that characterize traditional construction works (open question).
4. Are you experiencing them in this construction site? 5 levels Likert scale: Never – Rarely – Sometimes – Often – Always.
5. 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? 5 levels Likert scale: much more noisy (>+30%) – significantly more noisy (+30%) – same level – significantly less (-30%) – much less (more than -30%).

The target is considered met if the majority of the respondents agree that the noise generated by the construction works is significantly less (-30%) if compared with traditional ones.

In an alternative questionnaire, question 8 can be replaced by: *"How much did you experience noise nuisance? 5 levels Likert scale: very noisy – noisy – as expected – low noisy – little or no noisy".* In this case, the target is considered met if the comparison of the statistical mode measurement of the responses given by the two groups to question 8 confirms that the construction methodologies supported by the project are capable to significantly reduce noise when compared to traditional ones.

Concerning the quantitative assessment, some measures of environmental noise should be performed in order to understand the level of noise to which the respondents are exposed to. This task is accomplished using a phonometer or binaural head meters. The measure of some psychoacoustic parameter is optional but recommended to consider the effects of the spectral distribution of noise. The characterization of the sound pressure levels can further support the results obtained from the subjective evaluation of noise.

# 6. SOCIAL KPIS

A socially sustainable neighbourhood should be democratic and inclusive, where individuals or groups are able to participate economically, socially, and politically [32]. Shirazi et al. [33] emphasize the importance of understanding the social and physical qualities together, and have identified the following key principles for assessing the social and architectural qualities of a neighbourhood: **equity, democracy** and **social engagement, social inclusion** and **social mix, social interaction, sense of place, safety** and **security,** and **the quality of the built environment** and **dwellings** [33]. Where the ambition is to increase the overall social and environmental sustainability of a neighbourhood, other qualities associated with the built environment should also be included such as energy efficiency, environmental quality, and circularity.

An assessment of social quality is often subjective and cannot be easily calculated, and some supporting indicators have therefore been chosen to enable a qualitative assessment of the progress within neighbourhoods. An evaluation of actions to improve social sustainability should take place in a simple and flexible manner that promotes understanding of what improvement means within the context.

To achieve this, indicators for social quality are organised under three main categories: democracy, equity and community (**Figure 12**).

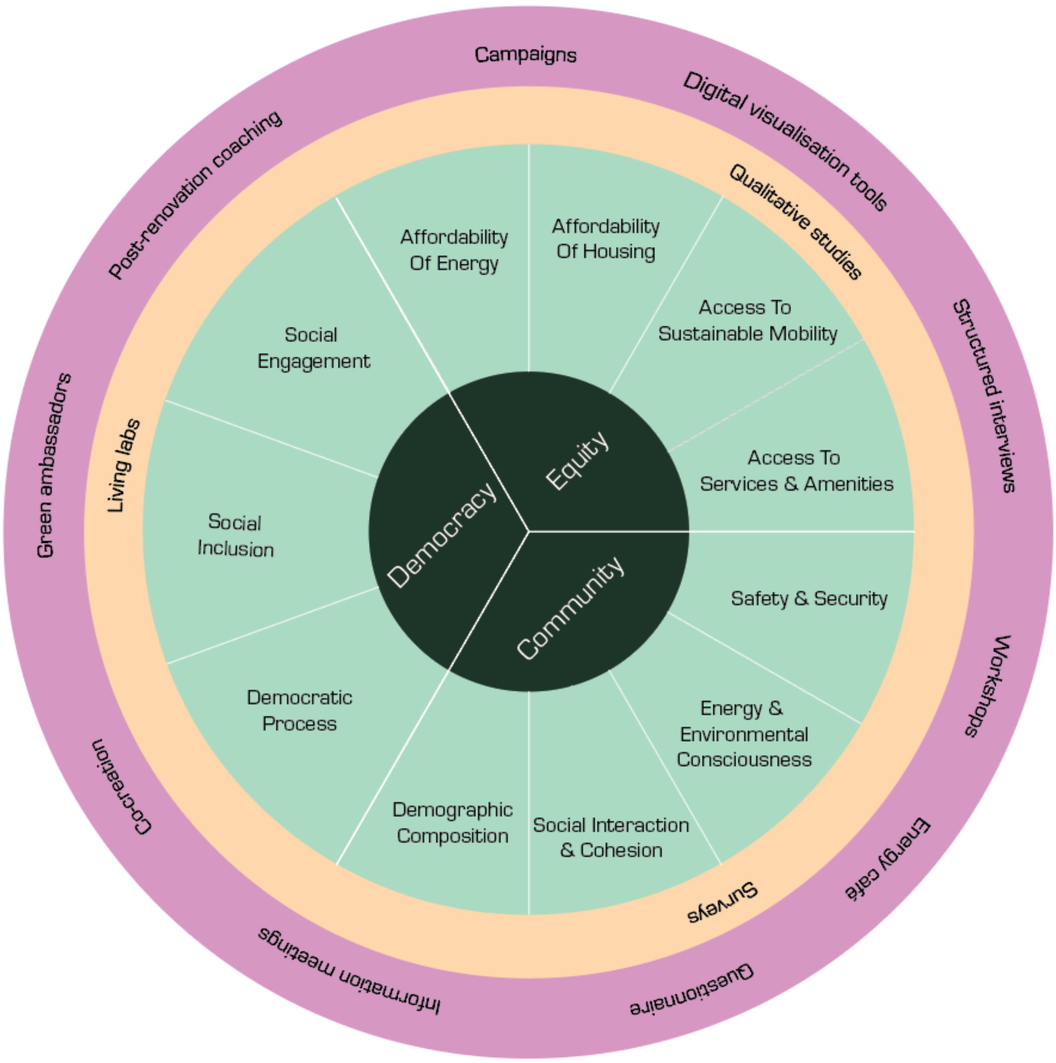



***Figure 12**. Structure of social KPIs.*

Each category is assigned a number of indicators associated with activities that encourage a neighbourhood or demo project to be, for example, more democratic. Communities working with social quality should attempt to follow up all three categories. The evaluation is flexible because the neighbourhoods may prioritise the indicators under each category that are most relevant for their social and physical environment and can ignore those that are less relevant for the context. Neighbourhoods and demo projects should therefore make a careful selection of the relevant indicators when evaluating social quality.

A qualitative approach to evaluating social KPIs is recommended because assessments by both citizens and experts are often subjective and are challenging to evaluate in a statistically viable quantitative manner. The evaluation when applying a qualitative approach regards subjective meanings and values as a resource [34]. The approach is characterised by sensitivity to the context where the research takes place and closeness to the people and place where the research is being done [35]. It is also a critical approach because researchers and methods are entangled in politics and practices found in the social world. At the same time it is flexible because adjustments to expectations and actions are essential to the research process, which is reflexive and requires the researcher to look both inwards and outwards exploring relationships between existing knowledge, previous experience and the world around us [36]. Yin [37] suggests that qualitative research processes have five main features and these can be connected to the living labs concept presented below:

1. Studying the meaning of people's lives in real-world conditions.
2. Representing the views and perspectives of people.
3. Uncovering the contextual conditions where people live.
4. Contributing insights that may help to explain behaviour.
5. Striving to use multiple sources of evidence rather than relying on a single source alone.

Three research practices are often associated with qualitative processes. Firstly, the use of flexible rather than fixed research designs. Secondly, the collection of field-based data to capture contextual conditions. Thirdly, the interpretation of findings which can challenge conventional generalisations and stereotypes [37]. The aim is to establish an understanding of social phenomena based on an in-depth study [38]. This means ample data about the people and situations under analysis.

### *The role of living labs*

Changes or improvements in social sustainability, buildings, and environmental quality are context dependent. Different needs and challenges will affect how citizens consider actions and events. Living labs can provide a context to understand the consequences and evaluate relevance and acceptance by citizens with respect to changes made to the neighbourhood. The citizen-centred approach applied by living labs has a multiple methods approach where both quantitative and qualitative methods can be applied to evaluate social sustainability and the interactions between social, architectural, and environmental qualities. When the living lab concept was developed in the 1980's, it was initially understood as a means to enable the careful study of people and their interaction with new technologies in a living environment [39]. Living labs have, since 2000, been applied to promote citizen participation in collaboration with research and development projects [40]. This has often been in association with three main trends within municipal governance; the carbonization of urban governance, experimental governance, and the transition to a low-carbon economy, inspiring different living lab formats and motivations [41]. Bulkeley et al. has identified three main types of living labs; strategic, civic, and organic [42]. When designing and developing climate positive circular communities, it is relevant to combine the interest in technical innovation associated with early living labs with the motivations for 'civic living labs' where user participation supports a democratic process [42].

Actions to involve citizens in processes intended to increase local participation in design, planning and development of neighbourhoods are at the core of living labs. These should be inclusive and empowering and improve the quality of life of citizens. It is possible to evaluate quantitatively the number of events and how many citizens participated. Additional quantitative methods, such as surveys may be applied, and statistical data may be gathered. Surveys should be cross-cutting and enable the assessment of several connected criteria. However, the citizen interaction with engagement processes, the quality of participation or social inclusion and the relevance of changes to the technical and environmental context of people's everyday lives are best-evaluated using qualitative methods. Qualitative methods go in depth and emphasise meaning, whilst quantitative methods emphasise prevalence and number. Results from qualitative methods are interpreted in relation to context where understanding is important, whilst quantitative methods are interpreted independently of the social context [38]. The target groups for the activities include all genders, ages, social and cultural backgrounds, and (dis) abilities, and depend on the citizen requirements and the demographic mix of the neighbourhood.

An ethical approach is required in research where citizens and stakeholders are at the centre of the data collection. Qualitative and quantitative research processes build upon international and national guidelines for governance and ethical codes of practice [36]. For example, all interviews and feedback through questionnaires must be based on informed consent. Informants who are involved in living lab activities should be offered confidentiality and anonymity, although social events where confidential information is not being gathered, may be exempt from this requirement. Informants should be given the right to withdraw at any time, be fully informed about the aims of the research, and given access to any publications resulting from the project.

## 6.1. DEMOCRACY

Democracy is a main category to understand and evaluate challenges experienced by citizens and the actions designed to promote the social quality of neighbourhood. Democracy within a neighbourhood context requires actions to ensure that all individuals and groups are offered opportunities to participate in decision-making processes and neighbourhood activities independent of their gender, age, social and cultural background, (dis)abilities, or economic resources. Citizens should experience that their voices are heard and that their challenges and needs are accounted for in a neighbourhood.

The category includes three indicators. The first two; democratic process and social inclusion, account for and describe actions to achieve democracy in the neighbourhoods. The third indicator, social engagement, asks whether citizens have participated in actions and if the citizens themselves believe that the neighbourhood is more or less democratic and inclusive after the transformation.

### 6.1.1. DEMOCRATIC PROCESS

***Motivation:***
A democratic process should enable citizen participation, ensuring the redistribution of power and benefits through decision-making, and increased community control over urban policymaking and planning processes, resulting in citizen empowerment [43]. It implies a two-way communication process, where citizens receive information, are able to offer input, and experience that changes are made based on their proposals. A democratic process requires a greater variety and depth of activities than is implied by standard and tokenish activities such as public consultation or public meetings.

***Description:***
The intention is to evaluate the increase in satisfaction among citizens before and after transformation of a neighbourhood. This aim is central to all the social indicators. The evaluation should establish if citizens have experienced that their voices have been heard. A proposed method is research interviews, a method that is often applied in qualitative research processes, where knowledge is constructed in the interaction between the interviewer and interviewee. An interview is a kind of conversation, but as part of a qualitative research process it is a conversation with structure and purpose, where careful questioning and listening take place and where the topic is introduced by the research project [44]. Qualitative research interviews are different from for example job interviews or journalistic interviews because they are, firstly, flexible and open-ended in style. Secondly, they focus on people's actual experiences rather than general opinions and beliefs and thirdly, the relationship between interviewer and interviewee is clearly defined [36].

***Unit:***
The number and length of interviews will depend on the number of citizens or stakeholders who participate in i.e. public meetings, world cafés [45] or other social activities.

***Calculation/assessment:***
A subjective evaluation of the process by participants in democratic processes through interviews and descriptive information collected through social activities organized by living labs. The assessment requires participants that have been involved with the neighbourhood or participation process over a longer period of time, for example the whole project period.

### 6.1.2. SOCIAL INCLUSION

***Motivation:***
Social inclusion refers to the efforts made to increase local participation. Actions can include local individual consultation and the inclusion of community groups, and widespread mobilization of different groups, thereby avoiding focus on one particular group. It can also include the development of community spaces where all citizens feel included, independent of social situation or economic status [43]. As with the democratic process, the indicator accounts for and describes actions for achieving social inclusion.

***Description:***
In addition to individual interviews (see democratic process) a proposed method is group interviews. An evaluation should establish whether the neighbourhood has become as more inclusive place, if there is more interaction between individuals and groups and if there is a potential to do more. Group interviews are useful because they can reveal the social and cultural context of people's understandings and beliefs. In addition, interacting and discussing as part of a group can be closer to everyday life than an individual encounter [36]. Other qualitative methods applied in living labs are workshops (co-creation and other methods where technical prototypes are tested and discussed) where a clearly defined group of stakeholders are engaged. Another method is mapping of the social, cultural, and physical context through public surveys. Actions for social inclusion could also include broader social events such as cafes and festivals where the intention is to reach out to as many people as possible but where long term involvement is not required.

***Unit:***
Number of informants and interviews and type of interviews, plus surveys. If surveys are distributed, changes in satisfaction can be evaluated in % or increase on a Likert-type-scale from 1 to 5.

***Calculation/assessment:***
Satisfaction may be evaluated quantitatively through ex-ante and ex-post surveys and qualitatively through individual and group interviews. Evaluation of the process depends upon of the number of participants, both individuals and from local groups. Questions posed or discussed will depend on the requirements of the neighbourhood and the kind of activities taking place. For example, a question may be if the activities require long-term or short-term participation by citizens or stakeholders. The questions may also depend on the context where inclusive actions take place, for example, if informants feel comfortable within the designated space.

### 6.1.3. SOCIAL ENGAGEMENT

***Motivation:***
This third category asks whether citizens approve of and are participating in relevant actions, if they have been provided with spaces for these activities to take place, and if they believe that social engagement has been achieved.

***Description:***
The intention is to evaluate the increase in satisfaction before and after the transformation of neighbourhood. Evaluation takes place in close association with democratic process and social inclusion, but where the first two indicators ask if the citizens have participated, have been given opportunities to use their voice, and feel that the community has become more inclusive, the engagement indicator asks about the number and quality of activities taking place. It also asks for suggestions for how improvements could be made or other activities that could take place.

***Unit:***
The number of people participating in activities will depend on the social and physical context and the type of activities in living labs. Percentage increase in satisfaction could be based on a Likert-type-scale of 1-5 (if ex-ante/ex-post survey is distributed). The survey’s applicability will depend on citizens participating over a period of time, experiencing participation activities and neighbourhood transformations and therefore can evaluate the changes over time.

***Calculation/assessment:***
Descriptive information collected through individual and group interviews. Ex-ante and post-ante surveys to measure if the level of satisfaction increases (ex-ante/ex-post), how many activities citizens participate in, and how many participants over time.

## 6.2. COMMUNITY

Communities that are socially sustainable are rich in social capital, which is defined as connections between people [46]. Ensuring that neighbourhoods are perceived to have social qualities requires investment in meeting places and establishing safe and secure physical and social environments. Community engagement should contribute to raising awareness on energy and environmental aspects and increase occupant well-being and satisfaction.

A community requires social connections that support mutual actions and spontaneous cooperation between people, which in turn strengthens social cohesion and avoids actions that are exclusionary. In addition to group needs, a socially sustainable community on an individual level indicates subjective well-being, satisfaction with life, and a sense of meaning [47]. Connections between people and places are supported by compact urban development that includes housing, public transport, and the accessibility of a variety of services and amenities.

Four indicators (demographic composition, social interaction and cohesion, safety and security, energy and environmental consciousness) may be used to assess the level of community satisfaction and the level of engagement with energy and environmental qualities.

### 6.2.1. DEMOGRAPHIC COMPOSITION

***Motivation:***
The gender, age, social and cultural mix of the population can be followed over time to enable an understanding of changes in the neighbourhood's economic, social, and cultural resources.

***Description:***
The demographic composition of a neighbourhood is the proportion or number of people in the area who can be identified according to a certain characteristic such as gender, age, social mix, etc., and relates to their needs, as well as the potential for increases in social capital.

***Unit:***
Statistical data from the start of a project period is compared to data collected at the end of the project period. Rate of change (%) to identify short-term trends are used.

***Calculation/assessment:***
Demographic composition is a descriptive KPI and if required, changes in the neighbourhood's demographic composition may be followed up by statistical data that is available in local, regional, or national registers or by means of a cohort measurement.

### 6.2.2. SOCIAL INTERACTION AND COHESION

***Motivation:***
Social interaction and cohesion require participation by citizens in groups and networks. A high degree of interaction and cohesion implies stability in the local community. A high degree of social mobility implies reduced contact with neighbours and low cohesion and is associated with reduced social quality.

***Description:***
Social mobility in and out of a neighbourhood can be a measure of perceived quality and care for the living environment, indicating the availability of services and amenities, as well as housing availability and suitable tenures. Social interaction and cohesion also indicate pride and sense of place. A positive sense of belonging is an expression of people's enjoyment of their neighbourhood and a feeling of having the right to belong [46].

***Unit:***
The number of activities and people reached through a living lab may be accounted for on a yearly basis and descriptive data may be collected through different interview formats and surveys. Descriptive statistical data may also be gathered to follow demographic changes to the neighbourhood (see the indicator for demographic composition).

***Calculation/assessment:***
Living Labs with a variety of engagement methods are proposed applied with follow-up evaluations. The activities are tailored to the needs of the respective communities. These may include workshops with a variety of local groups where actions to reduce social mobility and increase cohesion are designed by citizens for the local community. Other actions are experiments and interventions with schools including both pupils and teachers.

### 6.2.3. SAFETY AND SECURITY

***Motivation:***
People depend on feeling safe in their homes and in the places that they move through, and participate in. When an area is perceived as safe and secure, it supports the development of trust and reciprocity between the members of the local community. If a neighbourhood struggles with crime and is run-down, any negative changes may stimulate more antisocial behaviour and criminal activity [46]. In this framework, safety and security can be evaluated with the following indicators: normative perceived safety (quantitative indicator) and descriptive safety enablers (qualitative indicator). Normative perceived safety is measured using statistical data on crime and traffic safety collected by Eurostat. Where microdata is not available, subjective safety data must be surveyed annually on a statistically representative segment of the building occupants/neighbourhood inhabitants. The survey consists of a series of tests to evaluate perceived safety:

***Question 1:***
- Do you feel the traffic conditions are safe with respect to walking or using a bicycle in your neighbourhood?

***Question 2:***
- Is your neighbourhood free of crime, violence, and vandalism?

***Question 3:***
- Do you feel safe walking alone at night in your neighbourhood?

***Description:***
The normative perceived safety is presented as the mean of respondent scores on a 3-point scale and share of “True” responses (or 1 scores) for each question. The descriptive safety enablers is the set of enablers present/absent from the evaluated building/neighbourhood [25].

***Unit:***
Normative perceived safety: 3-point-scale.
Descriptive safety enablers: quantity of available enablers.

***Calculation:***

$$PS_{aggr} = \frac{1}{3} \cdot \sum_{i=1}^{3} PS_{test,i}$$

Where:

$PS_{aggr}$ - normative personal safety output [%];

$PS_{test,i}$ - score of individual test *i* of personal safety [%].

$$PS_{test} = \frac{PS_{test,True}}{N} \cdot 100$$

Where:

$PS_{test}$ - score of any individual test of personal safety [%];

$PS_{test,True}$ - number of responses for any test of personal safety, where the answer corresponds to a 1 score [respondent];

$N$ - number of respondents [respondent].

The scoring for both aggregated and individual test scores are on a 100-point scale, where lower values refer to lower degree of social cohesion.

### 6.2.4. ENERGY AND ENVIRONMENTAL CONSCIOUSNESS

***Motivation:***
The motivation for this indicator is to raise awareness within the communities about energy and environmental issues. Awareness raising activities about the implications of energy use, sustainable or non-sustainable activities, are expected to foster social interaction and to promote sustainable behaviour. The indicator is assessed through an annual survey on a statistically representative subset of building occupants/CPCC inhabitants. The questions are intended to provoke a subjective response to three subjects: environment, energy consumption, and novel technologies.

- The technologies implemented in this building/neighbourhood improve energy efficiency.
- The passive design choices (building shape, amount and placement of windows, building layout, surfaces, material choices) in this building/neighbourhood improve energy efficiency.
- Having shared energy management improves energy efficiency.
- 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.
- Tracking energy consumption improves (would help improving) energy efficiency.
- I am aware of my own energy consumption pattern and composition.
- I know how much money I can save through energy efficiency.
- I actively optimize my energy consumption and select appliances to reduce my cost of living.
- I aim to live a more environmentally friendly lifestyle.
- My friends, colleagues and family are strongly environmentally conscious and are vocal on environmental values.
- I actively optimize my energy consumption and select appliances to reduce my carbon footprint.

***Description:***
Each individual response returns a score between 1 and 5. Additionally, scores must be aggregated by type of determinant, and for all responses. All aggregations are by taking the mean of individual scores.

***Unit:***
5-point-scale.

***Calculation:***

$$EC_{aggr} = \frac{1}{N} \cdot \sum_{i=1}^{N} EC_{ind,i}$$

Where:

$EC_{aggr}$ - energy consciousness aggregated output [point];

$EC_{ind,i}$ - energy consciousness individual response score, for respondent $i$ [point];

$N$ - number of respondents [respondent].

## 6.3. EQUITY

***Motivation:***
Maintaining or achieving greater social equity in a neighbourhood means that all citizens independent of health, social, cultural, and economic resources have equal or equitable access to housing and energy, as well as basic services and amenities.

***Description:***
Deprivation is often expressed by the architectural and geographical context, and this can highlight a neighbourhood's lack of social equity which can be seen in poorer housing quality and reduced access to public services and amenities. A place's social equity may be evaluated based on housing quality and accessibility. It is also evident in the local environmental quality[32], [48].

The following four indicators (affordability of energy, affordability of housing, access to sustainable mobility and access to services and amenities) may be used to assess the level of equity within the neighbourhood.

### 6.3.1. AFFORDABILITY OF ENERGY

***Motivation:***
The 7$^{th}$ UN Sustainable Development Goal (SDG), states that everyone should have access to "clean, sustainable, reliable, and affordable energy" [15]. In this framework, affordability of energy can be accessed with two European Energy Poverty Observatory (EPOV) metrics [49]: assessment of energy costs in household expenditure versus income and assessment of people reporting arrears on utility bills.

Data is collected in annual household surveys of a statistically representative subset of households, comprising of two questions:

***Question 1*** *(related to affordability of energy as indicated by composition of household expenditure):*

- *Option 1:* Compared to your last residence: Have you spent more or less or the same on expenses connected to total annual energy consumption?
- *Option 2:* What is the "annual income of household" AND "number of people living in the household" AND "total annual energy spending"?

***Question 2*** *(related to affordability of energy as indicated by arrears in utility bills):*

- Has your household been at any time unable to pay utility bills on time due to financial difficulties for the last year?

***Description:***
Affordability of energy as indicated by composition of household expenditure could be assessed as the proportion of respondents with “True” answers in Question 1 to the total number of respondents. A “True” answer corresponds to higher energy costs in household expenditures compared to the previous residence. Similarly, affordability of energy as indicated by arrears in utility can be assessed as the proportion of residents with "True" answers to the total number of respondents from the surveys.

***Unit:***
% of respondents.

***Calculation:***

$$AE_E = \frac{P_{True,E}}{P_{tot}} \cdot 100\%$$

Where:

$AE_E$ - affordability of energy as indicated by composition of household expenditure [%];

$P_{True,E}$ - number of respondents responding with “True” for *Question 1* [respondent];

$P_{tot}$ - total number of respondents [respondent].

$$AE_A = \frac{P_{True,A}}{P_{tot}} \cdot 100\%$$

Where:

$AE_A$ - affordability of energy as indicated by arrears in utility bills [%];

$P_{True,E}$ - number of respondents responding with “True” for *Question 2* [respondent];

$P_{tot}$ - total number of respondents [respondent].

### 6.3.2. AFFORDABILITY OF HOUSING

***Motivation:***
The right to adequate and affordable housing was established by the United Nations within the Human Rights Convention in 1948 and is in SDG 11 entitled “adequate, safe, and affordable” housing for all [15]. The “affordability” component of this goal is usually represented as the presence/absence of cost overburden in access to housing and is measured by comparing the share of income spent on housing (including rent, utilities) with a benchmark. However, a lack of supply in the housing market can also increase prices, regardless of quality and location [50]. In this framework, affordability of housing can be assessed by two different indicators: internal affordability of housing (main indicator) and external affordability of housing (complementary indicator).

Data is collected in annual household surveys of a statistically representative subset of households, comprising of two questions:

***Question 1:***
- How much do you spend on expenses related to your dwelling (for example rent, mortgage, maintenance), excluding energy costs?

***Question 2:***
- Compared to your last residence: Have you spent more or less on expenses connected to your dwelling (for example rent, mortgage, maintenance), excluding energy costs?

***Description:***
Internal affordability of housing could be assessed as the proportion of respondents with “True” answers in Question 2 to the total number of respondents. Where “True” answer belongs to higher expenses connected to the dwelling.

External affordability of housing is calculated as the proportion of a target population that can afford to live in the CPCC without overburden. The minimum income is calculated from the median of household costs as reported in Question 1.

***Unit:***
Internal affordability: % of respondents.
External affordability: integer in range (1;10).

***Calculation:***

$$AH_{in} = \frac{P_{True}}{P_{tot}} \cdot 100$$

Where:

$AH_{in}$ - internal affordability of Housing [%];

$P_{True}$ - number of respondents responding with “True” for *Question 2* [respondent]*;*

$P_{tot}$ - total number of respondents [respondent].

$$AH_{ex} = min_{k=1}^{10} \left\{ D_{k,key} | D_{k,val} < \frac{med_{i=1}^{n}\{HE04_i\}}{40} \cdot 100 \right\}$$

Where:

$AH_{ex}$ - external affordability of housing [-];

$D_k$ - key-value pairs of target population income deciles, where the key is the index of the decile and the value is the endpoint income of the bin [€];

$HE04$ - the total cost of housing for household *i*, reported in *Question 1* [€].

### 6.3.3. ACCESS TO SUSTAINABLE MOBILITY

***Motivation:***
Emissions from mobility are considered a significant part of GHG emissions in CPCC. Access to sustainable mobility implies access to public transport, cycle routes and pedestrian-friendly areas. It also implies that citizens can move freely and not be hindered or endangered by traffic or infrastructure such as junctions, major roads, or railway lines. In this framework, access to sustainable mobility can be accessed with two indicators: modal share (quantitative indicator) and list of sustainable mobility enablers (descriptive indicator) as alternative one.

***Description:***
The modal share is presented as a distribution between the three modes of transport (private motorised, public, non-motorised). The individual shares of mode are calculated by dividing the sum of passenger kilometres in the given mode by the total sum of passenger kilometres.

The descriptive option of the indicator can be described as the list of enablers present/absent from the evaluated building/CPCC [25].

***Unit:***
Modal share: % of passenger km-s (or work journeys).
List of sustainable mobility enablers: quantity of available enablers.

***Calculation:***

$$SM_{mode} = \frac{\sum_{i=1}^{n} d_{mode,i}}{d_{tot}} \cdot 100$$

Where:

$SM_{mode}$ - share of transportation in mode of interest [%];

$d_{mode,i}$ - the distance travelled with mode of interest in journey $i$ [km];

$d_{tot}$ - the sum of all distances travelled [km].

### 6.3.4. ACCESS TO SERVICES AND AMENITIES

***Motivation:***
Services to which citizens should have equal access are social infrastructure: e.g. housing, local community centres, schools, kindergartens and workplaces. There should also be grocery stores, pharmacies, and other shops, as well as healthcare facilities. Amenities that are necessary to provide social equity are different kinds of indoor and outdoor public spaces that enable recreational activities within sports and culture, i.e. parks and sports arenas, as well as places for people to meet and socialize, such as cafés and public benches with shade and protection from noise and transport. In this framework, access to amenities can be evaluated by indication of the equitable access to amenities in the CPCC (accessibility score for amenities). Access to services can be evaluated with accessibility score for services.

***Description:***
The accessibility score for amenities indicates the equitable access to amenities in the CPCC and measures whether there is any amenity of the type within reach. Higher accessibility indicates that the population has more equitable access to valued amenities in CPCC compared to others, while lower scores indicate that people would have to spend a disproportionate amount of time or a different mode of transport to reach certain amenities [25].

The accessibility score for services signals equitable access to services, where the normative target is 100%. Lower values indicate that more people would have to spend a disproportionate amount of time, or a different mode of transport to access certain services.

***Unit:***
Accessibility score for amenities: % of population.
Accessibility score for services: % of population.

***Calculation:***

$$AM_A = \left(\frac{1}{N}\right) \cdot \sum_{z=1}^{N} \frac{\sum_{i=1}^{n} P_{ser,i}}{P_{tot}}$$

Where:

$AM_A$ - accessibility score for amenities [%];

$N$ - number of amenity types [type];

$\boldsymbol{n}$ - number of amenities within type [amenity];

$\boldsymbol{P_{ser,i}}$ - serviced population, the population in access_far zones containing at least one instance of amenity in type [person];

$\boldsymbol{P_{tot}}$ - total CPCC population [person].

$$AS_A = \left(\frac{1}{N}\right) \cdot \sum_{z=1}^{N} \frac{\sum_{i=1}^{n} P_{ser,i}}{P_{tot}}$$

Where:

$\boldsymbol{AS_A}$ - accessibility score for services [%];

$\boldsymbol{N}$ - number of service types [type];

$\boldsymbol{n}$ - number of services within type [service];

$\boldsymbol{P_{ser,i}}$ - serviced population, the population in access_far zones containing at least one instance of service in type [person];

$\boldsymbol{P_{tot}}$ - total CPCC population [person].

Evaluation of satisfaction with the community may also include satisfaction with the neighbourhood's infrastructures, services, and amenities, where considered relevant by the demos.

# 7. ARCHITECTURAL QUALITY KPIS

“Good architecture” is a very broad term that is often used quite holistically including both the single building as well as ensembles. Historically, the term combines the principles of firmitas (strength), venustas (beauty) and utilitas (functionality), a set of qualities that, for instance, the “design quality indicator (DQI)” refers to [51]. The “diamond” add-on for the German Sustainability rating system DGNB [52] divides its criteria for design and building cultural quality into “context”, “form”, adequacy”, and “plan”, adding the urban aspect, which is essential for the public dimension of architecture. A modern definition of good buildings adheres to the “3L” principle, they achieve “long life, loose fit, low energy”[53]. Recently, the New Bauhaus Vision proposed “beautiful, sustainable, together” as the vision for the future [5]. The European Level(s) macro-objective 4 “Healthy and comfortable spaces” [18] aims to “create buildings that are comfortable, attractive and productive to live and work in, and which protect human health.” These definitions of the qualities of the built environment show the importance of the architectural dimension for both buildings and communities.

The definitions of social and architectural qualities have in common that they are agreed upon in general, but are hard to evaluate in detail, are difficult to ensure in a building design process, and cannot easily be quantified. This does not mean that they should be disregarded, but that they need to be carefully assessed in a qualitative way to communicate social and architectural qualities by giving suitable examples that future projects can build upon.

For this category, a set of KPIs has been selected to best assess the architectural qualities. “Architectural quality” encompasses a wide range of criteria and qualities, overlapping with other broad terms, e.g. the term “sustainability”. Moreover, high architectural quality is claimed to be an overarching goal for good buildings, integrating all criteria related to economic, ecological, social, functional, cultural values that are vital for the ARV objective 4 “design and demonstrate integrated circular buildings for (…) high architectural quality”. However, the set of architectural quality indicators does not aim to capture architectural quality in its entirety, but rather complements the KPI framework with the values that are perceived to be core architectural qualities. While the architectural result is often difficult to influence in a direct and standardized way, the process leading to good results can be designed such that it enables good solutions, and is hence part of the category. It is also part of this criterion to assess the validity of design concepts for the building users. Therefore, the assessment includes both a description of design intentions and a Post Occupancy Evaluation (POE) to identify design concepts achieving high-quality buildings and neighbourhoods for their occupants.

## 7.1. AESTHETICS AND VISUAL QUALITIES

***Motivation:***
“Aesthetic delight is not a superficial concern – it is an environmental imperative. How long will buildings last if they fail to stir the imagination? No matter how efficiently something is designed, if people don't love it, it's likely to be rejected.“[54]. Aesthetics subconsciously affect comfort and well-being. However, the individual perception of aesthetics and visual qualities can strongly differ and depends on the social and urban context of the observer. To achieve high-quality architecture and urban spaces, it is vital that such qualities are part of design considerations and user involvement.

***Description:***
Aesthetics and visual qualities are a core criterion for high architectural qualities. They include the care that is taken for material choices, especially surfaces, and the overall view and appearance of buildings and urban spaces. This criterion is context-dependent and to a certain degree subjective. Aesthetics and

visual qualities are related to the sense of space and the social cohesion, as visual appearance contributes to a sense of belonging to an urban area.

***Unit:***
Dimensionless (score).

***Calculation/assessment:***
Design process and ambition is assessed in interviews with the design team. Collection on ex-ante and ex-post perception of users regarding the visual qualities of the urban space, façade, circulation spaces and private spaces. This criterion is seen as experimental, as there are no set criteria tested for this.

Qualities to be assessed in surveys are:

- Proportion/composition.
- Overall appearance.
- Materiality/form.
- Detailing.
- Visual connections.

For renovation cases:

- Coherence (volumes, façade patterns, colours) between the new/renovated building and the surrounding built environment.
- Blending/not blending in the surrounding natural environment (mimesis, transparency, imposition, indifference).
- Reconstruction of historical appearance (contrast, interpretation, anastylosis).

## 7.2. FLEXIBILITY AND ADAPTABILITY

***Motivation:***
Flexible and adaptable buildings are less likely to be demolished because of functional obsolescence, enabling a longer lifespan. This indicator is related to circularity indicators, as adaptive reuse enables an entire building to be re-used and stay in the cycle rather than re-using only its components or materials. As such, flexibility and adaptability have a strong influence on life cycle environmental performance and cost.

***Description:***
This indicator assesses how easily the building can be adapted for a future change of use. It takes into account the “shearing layers” concept [55], dividing the building into its sub-systems which differ in their lifespans.

***Unit:***
Dimensionless (score).

***Calculation / assessment:***
This criterion is assessed according to Level(s) indicator 2.3: Design for adaptability and renovation [56]. Level(s) provides two specific sets of criteria, one for residential, and one for office buildings. This

will be adjusted according to the function and design stage of the case studies. Adaptability for office buildings considers the ease of changes to the internal space distribution, the building services, and its façade and structure. For residential buildings, this adds changes to the use of units or floors and changes in access requirements, but disregards façade and structure.

Level 1 questionnaires [56] will be used in the description of process with respect to adaptability and ambition.

## 7.3. SUFFICIENCY AND ADEQUACY OF SPACE

***Motivation:***

Currently, efficiency efforts are in many parts of Europe counteracted by increasing demand for indoor spaces. Introducing the concept of sufficiency of areas is looking to alleviate this development, avoiding waste of space which is often characterized by underused or unused buildings. Reduced new building construction has been identified as one of the major win-win potentials in Europe to save energy, emissions, and resources while maintaining the quality of life [57]. Moreover, the amount of space has been identified to be one of the main influential factors for occupant satisfaction in offices [58]. This indicates that a careful balance must be struck between quantity of available space and limiting resources by space use efficiency.

***Description:***

This is a descriptive KPI, depending on the building function. In Europe, minimum area requirements for specific uses are specified by local codes. If and how buildings achieve good functionality while not exceeding such area requirements is highly influenced by floor layout, but also by smart use concepts, ensuring spaces do not remain empty for prolonged periods of time. This is assessed both in the design process as well as ex-post in user surveys.

***Unit:***

Descriptive assessment: area [$m^2$] per person, disaggregated by function.
Qualitative assessment: Score.

***Calculation/assessment:***

The area per person is assessed in the programming and design phases and compared to local codes, if applicable. User satisfaction should include:

- How satisfied are users with the quantity of space provided for various functions?
- How satisfied are users with the qualities (privacy, openness, ceiling height, connectivity...) of space?
- How often are spaces used (hours per week/day)?

The criterion is a part of a POE survey.

## 7.4. SOLAR AND DAYLIGHT ACCESS

***Motivation:***

Access to daylight has a proven positive effect on the health of building users. In this criterion, the amount and quality of daylight access is assessed in the design phase by calculations and measurements (for renovation projects) and by measurements in the occupancy phase.

***Description:***
Solar and daylight access is a core criterion to achieve high spatial qualities. Daylight access also influences flexibility and adaptability of buildings, as well as user comfort and energy demand (for artificial lighting). Target values depend on building location and building use. The daylight factor is the ratio between illuminance level of daylight in an unobstructed field and that of the illuminance at a defined point inside a room [59].

***Unit:***
Number of aspects addressed in the design process: Score.
Daylight factor: %.

***Calculation/assessment:***
Solar and daylight access are assessed at two stages in the design and execution process of the demo projects:

- Design intentions: description of process and ambition: *Is solar and daylight access part of the design considerations beyond code compliance?* This can be done by daylight studies, insolation studies of outdoor spaces, considering construction form surrounding buildings, etc. This is assessed based on interviews with design teams and clients.
- For renovation projects, pre- and post-renovation daylight availability should be assessed.
- New construction: Daylight factor and daylight autonomy should be assessed.

Level(s) indicator 4.3: Lighting and Visual Comfort (L1.4 Checklist of lighting and visual comfort design concepts) is referred to for a checklist in the design process [59]. Quantitative assessment of the daylight factor and daylight autonomy.

## 7.5. ACCESSIBILITY

***Motivation:***
ISO 21542:2021 "Building construction — Accessibility and usability of the built environment" highlights the importance of access for everyone with different abilities (visual, movement, mental...) and diversity in age and structure. It states that public areas need to be accessible by code, percent of semi-public areas which are accessible, and the accessibility of bathrooms.

***Description:***
Universal design.

***Unit:***
% of interior space accessible.
% of exterior space accessible.

***Calculation/assessment:***
Compliance with local codes.

## 7.6. INDOOR AIR QUALITY

***Motivation:***
CPCCs focus on people, i.e. their specific needs and well-being, and therefore aim for excellent IEQ. In this context, it is crucial to address the $CO_2$ level, which is a recognised indicator of poor indoor ventilation. Lack of ventilation significantly affects people's health by causing various building-related health symptoms such as respiratory diseases, allergies, headaches, and others [60].

The European Standard EN16798-1-2019 [61] defines four categories of IEQ, related to the level of expectations of the building occupants (**Table 5**). Pre-and post-occupancy evaluations will be carried out in all ARV renovation demos to ensure at least 30% improvement in IEQ.

***Table 5.*** *Categories of IEQ* [61].

| Category | Level of expectations |
|---|---|
| $IEQ_{I}$ | High |
| $IEQ_{II}$ | Medium |
| $IEQ_{III}$ | Moderate |
| $IEQ_{IV}$ | Low |

***Description:***
Indoor Air Quality (IAQ) KPI indicates the percentage of time that air quality is in each category during occupied hours. The Carbon Dioxide ($CO_2$) concentration range is used to assess IAQ according to the four quality categories listed in **Table 6**. In addition, IAQ assessment can be complemented with surveys.

***Table 6.*** *$CO_2$ concentrations per category based on a standard $CO_2$ emission of 20 l/h per person [61].*

| Category | Carbon Dioxide concentrations above outdoors during full occupancy (outdoor level assumed to be equal to 400 ppm) |
|---|---|
| $IEQ_{I}$ | ≤ 550 ppm |
| $IEQ_{II}$ | >550 and ≤ 800 ppm |
| $IEQ_{III}$ | >800 ppm and ≤1350 ppm |
| $IEQ_{IV}$ | >1350 ppm |

***Unit:***
% , based on time in each category (ppm).

***Calculation:***
The calculation method refers to the percentage of time that the indicator for $CO_2$ concentration is in each category during the occupied hours. It can be visualized in the form similar to **Figure 13.**

| **Percentage of time (%)** | **5** | **15** | **60** | **20** |
|---|---|---|---|---|
| Air quality IEQ | IV | III | II | I |

***Figure 13.*** *Visualisation of the evaluation of the air quality in the four categories.*

In a further step, the time outside the comfort range should be calculated as the percentage of time the $CO_2$ concentrations are out of the established comfort ranges.

## 7.7. THERMAL COMFORT

***Motivation:***

The temperature range of the air is a recognised indicator of a thermal comfort. Extreme temperature fluctuations can lead to reduced air quality for the building's occupants and significantly affect their productivity and sleep quality, reducing overall well-being.

***Description:***

Thermal comfort KPI indicates the percentage of time that air temperature is within certain categories during occupied hours. Air temperature ranges are used to assess thermal comfort for buildings according to the four quality categories listed in **Table 7**. Alternatively, thermal comfort can be assessed using the predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD) indexes. Recommended PMV and PPD ranges are defined in EN16798-1-2019 [61].

***Table 7.*** *Operative temperature ranges for summer and winter in buildings with and without mechanical cooling systems [61].*

| **Category** | **Operative temperature (°C)** | | | |
|---|---|---|---|---|
| | Buildings with mechanical cooling systems | | Buildings without mechanical cooling systems | |
| | Minimum for heating season (Winter) ~ 1,0 clo | Maximum for cooling season (Summer) ~ 0.5 clo | Minimum for heating season (Winter) ~ 1,0 clo | Maximum for cooling season (Summer) ~ 0.5 clo |
| IEQ I | 21 | 25.5 | 21 | upper limit: $\Theta_o = 0{,}33\ \Theta_{rm} + 18{,}8 + 2$<br>lower limit: $\Theta_o = 0{,}33\ \Theta_{rm} + 18{,}8 - 3$ |
| IEQ II | 20 | 26 | 20 | upper limit: $\Theta_o = 0{,}33\ \Theta_{rm} + 18{,}8 + 3$<br>lower limit: $\Theta_o = 0{,}33\ \Theta_{rm} + 18{,}8 - 4$ |
| IEQ III | 18 | 27 | 18 | upper limit: $\Theta_o = 0{,}33\ \Theta_{rm} + 18{,}8 + 4$<br>lower limit: $\Theta_o = 0{,}33\ \Theta_{rm} + 18{,}8 - 5$ |
| IEQ IV | 16 | 28 | 16 | |

***Unit:***

%, based on time in each category (°C, PMV or PPD).

***Calculation:***

The calculation method refers to the percentage of time that the indicator for air temperature is in each category during the occupied hours. It can be visualized in a form similar to **Figure 14.**

| Percentage of time (%) | 5 | 15 | 60 | 20 |
|---|---|---|---|---|
| Thermal Comfort IEQ | IV | III | II | I |

***Figure 14.*** *Visualisation of the evaluation of the thermal comfort in the four categories.*

In a further step, the time outside the comfort range should be calculated as the percentage of time the temperatures are out of the established comfort ranges.

## 7.8. OVERHEATING RISK

***Motivation:***
There is growing evidence that overheating occurs in warm weather in buildings without air conditioning [62]. Overheating affects the health and well-being of occupants, especially when sleep is compromised. In extreme cases, heat stress can lead to premature mortality, especially among the more vulnerable members of society. For the assessment framework, two risk parameters for accessing overheating risk in the building are proposed: Humidex (a main indicator) and Heat index (an alternative option).

***Description:***
The Humidex describes how hot the weather feels to the average person, by combining the effect of temperature and humidity, derived from the dew point. The Heat Index, also known as apparent temperature, represents the human-perceived equivalent temperature in shaded areas when relative humidity (RH) is combined with the air temperature. This KPI indicates the percentage of time that Humidex is in each discomfort band or Heat Index is in each category during occupied hours.

***Unit:***
Humidex: % of time in each category
Heat Index: % of time in each category, based on °C.

***Calculation:***
Humidex can be calculated as follows [63]:

$$\boldsymbol{H = T_{air} + 0.5555 \cdot (V - 10)}$$

Where:

$\boldsymbol{H}$ – Humidex [-];
$\boldsymbol{T_{air}}$ - air temperature [°C];
$\boldsymbol{V}$ - vapour pressure [hPa].

$$\boldsymbol{V = 6.11 \cdot e^{5417.7530 \cdot \left[\left(\frac{1}{273.16}\right) - \left(\frac{1}{T_{dew}}\right)\right]}}$$

$\boldsymbol{V}$ – vapour pressure [hPa];
$\boldsymbol{T_{dew}}$ – dew point temperature [K].

**Table 8** defines Humidex discomfort bands [64]. The share of time spent in each Humidex discomfort band can be visualized in the form similar to **Figure 15.**

*Table 8. Humidex discomfort bands.*

| Discomfort band | Range |
|---|---|
| Little or no Discomfort | H<30 |
| Noticeable Discomfort | 30<H<35 |
| Evident Discomfort | 35<H<40 |
| Intense Discomfort | 40<H<45 |
| Dangerous Discomfort | 45<H<55 |
| Heat Stroke Probable | H>55 |

| Percentage of estimated occupied time (%) | 10 | 30 | 25 | 15 | 15 | 5 |
|---|---|---|---|---|---|---|
| Humidex discomfort band | | | | | | |

***Figure 15.*** *Share of time spent in each Humidex discomfort band.*

Where each colour represents Humidex discomfort band:

Little or no Discomfort

Noticeable Discomfort

Evident Discomfort

Intense Discomfort

Dangerous Discomfort

Heat Stroke Probable

The equation for obtaining the Heat Index is described in [65] and **Table 9** describes the Heat Index categories.

***Table 9.*** *Correlation between Heat Index category and possible health effects [66].*

| Heat Index Category | Effects description | Heat Index [°C] |
|---|---|---|
| Caution | Fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps. | 26-32 |
| Extreme | Heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke. | 32-41 |
| Danger | Heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity. | 41-54 |
| Extreme danger | Heat stroke is imminent. | >54 |

The share of time spent in each Heat Index category can be visualized in the form similar to **Figure 15.**

## 7.9. ACOUSTIC COMFORT

***Motivation:***
Noise levels have been identified as one of the key factors for workspace satisfaction [67]. Moreover, distraction from outdoor noise does not only affect well-being and productivity of building occupants, but it also limits the possibility of natural ventilation [68].

***Description:***
Requirements of noise protection and sound dampening depend on the function of a space. Of indoor spaces, habitable rooms, common access areas, offices and meeting spaces should be given special attention [69].

***Unit:***
Score (number of aspects addressed in the design process).
Sound pressure level (dBA): execution phase.

***Calculation / assessment:***
For the assessment of noise protection, Level(s) indicator 4.4 (Acoustics and protection against noise) is referred to [69]. The checklists for Level 1 will be used as a basis for the interviews.

## 7.10. OUTDOOR COMFORT

***Motivation:***
One of the essential goals of architecture is a shelter from uncomfortable weather conditions. Access to sun or shade (depending on the climate), and protection from wind and noise are important for human comfort.

***Description:***
This criterion will be qualitatively assessed on a design process level and in ex-ante ex-post interviews with users.

***Unit:***
Design phase: dimensionless (score).

***Calculation/assessment:***
Design process and ambition is assessed in interviews with the design team [69]. Additionally, interviews with users for the perceived qualities, both ex-ante and ex-post will be conducted.

# 8. CIRCULARITY KPIS

## 8.1. MATERIALS FROM CYCLED SOURCES

***Motivation:***
Materials from cycled sources is one of the key indicators to assess the degree of circularity in building construction and retrofitting. On the one hand, materials from cycled sources help to avoid resource depletion, reduce energy consumption, and the resulting GHG emissions that would be required to manufacture products from raw materials. On the other hand, the use of materials from cycled sources ensures that these materials are kept in the technical loop of the building cycle, which also avoids waste-related impacts.

***Description:***
Materials from cycled sources is a ratio between the sum of the quantity of the materials used in the construction or retrofitting work that come from cycled sources and the sum of the quantity of all materials used in the construction or retrofitting work. Reused, recycled, and remanufactured materials are considered materials from cycled sources.

***Unit:***
%.

***Calculation*:**

$$\boldsymbol{m}_{\boldsymbol{cycled\ sources}} = \frac{\sum_i \boldsymbol{m}_{\boldsymbol{reused\ i}} + \sum_i \boldsymbol{m}_{\boldsymbol{recycled\ i}} + \sum_i \boldsymbol{m}_{\boldsymbol{remanufactured\ i}}}{\sum_i \boldsymbol{m}_{\boldsymbol{reused\ i}} + \sum_i \boldsymbol{m}_{\boldsymbol{recycled\ i}} + \sum_i \boldsymbol{m}_{\boldsymbol{remanufactured\ i}} + \sum_i \boldsymbol{m}_{\boldsymbol{non-cycled\ i}}}$$

Where:

$\boldsymbol{m}_{\boldsymbol{cycled\ sources}}$- ratio of materials from cycled sources [%];

$\boldsymbol{m}_{\boldsymbol{reused\ i}}$ - quantity of the reused material *i* used in the construction or retrofitting works [kg];

$\boldsymbol{m}_{\boldsymbol{recycled\ i}}$ - quantity of the recycled material *i* used in the construction or retrofitting works [kg];

$\boldsymbol{m}_{\boldsymbol{remanufactured\ i}}$ - quantity of the remanufactured material *i* used in the construction or retrofitting works [kg];

$\boldsymbol{m}_{\boldsymbol{non-cycled\ i}}$ - quantity of the material from non-cycled sources used in the construction or retrofitting works [kg].

## 8.2. REUSABILITY

***Motivation:***
Reusability means the share of materials applied to a building that, at the end of its service life, can be directly reused without further reprocessing. The EU Circular economy action plan [70] points out material recovery as a key action to promote circularity in the construction sector. Reusable materials can be upcycled without requiring industrial processing. A circular approach to construction must prioritize re-use loops. Resorting to existing materials leads to a reduction of the need for virgin material extraction and processing, and thus limits the impact on natural resource overexploitation and climate change, two of the key drivers of biodiversity loss.

***Description:***
Reusability is a ratio between the sum of the weight of the reusable materials used in the construction or retrofitting works and the sum of the weight of all materials used in the construction or retrofitting works.

***Unit:***
%.

***Calculation*:**

$$\boldsymbol{Reusability} = \frac{\sum_i \boldsymbol{m}_{\boldsymbol{reused\ i}}}{\sum_i \boldsymbol{m}_i} \cdot \mathbf{100}$$

Where:

$\boldsymbol{Reusability}$ - ratio of materials potentially reusable after the service life of the building [%];

$\boldsymbol{m}_{\boldsymbol{reused\ i}}$ - quantity of the material *i* that can be reusable, applied in the construction or retrofitting works [kg];

$\boldsymbol{m}_i$ – quantity of any material *i* applied in the construction or retrofitting works [kg].

As an alternative methodology, a calculation method developed for a similar indicator in Level(s) (Indicator 2.4: Design for deconstruction) can be used [71]. This calculation method applies circularity coefficients based on the best practical outcome of the material (**Table 10**). This indicator results in a score from 0 to 100 for the corresponding building elements and components. A score of 100 represents a complete reuse of elements and components. In addition, this score can be weighted by mass or value of the respective components and elements.

***Table 10.*** *Correlation between a circularity practice and corresponding circularity coefficients.*

| Circularity (best practical outcome) | Circularity coefficient |
|---|---|
| Reuse (direct) | 1.00 |
| Reuse (preparing for) | 0.90 |
| Recycling (pure stream) | 0.75 |
| Recycling (mixed stream) | 0.50 |
| Recovery (material) | 0.25 |
| Recovery (energy) | 0.15 |
| Landfill (inert or non-hazardous) | 0.01 |
| Hazardous waste | 0.00 |

# 9. ECONOMIC KPIS

## 9.1. GLOBAL COST

***Motivation:***
Global cost helps to select the most cost-effective design alternative in a life cycle perspective, taking into account construction, operation, maintenance, replacement and end-of-life value, and can be used in different stages:

- **Design phase:** rapid selection of alternatives with the lowest/optimal global costs.
- **Detailed post-implementation assessment:** review of the performance targets from the design phase and comparison with the baseline building defined by legal requirements.
- **Evaluation of retrofit measures:** comparison of global costs before and after the intervention.

The global cost methodology proposed in this indicator is based on a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements established in the Commission Delegated Regulation (EU) No 244/2012 [72] and other sources on cost-optimality for energy refurbishment [73].

***Description:***
The global costs for buildings and building elements is a sum of the different types of costs and applying to these the discount rate by means of a discount factor so as to express them in terms of value in the starting year (Net Present Value (NPV)). When applied to the building's life cycle, global cost is associated with the building design and construction costs (Stage A: product stage and construction process stage), operation and maintenance of the building (Stage B: Use stage), and the cost of disposing of the building at the end of its life cycle (Stage C: End of life).

Initial investment costs are all costs incurred up to the point when the building or the building element is delivered to the customer, ready to use. These costs include design, purchase of building elements, connection to suppliers, installation, and commissioning processes.

Annual cost are the sum of running costs and periodic costs or replacement costs paid in a certain year. Running costs are the sum of annual maintenance costs, operational costs, and energy costs. Replacement cost is the substitute investment for a specific building element, according to its estimated lifecycle during the calculation period.

Disposal costs are the costs for deconstruction at the end of-life of a building or building element and include deconstruction and removal of building elements that have not yet come to the end of their lifetime, as well as related transport and recycling.

The structure of the global costs calculation is presented in **Figure 16.**

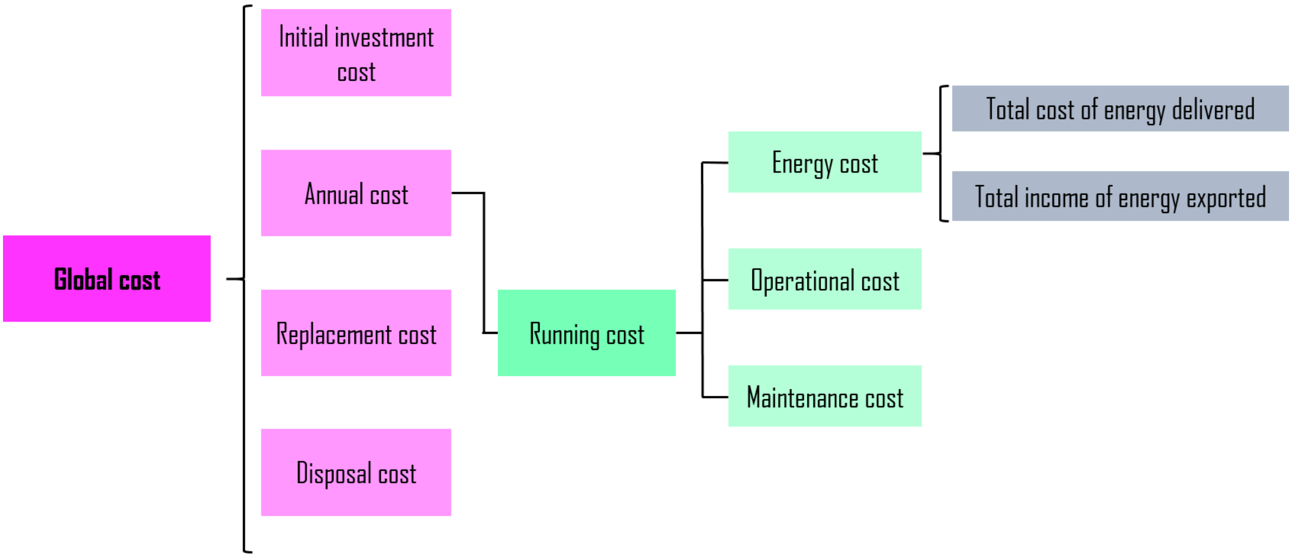



***Figure 16****. Global cost calculation scheme. Adopted from* [74].

***Unit:***
€/m$^2$.

***Calculation*:**
Global costs can be calculated as follows:

$$C_g = C_I + \sum_j \left[ \sum_{i=1}^{t} (C_{a,i}(j) \cdot R_d(i)) + C_{repl}(j) - V_{f,t}(j) \right] + C_D$$

Where:

$C_g$ – global cost (referred to starting year $t_0$) over the calculation period (t) [€/m$^2$];
$C_I$ - initial investment costs for measure or set of measures *j* [€/m$^2$];
$C_{a,i}(j)$ – annual running cost during year *i* for measure or set of measures *j* [€/m$^2$ y];
$V_{f,t}(j)$ – residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year $t_0$) [€/m$^2$];
$C_{repl}(j)$ – replacement cost [€/m$^2$];
$R_d(i)$ - discount factor for year *i* based on discount rate *r* to be calculated [-];
$C_D$ – disposal cost [€/m$^2$] (if applicable).

$$R_d(i) = \frac{1}{(1+r)^i}$$

Where:

$R_d(i)$ - discount factor for year *i* [-];
$i$ – number of years from the starting period [y];
$r$ – real discount rate [-].

$$C_a = C_e + C_{op} + C_m$$

Where:

$C_{a,i}$ – annual running cost [€/m$^2$ y];
$C_e(i)$ – energy cost [€/m$^2$ y];
$C_{op}(i)$ – operational cost [€/m$^2$ y];
$C_m(i)$ – maintenance cost [€/m$^2$ y].

## 9.2. ENERGY RENOVATION RATE

***Motivation:***

Increasing the energy renovation rate of buildings has been highlighted as one of the most important measures to increase energy efficiency in the building sector [2]. A long-term target for energy renovation of buildings in EU is at least 3% of the total useful floor area, however, the current figures are far from the EU targets: the weighted annual energy renovation rate is around 1% [8]. Therefore, the assessment of the energy renovation rate is important to promote the energy renovation of the building stock.

Renovated buildings that achieved an energy renovation target are defined in terms of the improvement in delivered energy after renovation (post works) compared to the national Nearly Zero Energy Building (NZEB) renovation methodology or other national/local considerations (e.g. eligible for energy renovation grant). Some Member States [75] have chosen to link the NZEB level to one of the best energy performance classes (e.g. building class A++), as specified in an energy performance certificate (EPC).

***Description:***

The energy renovation rate is an indicator that shows the percentage of useful floor area of renovated buildings that achieved the NZEB or another national/local target.

***Unit:***

%.

***Calculation:***

$$\boldsymbol{ERR} = \frac{\boldsymbol{S_{ren}}}{\boldsymbol{S_{total}}} \cdot \mathbf{100}$$

Where:

$\boldsymbol{ERR}$ **–** energy renovation rate [%];

$\boldsymbol{S_{ren}}$ **–** useful floor area of renovated buildings that achieved the NZEB or another national or local target [$m^2$].

$\boldsymbol{S_{total}}$ **–** total useful area of a CPCC [$m^2$].

## 9.3. NUMBER OF JOBS CREATED

***Motivation:***

The deployment of CPCCs promotes job creation and industry competitiveness through construction and retrofitting interventions. As reported in [76], for every €1 million invested in energy retrofitting of buildings, an average of 18 jobs are created in the EU. Therefore, this KPI aims to show a positive impact of CPCC deployment on the labour market by stimulation of economic activities across the EU.

***Description:***

In this framework, the number of jobs created in energy renovation (or RES implementation) is calculated as a share of full-time equivalent (FTE) days in a total number of productive days in a reporting period or by applying multipliers to investment in energy renovation (based on FTE jobs per mln € euro spent) [77].

***Unit:***

FTE.

***Calculation:***

$$FTE = \frac{\sum FTE_{days}}{N_{productive\ days}}$$

Where:

$FTE$ - direct full-time equivalent jobs created in a reporting period [FTE];
$FTE_{days}$– number of FTE days in a reporting period [day];
$N_{productive\ days}$ – total number of productive days in a reporting period [day].

$$FTE = C_I \cdot 0.33 \cdot x$$

Where:

$FTE$ - direct full-time equivalent jobs created in a reporting period [FTE];
$C_I$ – investment in energy renovation/RES implementation in the reporting period [mln €];
$x$ – multiplier for direct jobs in energy efficiency renovation [FTE/mln €].

When local studies detailing the impact of energy renovation (or RES implementation) on jobs creation are not available, the following default values should be used for a multiplier [77]:

- Lower bound: 12.8 FTE/mln €.
- Median bound: 17.12 FTE/mln €.
- Upper bound: 26.3 FTE/mln €.

## 9.4. CONSTRUCTION TIME REDUCTION

***Motivation:***

The indicator aims at demonstrating how innovative construction methodologies (e.g., prefabrication of building components and dry assembly) can save up to the 30% of the time compared to a traditional construction work method. The construction time reduction is required to speed up the market uptake.

Prefabrication and dry assembly of building components can significantly reduce the total time spent on construction activities due to more effective on-site implementation. However, it may require more complex and detailed design process.

In order to meet the aims of the project, the construction time of the ARV interventions will be compared to local practices, defined in statistical data about the average construction times published by independent local authorities for public buildings. If the statistical data is not available, the construction time will be compared to the time of a reference project. Other strategies aim to act in a large scale when retrofitting buildings in the area, aiming to reduce time both in the design and the realization stages.

***Description:***

This indicator measures construction time reduction compare to a local practice or a reference project.

***Unit:***

% (based on rate of time in days or hours).

***Calculation:***

$$\%\boldsymbol{Time} = (\boldsymbol{Time} - \boldsymbol{Time_{ref}})/\boldsymbol{Time_{ref}}$$

Where:

$\%\boldsymbol{Time}$ – reduction of the construction time [%];

$\boldsymbol{Time}$ - construction time [day or h];

$\boldsymbol{Time_{ref}}$ - average construction time for a building of comparable size/cost [day or h].

# 10. APPLICATION OF ASSESSMENT FRAMEWORK TO ARV DEMO PROJECTS

The proposed assessment framework attempts to cover a wide range of aspects related to the effective design and successful implementation of CPCC and to provide a comprehensive methodology for the ongoing international activities to harmonise the characterisation of climate neutral neighbourhoods. However, due to the complexity of the assessment framework, not all KPIs can therefore be applied to the demo projects presented in ARV. A number of KPIs specified in the ARV grant agreement are mandatory for the demo projects and are highlighted in **Figure 17.**


***Figure 17.*** *List of mandatory KPIs for ARV demo projects.*

Beyond the mandatory ones, each demo project can select a set of indicators, which are considered relevant to evaluate the impact of demo actions. In **Appendix D** – Preliminary Plans for the Application of the Assessment Framework in the Demonstration Projects are identified. The main objective of this appendix is to show how the proposed assessment framework can be linked to the ARV demo cases by identifying which demo's actions are impacting on the proposed KPIs.

# CONCLUSIONS AND FUTURE UPDATES

This document is the first version of the assessment framework for the ARV project, which will be complemented by monitoring guidelines. This innovative framework has been developed with the aim to be applied to assess community and urban interventions leading to climate neutral societies. Therefore, it will be further evaluated by observing how effectively the proposed KPIs and suggested calculation methodologies are implemented and used by the demo projects. Based on the demo sites, it will be possible to analyse the energy and environmental patterns as well as the behaviour of the residents. This will create a deeper understanding of the local culture, climate and markets and lead to practical recommendations for the refinement of the assessment framework. At the same time, it will help identify potential barriers and propose solutions for the effective implementation of this framework during the project period and beyond. It will ensure that all measures are well embedded in the spatial, economic, technical, regulatory, environmental and social context of the project.

Dissemination of the proposed framework will be done in interaction with on-going international activities around the concept of Positive Energy Districts, Zero Emissions Neighbourhoods and Climate Neutral Cities and other EU projects. Close and mutual interaction will be positive to increase the impact and the harmonization of the assessment methods.

Based on feedback received in the first year of the project, this framework will be assessed annually and adjusted, as necessary. This process will mainly take place in two steps. Firstly, the evaluation of the framework will be done in annual workshops and through follow-up questionnaires or interviews in cooperation with monitoring (WP 8) and demo leaders, who are developing guidelines for monitoring and evaluation and performing the impact assessment in their sites, respectively. Feedback from monitoring and evaluation will help to provide a comprehensive picture of the complexity of the proposed framework. For the social and architectural KPIs, further developments and feedback are expected from WP 3: Community Engagement, Environment, and Well-Being. The KPIs related to construction will be tested as part of the work of WP 5: Resource Efficient (Pre-) Manufacturing and Construction Processes. Additional feedback can be expected from other WPs working on the proposed KPI categories. The framework will be revised based on the feedback given and lessons learned. This continuous process will lead to a proven, validated, and consistent framework at the end of the project which will be reported in an updated version of the current document.

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# APPENDIX A – GLOSSARY OF TERMS

***Table A.1.*** *Abbreviations used in the report.*

| Abbreviation | Description |
|---|---|
| BAPV | Building Applied Photovoltaics |
| BEMS | Building Energy Monitoring System |
| BIPV | Building-Integrated Photovoltaics |
| CEC | Citizen Energy Community |
| $CO_2$ | Carbon Dioxide |
| CPCC | Climate Positive Circular Communities |
| DHW | Domestic Hot Water |
| DQI | Design Quality Indicator |
| DSO | Distribution System Operators |
| DUT | Driving Urban Transition |
| EIC | Expected Impact from the Call |
| EPBD | Energy Performance of Buildings Directive |
| EPC | Energy Performance Certificate |
| EPOV | European Energy Poverty Observatory |
| EV | Electric Vehicle |
| FI | Flexibility Index |
| FTE | Full Time Equivalent |
| GHG | Greenhouse Gas |
| H2020 | Horizon 2020 |
| HVAC | Heating, Ventilation, and Air Conditioning |
| IAQ | Indoor Air Quality |
| ICT | Information and Communication Technologies |
| IEQ | Indoor Environmental Quality |
| KPIs | Key Performance Indicators |
| LCA | Life Cycle Assessment |
| LCC | Life Cycle Cost |
| LCE | Life Cycle Energy |

| | |
|---|---|
| LED | Light-Emitting Diode |
| LowEx | Low Exergy |
| NPV | Net Present Value |
| NZC | Net Zero Cities |
| NZEB | Nearly Zero-Energy Building |
| PED | Positive Energy District |
| PMV | Predicted Mean Vote |
| POE | Post Occupancy Evaluation |
| PPD | Predicted Percentage Dissatisfied |
| PV | Photovoltaic |
| PV-T | Photovoltaic-Thermal |
| RER | Renewable Energy Ratio |
| RES | Renewable Energy Systems |
| RH | Relative Humidity |
| SDGs | Sustainable Development Goals |
| SPEN | Sustainable Plus Energy Neighbourhood |
| TSP | Total Suspended Particles |
| V2G | Vehicle-to-Grid |
| V2H | Vehicle-to-Home |
| WP | Work Package |
| ZEN | Zero Emission Neighbourhood |

## APPENDIX B – GHG EMISSIONS IN MOBILITY

***Table B.1.*** *Reference data for the determination of the GHG emissions in the use stage (mobility).*

| Item | Transportation data | GWP reference data | Source |
|---|---|---|---|
| External district | 22 km/person/day | - | 10.1061/(ASCE)0733-9488(2006)132:1(10) |
| Inner district | 6 km/person/day | - | 10.1061/(ASCE)0733-9488(2006)132:1(10) |
| Private car/scooter | 70% ($\alpha_i$) | 0.23050 kg $CO_2$/ person*km | ISTAT, ecoinvent |
| Bus | 5% ($\alpha_i$) | 0.10036 kg $CO_2$/person*km | ISTAT, ecoinvent |
| Metro/railways | 10% ($\alpha_i$) | 0.045533 kg $CO_2$/person*km | ISTAT, ecoinvent |
| Foot/bike | 15% ($a_{vt}$) | 0 g $CO_2$/km | ISTAT |

***Table B.2.*** *Reference data for the determination of the GHG emissions in the product stage (mobility).*

| Item | Reference data | Source |
|---|---|---|
| n. passengers per car | 1.45 passengers/car | EEA |
| n. cars per inhabitant | 0.670 cars/person (IT)<br>0.521 cars/person (SP)<br>0.503 cars/person (ND)<br>0.466 cars/person (DN)<br>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

# APPENDIX C – EMISSION FACTORS FOR AIR POLLUTANTS PER ENERGY CARRIER

***Table C.1.*** *Emission factors for air pollutants per energy carrier (technology: conventional boilers <50 kW). Adopted from [31].*

| | **PM 2.5** | **NOx** | **$SO_x$** |
|---|---|---|---|
| | **g PM2.5/kWh** | **g NOx/kWh** | **g $SO_x$/kWh** |
| Solid fuels | 7.24E-01 | 5.69E-01 | 3.24E+00 |
| Natural Gas | 7.20E-04 | 1.51E-01 | 1.08E-03 |
| Liquid fuels | 5.40E-03 | 2.48E-01 | 2.84E-01 |
| Biomass | 1.69E+00 | 2.88E-01 | 3.96E-02 |

***Table C.2.*** *Reference emission factors for air pollutants low-voltage electricity from in the ARV demo locations. Adopted from* [78].

| | **PM 2.5** | **NOx** | **$SO_2$** |
|---|---|---|---|
| | **g PM2.5/kWh** | **g NOx/kWh** | **g $SO_2$/kWh** |
| Electricity (grid – low V - Norway) | 5.18E-02 | 5.26E-02 | 1.29E-01 |
| Electricity (grid – low V - Denmark) | 2.92E-01 | 5.72E-01 | 8.89E-01 |
| Electricity (grid – low V - Netherlands) | 3.31E-01 | 8.42E-01 | 9.76E-01 |
| Electricity (grid – low V - Italy) | 5.18E-01 | 7.63E-01 | 1.57E+00 |
| Electricity (grid – low V - Spain) | 7.92E-01 | 1.10E+00 | 2.06E+00 |
| Electricity (grid – low V – Czech Republic) | 9.43E-01 | 1.59E+00 | 2.87E+00 |

# APPENDIX D – PRELIMINARY PLANS FOR THE APPLICATION OF THE ASSESSMENT FRAMEWORK IN THE DEMONSTRATION PROJECTS

In this appendix, preliminary plans for the application of the assessment framework in the ARV demonstration projects are described. The main objective is to show how the proposed assessment framework can be linked to the ARV demo cases by identifying which demo's actions are impacting the proposed KPIs.

## DEMONSTRATION PROJECT SPAIN

The Spanish demo case is the *Llevant Innovation District* in Palma de Mallorca. It encompasses a mixed used development area including residential, tertiary, and educational buildings, with both new construction and renovation activities. The set of actions that will be undertaken by the ARV project will encompass resource efficient renovation processes at large scale and district energy analysis and operation, highlighting social, educational, and digital aspects to enhance citizens involvement. Key actions in the district can be summarized as follows:

- **Large Scale retrofitting action** in La Soledat Sud and Nou Llevant of 250 private dwellings (26 800 m$^2$) by means of a novel Public Private Partnership mechanism. Total built area is 191 000 m$^2$.
- New Positive Energy **Social Housing Building** promoted by IBAVI: 36 apartments; 1750 m$^2$.
- New high efficiency Residential Multifamily Buildings where **optimization of the HPs operation** will be demonstrated. Demo project involves 2 buildings; 114 + 88 apartments; 14 400 m$^2$.
- Proposal of Energy Renovation of a flagship heritage protected building from the 70's modern movement.
- The creation of a **Citizen Energy Community (CEC),** a private crowd-funded, innovative mechanism to facilitate the deployment of renewable energy using available public and private roofs in the area.
- The creation of a PalmaLab, as a Living Lab, exhibition space for citizen engagement towards the energy transition in urban areas, setting training actions and awareness raising campaigns with special attention to engagement with the younger generations.

**Table D.1** summarises demo's actions impacting proposed KPIs of the assessment framework.

***Table D.1.*** *Preliminary plan for application of assessment framework to Llevant Innovation District.*

| Cate-gory | KPI | Rele-vance to demo | Demo actions impacting the KPIs | Type of buildings/Comments |
|---|---|---|---|---|
| Energy | Non-renewable Primary Life Cycle Energy in the Built Environment | 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 | x | Deployment of renewable energy using available private and public roofs in the area | New and renovated residential and non-residential buildings |
| | Grid Delivered Factor | x | Implementation of CEC | Mainly public buildings |

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|---|---|---|---|---|
| | Net Energy/Net Power | x | All actions | |
| | Flexibility Index | x | Optimization of the operation of heat pumps for DHW | New residential buildings |
| **Environment** | Life-cycle GHG Emissions in CPCC | x | All actions | Emissions will be accessed from buildings and water consumption |
| | Air Pollution from the Energy Consumption | x | Large scale retrofitting actions | Renovated residential and non-residential buildings |
| | Dust during Retrofitting | | | |
| | Noise during Retrofitting | | | |
| **Social** | Democratic Process | x | PalmaLab as a Living Lab | |
| | Social Inclusion | x | PalmaLab as a Living Lab | |
| | Social Engagement | x | PalmaLab as a Living Lab | |
| | Demographic Composition | | | |
| | Social Interaction and Cohesion | x | PalmaLab as a Living Lab | |
| | Safety and Security | | | |
| | Energy & Environmental Consciousness | x | PalmaLab as a Living Lab | |
| | Affordability of Energy | x | Large scale renovation | |
| | Affordability of Housing | | | |
| | Access to Sustainable Mobility | | | |
| | Access to Services and Amenities | | | |
| **Architecture** | Aesthetics and Visual Qualities | x | Renovation of a flagship heritage protected office building. Large Scale Renovation | |
| | Flexibility and Adaptability | | | |
| | Sufficiency and Adequacy of Space | | | |
| | Solar and Daylight Access | | | |
| | Accessibility | | | |
| | Air Quality | x | Optimal use of comfort-driven ventilation system in social housing | New social housing |
| | Thermal Comfort | x | Large scale renovation | New buildings |
| | Overheating Risk | x | Large scale renovation | |

| | | | | |
|---|---|---|---|---|
| | Acoustic Comfort | | | |
| | Outdoor Comfort | | | |
| Circularity | Materials from Cycled Sources | x | Use of innovative local materials | New residential buildings |
| | Reusability | | | |
| Economics | Global Cost | x | Off-site prefabrication and integrated design since the beginning of the project | |
| | Energy Renovation Rate | x | Large scale renovation | |
| | Number of Jobs Created | x | Large scale renovation | |
| | Construction Time Reduction | | | |

## DEMONSTRATION PROJECT ITALY

The Italian demo case is called *Piedicastello Destra Adige* and is located in the Northern Italian city of Trento. The demo case consists of four areas:

- **Area 1,** the former Italcementi industrial site, will host an entirely new mixed-use district of Trento, containing residential and tertiary buildings. The new self-sufficient wooden building, that was initially located in this area, has been moved to Area 4 because of administrative and time constraints.
- **Area 2** is an urbanization from the 50s–70s. Most of the buildings are close to or have already reached the end of their life cycle. The area was developed with a strong focus on social housing and is largely still owned by the Trentino Institute for Social Housing. These residences are to be renovated by using standardized prefabricated timber-based façade elements, implementing the so-called "One-Stop-Shop" which provides technical support at all stages of design and realization. Also the private owners of the area are invited to associate themselves in the redevelopment process, thus guaranteeing a high degree of replicability also for other areas of Trento.
- **Area 3** includes the former Piedicastello highway tunnels encompassing two 250-m holes in the Dos Trento mountain which are currently used as an art and exhibition gallery. This geostructure is intended to supply and store energy for one of the retrofitted building in Area 2.
- **Area 4** which is currently used as a parking lot, will be redeveloped with a service HUB for the district and city. It will connect commuter flows to commercial services and will host an energy storage system simultaneously promoting the market penetration of electric mobility.

**Table D.2** summarises demo's actions impacting proposed KPIs of the assessment framework.

***Table D.2.*** *Preliminary plan for application of assessment framework to Piedicastello Destra Adige.*

| Category | KPI | Relevance to demo | Demo actions impacting the KPIs | Type of buildings/Comment |
|---|---|---|---|---|
| Energy | Non-renewable Primary Life Cycle Energy in the Built Environment | 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 | |
| | Renewable Energy Ratio | x | Building envelopes with active (BAPV/BIPV) and passive elements. Using geothermal potential | New and renovated residential and non-residential buildings |
| | Grid Delivered Factor | | | |
| | Net Energy/Net Power | x | All actions | |
| | Flexibility Index | | | |
| **Environment** | Life-cycle GHG Emissions in CPCC | 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 | x | Local RES production | New and renovated residential and non-residential buildings |
| | Dust during Retrofitting | | | |
| | Noise during Retrofitting | | | |
| **Social** | Democratic Process | | | |
| | Social Inclusion | x | Involvement of local stakeholders in the co-design phase | |
| | Social Engagement | | | |
| | Demographic Composition | | | |
| | Social Interaction and Cohesion | | | |
| | Safety and Security | | | |
| | Energy & Environmental Consciousness | | | |
| | Affordability of Energy | | | |
| | Affordability of Housing | | | |
| | Access to Sustainable Mobility | x | Redesign of car park: Hub for mobility services | |
| | Access to Services and Amenities | | | |
| **Architecture** | Aesthetics and Visual Qualities | x | Architectural and aesthetic integration of BIPV/BAPV solutions | |
| | Flexibility and Adaptability | | | |
| | Sufficiency and Adequacy of Space | | | |
| | Solar and Daylight Access | | | |

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|---|---|---|---|---|
| | Accessibility | | | |
| | Air Quality | x | Natural and mechanical ventilation concepts | |
| | Thermal Comfort | | | |
| | Overheating Risk | | | |
| | Acoustic Comfort | | | |
| | Outdoor Comfort | | | |
| **Circularity** | Materials from Cycled Sources | x | Wood prefabrication, local supply chain. Circular economy-based design process | Renovated residential buildings and new non-residential buildings |
| | Reusability | | | |
| **Economics** | Global Cost | x | One-stop-shop platform business model connected to Italian national incentives for refurbishment | |
| | Energy Renovation Rate | | | |
| | Number of Jobs Created | | | |
| | Construction Time Reduction | x | Definition of standard modules (shape and dimension) with some flexibility (dimension, materials, layers) | |

## DEMONSTRATION PROJECT NETHERLANDS

The Dutch demo case consists of two clusters of residential buildings in *the Overvecht-Noord district* and *the Kanaleneiland-Zuid district* in the city of Utrecht. Both districts were built in the 1960s and 1970s to cope with quick rise in urban population and are generally of low-quality. They both possess the characteristics of lively multicultural districts, with high share of social housing, schools and shops. The residential areas are densely populated and home to a majority of low-income households. Both districts have a triple energy infrastructure: a district heating network, gas infrastructure for home-boilers and an electricity grid.

The demonstration actions that will be undertaken by the ARV project are the resource efficient, systematic retrofitting of:

- 6 apartment buildings to NZEB (with the ambition to improve the energy performance to Positive Energy Building through the tailor making of ARV innovations);
- 4 residential apartment buildings from the 1960s into Positive Energy Buildings embedded in a green neighbourhood.

In both districts, an interconnected smart grid will be demonstrated with (BI)PV, battery storage and vehicle-to-grid (V2G) storage assets in connection to the Distribution System Operators (DSO) grid will be created including the 8 mid-rise residential buildings and 2 high-rise Intervam-10 story residential buildings.

**Table D.3** summarises demo's actions impacting proposed KPIs of the assessment framework.

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

| Cate-gory | KPI | Rele-vance to demo | Demo actions impacting the KPIs | Type of buildings/Comment |
|---|---|---|---|---|
| Energy | Non-renewable Primary Life Cycle Energy in the Built Environment | 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 | x | Plug-and-play BIPV/BAPV solutions | Renovated residential buildings |
| | Grid Delivered Factor | | | |
| | Net Energy/Net Power | x | Deployment of solutions for forecasting (city weather, solar, load) | |
| | Flexibility Index | x | Smart building control optimisation | |
| Environment | Life-cycle GHG Emissions in CPCC | x | One-piece flow optimized construction workflow | Renovated residential buildings |
| | Air Pollution from the Energy Consumption | x | Plug-and-play BIPV/BAPV solutions | Renovated residential buildings |
| | Dust during Retrofitting | x | Prefabrication of modular building components | Renovated residential buildings |
| | Noise during Retrofitting | x | Prefabrication of modular building components | Renovated residential buildings |
| Social | Democratic Process | | | |
| | Social Inclusion | x | Social renovation with housing tenants | |
| | Social Engagement | x | Human Capital program Bouw=Wouw!. Physical Hub in district | |
| | Demographic Composition | | | |
| | Social Interaction and Cohesion | | | |
| | Safety and Security | | | |
| | Energy & Environmental Consciousness | x | Energy coaching of residents to reduce energy poverty | |
| | Affordability of Energy | | | |
| | Affordability of Housing | | | |
| | Access to Sustainable Mobility | | | |

| | | | | |
|---|---|---|---|---|
| | Access to Services and Amenities | | | |
| Architecture | Aesthetics and Visual Qualities | x | Architectural and aesthetic plug-and-play BIPV/BAPV solutions | |
| | Flexibility and Adaptability | | | |
| | Sufficiency and Adequacy of Space | | | |
| | Solar and Daylight Access | | | |
| | Accessibility | | | |
| | Air Quality | x | Renovation concepts with mechanical ventilation solutions | |
| | Thermal Comfort | x | Inside-Out system design for retrofitting | |
| | Overheating Risk | x | Inside-Out system design for retrofitting | |
| | Acoustic Comfort | | | |
| | Outdoor Comfort | | | |
| Circularity | Materials from Cycled Sources | x | Circular hub for optimized construction | Renovated residential buildings |
| | Reusability | x | Circular hub for optimized construction | Renovated residential buildings |
| Economics | Global Cost | x | Innovative business models | |
| | Energy Renovation Rate | | | |
| | Number of Jobs Created | | | |
| | Construction Time Reduction | x | Inside-Out system design for retrofitting. Zero-engineering of construction process | Renovated non-residential buildings |

## DEMONSTRATION PROJECT CZECH REPUBLIC

The Czech demo case encompasses the *Karviná Mizerov Health Centre* in the city of Karviná. It is a 5-storey building that was built in late 80s. It is owned by the Municipality of Karviná and partly rented to private practices that specialize in a variety of different medical professions, i.e. immunology, dentistry, dermatology, radio diagnostics etc.

The use of RES and building envelope retrofitting will ensure to reach the ZEB standard after renovation. For that, a combination of heat pumps, PV, as well as hybrid solar panels and waste heat and energy storages will be utilized. An advanced building energy monitoring system (BEMS) and the monitoring of the IAQ will ensure the effectivity of the measures. EV charging facilities both for private and company cars as well as the ambulances promote the market penetration of electro mobility in the area.

**Table D.4** summarises demo's actions impacting proposed KPIs of the assessment framework.

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

| Category | KPI | Relevance to demo | Demo actions impacting the KPIs | Type of buildings/Comment |
|---|---|---|---|---|
| Energy | Non-renewable Primary Life Cycle Energy in the Built Environment | x | NZEB | Renovated non-residential building |
| | | | BIPV, BAPV, PV-T (Photovoltaic-Thermal) | |
| | Renewable Energy Ratio | x | BIPV, BAPV, PV-T | |
| | Grid Delivered Factor | | | |
| | Net Energy/Net Power | x | Forecasting of electricity and heat load profiles | |
| | Flexibility Index | x | A central second-life energy storage | |
| Environment | Life-cycle GHG Emissions in CPCC | x | Green roof sample for reducing heat islands and slowing down the water runoff, application of recycled and/or secondary materials. LCA of HVAC systems with focus on carbon footprint. Small-scale pilots of climate change resilient solutions – use of heat pumps for summer cooling | |
| | Air Pollution from the Energy Consumption | x | BIPV, BAPV, PV-T | |
| | Dust during Retrofitting | | | |
| | Noise during Retrofitting | | | |
| Social | Democratic Process | | | |
| | Social Inclusion | x | Creation of Living Lab | |
| | Social Engagement | x | Creation of Living Lab | |
| | Demographic Composition | | | |
| | Social Interaction and Cohesion | | | |
| | Safety and Security | | | |
| | Energy & Environmental Consciousness | | | |
| | Affordability of Energy | | | |
| | Affordability of Housing | | | |
| | Access to Sustainable Mobility | x | EV charging stations and the implementation of V2G/vehicle-to-home (V2H) services | |
| | Access to Services and Amenities | | | |

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|---|---|---|---|---|
| Architecture | Aesthetics and Visual Qualities | x | Keeping architectural aesthetics of the BIPV, digital twin | |
| | Flexibility and Adaptability | | | |
| | Sufficiency and Adequacy of Space | | | |
| | Solar and Daylight Access | x | Digital design and 3D simulations (digital twins) for solar irradiation potential and design of optimum shading devices | |
| | Accessibility | | | |
| | Air Quality | x | IAQ monitoring platform | |
| | Thermal Comfort | x | Innovative cooling solutions | |
| | Overheating Risk | | | |
| | Acoustic Comfort | | | |
| | Outdoor Comfort | | | |
| Circularity | Materials from Cycled Sources | x | Green roof sample - application of recycled and/or secondary materials | |
| | Reusability | | | |
| Economics | Global Cost | | | |
| | Energy Renovation Rate | | | |
| | Number of Jobs Created | | | |
| | Construction Time Reduction | x | Installation of swappable façade elements with integrated RES | |

## DEMONSTRATION PROJECT DENMARK

The Danish demo case is called *SAB Department 22: Kløvermarken/Hvedemarken* and is located in the central part of the City of Sønderborg. It includes 19 apartment blocks of 3 floors, in total 432 apartments with a floor area of 32,000 m$^2$. The apartment blocks were constructed in 1970-1973.

In 2010, the buildings were renovated with more insulation, new low-energy windows, new radiator systems and new district heating substations with heating controls connected to Danfoss Portal. There are 9 substations covering the 19 apartment blocks. In 2017, more than 3,000 m$^2$ solar PV panels were integrated in the roofs of all 19 apartment buildings. The solar PV system can produce 460 kW solar electricity corresponding to 408,000 kWh per year covering 37% of the total electricity consumption in the 432 apartments. At the same time, new light-emitting diode (LED) outdoor lamps were implemented in the area around the 19 apartment blocks and in the corridors and basement.

**Table D.5** summarises demo's actions impacting proposed KPIs of the assessment framework.

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

| Category | KPI | Relevance to demo | Demo actions impacting the KPIs | Type of buildings/ Comments |
|---|---|---|---|---|
| Energy | Non-renewable Primary Life Cycle Energy in the Built Environment | 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 | x | Demonstration and monitoring existing BIPV panels in combination with battery solutions | Three floors apartment buildings. 432 apartments in 19 buildings. |
| | Grid Delivered Factor | | | |
| | Net Energy/Net Power | x | All actions | |
| | Flexibility Index | x | Smart electricity and lighting control in homes. Intelligent and flexible management of the electricity/district heating network | Renovated residential buildings |
| Environment | Life-cycle GHG Emissions in CPCC | x | Focusing on low carbon intensive technical components used in the buildings | |
| | Air Pollution from the Energy Consumption | x | Demonstration and monitoring existing building integrated PV panels in combination with battery solutions | |
| | Dust during Retrofitting | | | |
| | Noise during Retrofitting | | | |
| Social | Democratic Process | x | | Social housing associations |
| | Social Inclusion | | | |
| | Social Engagement | x | Number of information and training activities are planned | |
| | Demographic Composition | | | |
| | Social Interaction and Cohesion | | | |
| | Safety and Security | | | |
| | Energy & Environmental Consciousness | x | Green Ambassadors will be appointed among the tenants | |
| | Affordability of Energy | | | |

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|---|---|---|---|---|
| | Affordability of Housing | | | |
| | Access to Sustainable Mobility | | | |
| | Access to Services and Amenities | | | |
| **Architecture** | Aesthetics and Visual Qualities | | | |
| | Flexibility and Adaptability | | | |
| | Sufficiency and Adequacy of Space | | | |
| | Solar and Daylight Access | | | |
| | Accessibility | | | |
| | Air Quality | | | |
| | Thermal Comfort | | | |
| | Overheating Risk | | | |
| | Acoustic Comfort | | | |
| | Outdoor Comfort | | | |
| **Circularity** | Materials from Cycled Sources | x | Technical components | Renovated residential buildings |
| | Reusability | | | |
| **Economics** | Global Cost | x | Design of innovative financing models for implementation of energy retrofitting measures in social housing associations | |
| | Energy Renovation Rate | | | |
| | Number of Jobs Created | | | |
| | Construction Time Reduction | | | |

## DEMONSTRATION PROJECT NORWAY

The Norwegian demo case is the *Voldsløkka School* and *Cultural area*. The project includes the construction of a secondary school for 810 students, a new culture hall, a dance hall and rehearsal space. The project includes the construction of new buildings and the renovation of an existing listed building, in total about 14.000 m$^2$ floor area.

The area has high environmental ambitions and will be built as Oslo's first plus energy school, with a surplus of energy generated, covering all energy needs including appliances/plug-loads. The total area of the PV-installation is 1556 m² w with a yearly estimated production of 192 MWh. The new school facility will be integrated as part of the surrounding local area, which complements the area with new functions and activities and strengthens the area's green structure. The set of actions that will be undertaken by the ARV project will encompass resource efficient renovation processes and district energy analysis and operation, highlighting social, educational, and digital aspects to enhance citizens' involvement and generating CECs.

**Table D.6** summarises demo's actions impacting proposed KPIs of the assessment framework.

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

| Category | KPI | Relevance to demo | Demo actions impacting the KPIs | Type of buildings/Comments |
|---|---|---|---|---|
| Energy | Non-renewable Primary Life Cycle Energy in the Built Environment | x | Low-temperature thermal heating and high temperature thermal cooling Low Exergy (LowEx) HVAC system | |
| | | | Renewable energy generation using innovative BIPV and BAPV | |
| | Renewable Energy Ratio | x | Renewable energy generation using innovative BIPV and BAPV | |
| | Grid Delivered Factor | | | |
| | Net Energy/Net Power | x | All actions | |
| | Flexibility Index | x | Models for energy generation forecasting and control of the LowEx system | New and renovated non-residential buildings |
| Environment | Life-cycle GHG Emissions in CPCC | 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. | |
| | Air Pollution from the Energy Consumption | x | Electric- and bio-based fuels construction machinery will be used | |
| | Dust during Retrofitting | x | Electric- and bio-based fuels construction machinery will be used | |
| | Noise during Retrofitting | x | Electric- and bio-based fuels construction machinery will be used | |
| Social | Democratic Process | x | Social Renovation | |
| | Social Inclusion | x | The development of VR and AR applications are targeted toward several distinct stakeholders and citizen user groups | |
| | Social Engagement | x | Raising climate awareness through education and local community engagement | |
| | Demographic Composition | | | |

| | | | | |
|---|---|---|---|---|
| | Social Interaction and Cohesion | | | |
| | Safety and Security | | | |
| | Energy & Environmental Consciousness | x | Raising climate awareness through education and local community engagement. Energy coaching of occupants | |
| | Affordability of Energy | | | |
| | Affordability of Housing | | | |
| | Access to Sustainable Mobility | | | |
| | Access to Services and Amenities | | | |
| Architecture | Aesthetics and Visual Qualities | | | |
| | Flexibility and Adaptability | | | |
| | Sufficiency and Adequacy of Space | | | |
| | Solar and Daylight Access | | | |
| | Accessibility | | | |
| | Air Quality | x | Climate adapted design | |
| | Thermal Comfort | x | Climate adapted design | |
| | Overheating Risk | | | |
| | Acoustic Comfort | | | |
| | Outdoor Comfort | | | |
| Circularity | Materials from Cycled Sources | x | Circular renovation design strategies | New and renovated non-residential building |
| | Reusability | x | Circular renovation design strategies | |
| Economics | Global Cost | | | |
| | Energy Renovation Rate | | | |
| | Number of Jobs Created | | | |
| | Construction Time Reduction | x | On-site monitoring with devices and/or evaluations based on visits/reports | |

## ACKNOWLEDGEMENTS AND DISCLAIMER

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

This deliverable contains information that reflects only the authors’ views, and the European Commission/CINEA is not responsible for any use that may be made of the information it contains.

## PARTNER LOGOS

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