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NEST InGrained ecosystem foR zEro EmissioN buildings

D1.2 – KEY PERFORMANCE INDICATORS

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Terms, definitions and abbreviated terms

CBA	Cost Benefit Analysis
DC	Demo Case
DGI	Daylight Glare Index
DH	Thermal Discomfort Hours
EB	Intangible Environmental benefits
ECE	Embodied Carbon Emissions
EoL	End-of-life
FB	Financial Benefits for the locals
GA	Grant agreement
GHG	Green House Gas
GWP	Global Warming Potential
IAQ	Indoor Air Quality
IC	Investment Cost
IEQ	Indoor Environmental Quality
KPIs	Key Performance Indicators
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
NZEB	Nearly Zero Energy Building
OPEX	Operational Expenditures
PE	Primary Energy
PMV	Percentage Mean Vote

PPD	Predicted Mean Vote
REC	Recyclability
RER	Renewable Energy Ratio
RES	Renewable Energy Sources
SB	Intangible Social benefits
SDGs	Sustainable Development Goals
SP	Standardized Package
SRI	Smart Readiness Indicator
SS	Stakeholders Satisfaction
TCA	Thermal Comfort Availability
VCA	Visual Comfort Availability
VDC	Virtual Demo Case
VOCs	Volatile Organic Compounds
WP	Work Package
ZeB	Zero emission Building

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1. Executive summary

The main objective of the GreeNest project is to develop, validate and promote an integrated solution based on a digitized platform to deliver a unified ecosystem comprising abiotic and biotic solutions approaching and facilitating a fast and extensive adoption of Zero emission Buildings (ZeB). The overarching goals of the GreeNest ecosystem include 100% carbon free constructions by utilizing biogenic materials that store carbon, alongside a 50% reduction in embodied emissions according to the Nearly Zero Energy Building (NZEB) standard. Additionally, the reduction of the Greenhouse Gas (GHG) emissions by 60% is a key objective, accomplished through minimizing the energy needs and transitioning to ZeB status via the installation of Renewable Energy Sources (RES). Moreover, GreeNest aims to enhance productivity by more than 30%, using earthen materials and components based on local value chains. This will also support the circular economy through the development of circular construction elements based on waste wood with reversible connections that could be reused or recycled at the end of the life. During the GreeNest project, 17 innovative Standardized Packages (SPs) will be demonstrated, that will be applied and installed in demos sites, creating a range of solutions for a cost-effective construction on ZeBs.

The GreeNest project aims to cluster manageable Key Performance Indicators (KPIs), that could help the various project stakeholders to map, monitor, optimize and evaluate all the above main objectives. This report titled "Key Performance Indicators", sets the basis for assessing the sustainability of the GreeNest concept, based on the definition of the corresponding KPIs.

The analysis conducted in this report resulted in the development of a comprehensive KPI framework, initially comprising 60 indicators, which was systematically refined into a core set of 20 Key Performance Indicators aligned with the Level(s) framework and relevant EU policies. The selected KPIs cover five key dimensions: environmental performance, energy efficiency, indoor comfort and air quality, economic performance, and social impact. The results demonstrate that this structured KPI framework enables a consistent and measurable assessment of GreeNest solutions across the entire building lifecycle, supporting the quantification of key parameters such as greenhouse gas emissions, energy consumption, circularity, life cycle costs, and occupant well-being. Furthermore, the proposed KPI set ensures applicability across different building typologies and project stages, providing a robust and scalable basis for the design, optimisation, monitoring, and validation of Zero Emission Building solutions.

In this context, the formulated list of KPIs addresses the construction value chain, the building's performance, internal comfort, economic, social and environmental aspects. The current report outlines the methodology for selecting the basic KPIs based on the Level(s) approach. The KPIs are thoroughly analyzed, with detailed explanations of the calculation methods, as well as the SPs and/or demos referenced.

2. Planned criteria

The Key Performance Indicators (KPIs) framework is designed to reflect the capabilities and performance of the GreeNest ecosystem, taking into account existing European and national regulatory frameworks as well as recognised sustainability standards. In particular, the development of the KPIs is guided by the United Nations Sustainable Development Goals (SDGs), with emphasis on Goals 7, 9, 11 and 12, which address clean energy, sustainable industry and infrastructure, sustainable cities, and responsible consumption and production.

The KPI framework supports a multi-dimensional assessment of the GreeNest solutions across the construction value chain. It covers key aspects such as construction productivity, circularity, building performance, environmental impact, and economic efficiency throughout the different lifecycle stages, including construction, operation, and end-of-life. In addition, the framework incorporates indicators related to indoor environmental quality, including Indoor Air Quality (IAQ) and Indoor Environmental Quality (IEQ), ensuring that occupant comfort and well-being are also addressed.

The KPIs defined in this report are intended to support the design, optimisation, monitoring, and evaluation of the GreeNest Standardized Packages (SPs) and demonstration buildings. They enable the assessment of core performance aspects such as energy efficiency, environmental impact, and economic performance, as well as co-benefits including circularity, embodied emissions, occupant well-being, social cohesion, resilience, and the capacity to address challenges such as energy poverty.

Overall, the planned KPI framework provides a structured and consistent basis for evaluating the performance of GreeNest solutions, ensuring alignment with sustainability objectives and supporting the transition towards Zero Emission Buildings.

3. Introduction

3.1 Purpose and scope of the document

The purpose of this document is to define the Key Performance Indicators (KPIs) for the upcoming activities of the GreeNest project. These KPIs will be used in the design, monitoring, and evaluation of Standardized Packages (SPs) and demonstration buildings, focusing on energy, environmental, living quality (comfort), economic, and social aspects.

Two different lists of KPIs are defined in the current report. The first one is an extensive list of KPIs classified in five categories: Environmental performance; Comfort and Indoor Air Quality (Living Quality); Technical performance; Economics; Social and stakeholders' behaviour. This list is provided in the Annex of this report. These KPIs could be used during the different phases of the project for the design and optimization of specific technologies, Standardized Packages (SPs) and demonstration buildings.

The second list of KPIs, referred to as the "selected KPIs", is a concise list of fundamental KPIs to be used in the upcoming activities for the design, optimization, monitoring, and evaluation of technologies/SPs and demos. The selected KPIs are defined based on Level(s) approach and align with the Sustainable Development Goals 7, 9, 11 and 12 for sustainable and green construction as well as the existing EU and national regulations. Each KPI is thoroughly analyzed, including the calculation methodology, required inputs, and the referenced SPs and/or demos.

3.2 Relation to other Project Activities

The definition of Key Performance Indicators (KPIs) constitutes a central element of the GreeNest project, establishing a common framework for the assessment, monitoring, and optimisation of the proposed solutions. The KPI framework developed in this report is closely linked to several subsequent project activities and provides essential input for their implementation (**Error! Reference source not found.**).

The defined KPIs support the development of the GreeNest digital framework and taxonomy by identifying the key variables required for performance assessment. These variables are incorporated into a structured database that describes the technical characteristics, application areas, and expected impacts of the Standardized Packages (SPs).

Furthermore, the KPI framework is integrated into the digital platform developed within the project, enabling the evaluation and comparison of alternative solutions based on quantitative performance indicators. This allows for informed decision-making during the design and optimisation of building solutions.

The KPIs also guide the design and integration of the GreeNest solutions in the demonstration cases. They support the selection of appropriate technologies and components, the development of final design configurations, and the optimisation of system performance in line with the project objectives.

In addition, the KPI framework contributes to the assessment of sustainable value chains, particularly by incorporating economic and social indicators that support cost-benefit analysis and stakeholder evaluation.

Finally, the defined KPIs are used in the monitoring and validation activities, where they enable the evaluation of the performance of the implemented solutions under real operating conditions. They also support life cycle assessment and cost analysis, providing a comprehensive evaluation of environmental, economic, and social impacts across the full life cycle of the building systems.

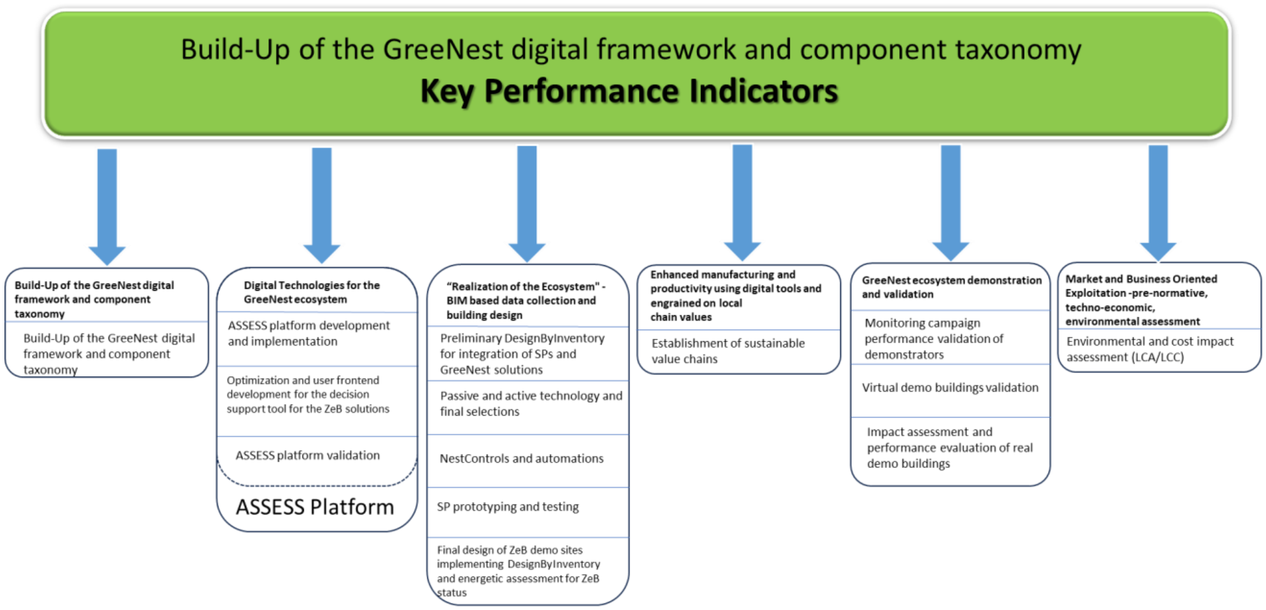

FIGURE 1 RELATIONSHIP OF THIS REPORT WITH OTHER PROJECT ACTIVITIES

3.3 Contributing Partners

The work is led by NTUA with contributions from other project partners. AMS, TUB, KET, and INEB are participating in this task, contributing to the extended list of KPIs providing feedback for different category. The Table 1 indicates the contributions of each partner.

TABLE 1: PARTNER CONTRIBUTIONS

Partner	Contribution
NTUA	Leader of Task, Preparation of report, Selection and analysis of KPIs, final review of report
AMS	Propose and approval of social KPIs

TUB	Propose and approval of technical KPIs
KET	Propose and approval of economic KPIs
INEB	Propose and approval of environmental KPIs

4.Methodology considered for GreeNest project

The most effective approach for assessing the achievements of the expected results on the GreeNest project is the definition of KPIs. Initially, a comprehensive set of KPIs, relevant to Level(s) framework is compiled, and the list of indicators is narrowed down through a careful process, aligned with the project's specific targets and goals, which are derived from established reports and standards within existing EU and national regulations. The final list of the KPIs is classified into 5 main categories:

- Environmental performance.
- Comfort and Indoor Air Quality (Living Quality).
- Technical performance.
- Economics.
- Social and stakeholders' behavior.

The methodology for KPI selection consists of three main steps: (i) identification of relevant indicators based on the Level(s) framework and existing research projects, (ii) alignment of these indicators with the specific objectives of the GreeNest project, and (iii) refinement of the KPI set to ensure applicability across building types and lifecycle stages. The first step is to make a compilation of a set of KPIs identifying relevant indicators from Levels(s) framework. The source of the comprehensive data is also from research of projects relevant to zero emissions buildings and integrated circular building materials, while also gathering input from stakeholders including engineers, scientists and policymakers. The following step is the alignment with the project's specific goals. The main objectives and ambitions are the zero generation of pollutants using circular, natural building materials, 100% carbon free construction through the application of biogenic materials that store carbon, the extension of the carbon storage via reused timber, and the application of earth-based materials that can be reused endless times. Moreover, the reduction of GHG emissions is a significant objective of GreeNest project, by the maximizing recyclability and use of reused material. Also, the project aims to ensure flexibility and adaptability through the creation of components and system combinations reaching easy adaptation to various building typologies in all EU climatic zones. Figure 2, depicts the procedure followed to select the KPIs for the GreeNest project.

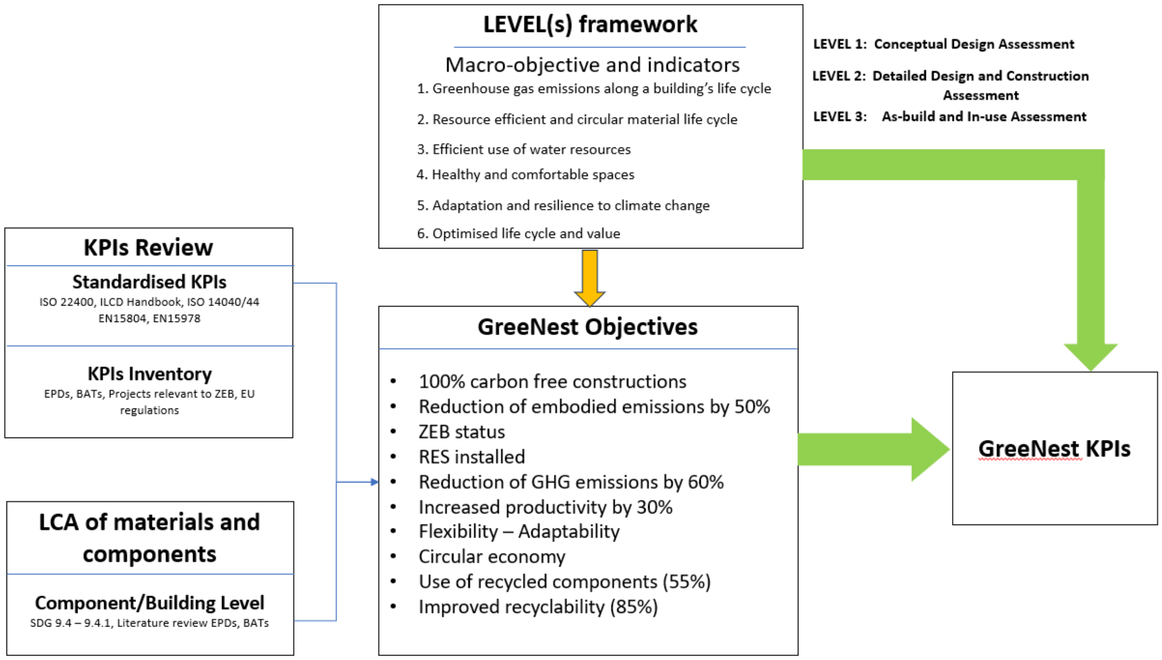

FIGURE 2: FLOWCHART FOR THE SELECTION OF THE KPIS FOR THE GREENEST SPS AND DEMO BUILDINGS.

4.1 UN's Sustainable Development Goals (SDGs)

The UN's Sustainable Development Goals are a call for action by all countries, to promote prosperity while protecting the planet. They emphasize that ending poverty should be accompanied with strategies that build economic growth and address various social needs such as education, healthcare, social security and employment opportunities while tackling climate change and ensuring the environmental protection. There are 17 interconnected Goals in total, aiming to be achieved all by 2030. Key Performance Indicators definition framework will showcase the capabilities of the GreeNest ecosystem, based primarily on the SDGs 7, 9, 11 and 12 (Figure 3), for sustainable and green construction, sourcing renewable and recyclable resources and reusing materials whenever possible to minimize landfill waste. [1]

FIGURE 3: SUSTAINABLE DEVELOPMENT GOALS 7, 9, 11, 12.

GOAL 7 – AFFORDABLE AND CLEAN ENERGY.

Goal 7 is about ensuring access to clean and affordable energy, which is the key to the development of agriculture, business, communications, education, healthcare and transportation. As the consumption of energy is dominant contributor to climate change, accounting for around 60% of global Greenhouse Gas emissions, investing in sources such as solar, wind and thermal, while upgrading infrastructure and technologies, provide clean energy as a crucial goal that can both encourage growth and help the environment. To ensure access to clean energy for all by 2030, investments in renewable energy must be increased, by investing more in sustainable energy services, bringing new technologies to the market quickly from diverse supplier base, prioritizing energy efficient practices [1].

GOAL 9 – INDUSTRY, INNOVATION AND INFRASTRUCTURE.

Goal 9 seek to build resilient infrastructure, promote sustainable industrialization and foster innovation. Economic growth, social development and climate action are heavily developed on investments in infrastructure, sustainable industrial development and technological progress. To achieve Goal 9 by 2030, it also essential to invest in advanced technologies with lower carbon emissions [1].

GOAL 11 – MAKE CITIES INCLUSIVE, SAFE, RESILIENT AND SUSTAINABLE.

Goal 11 is about making cities and human settlements inclusive, safe, resilient and sustainable. Cities represent the future of global living. The world's population reached 8 billion on 2022 over half living in urban areas. This figure is expected to rise, with 70% of people to live in cities by 2050. Although cities occupy just 3% of the Earth's land, they account for 60-80% of energy consumption and 75% of carbon emissions. Sustainable development cannot be achieved without significantly transforming the way urban spaces are built and managed. By acting sustainably, citizens of cities can live a descent quality of life, creating shared prosperity and social stability without harming the environment [1].

GOAL 12 – ENSURE SUSTAINABLE CONSUMPTION AND PRODUCTION PATTERNS.

Goal 12 is about ensuring sustainable consumption and production patterns, which is the key to sustain the livelihoods of current and future generations. The planet is running out of resources, so people need to change their consumption habits, shifting energy supplies to more sustainable reducing the consumption levels. Transitioning to a circular economy involves designing products for longevity repairability, and recyclability while also promoting practices such as reusing, refurbishing, and recycling products as to minimize the waste and resource depletion [1].

4.2 Level(s) methodology

Level(s) is an assessment and reporting tool for sustainability performance of buildings, throughout their life cycle, established by the European Commission, firmly based on circularity principles. It provides a set of indicators and standardized metrics evaluating four different areas. The environmental performance of the building, user's health and comfort aspects, life cycle cost (LCC), and potential risk affecting future performance. The overarching aim of this framework is to provide with a comprehensive dataset which enables to understand, improve and optimize the sustainability performance of the building. It empowers professionals working in the building sector, to evaluate the construction at different stages of the life cycle, in ways to improve buildings' performance and longevity. Its methodology proposes three levels of accuracy for input data sources and data processing, while also a Life Cycle Assessment (LCA) methodology, addressing key sustainability aspects over the building life cycle, across six macro-objectives, tracked through sixteen main indicators. [2]

1. **Greenhouse gas emission along building's life cycle**, as to minimize the whole life carbon emissions, taking into account both energy consumption during the use stage of the building and embodied energy in building material and construction products.
2. **Resource efficient and circular material lifecycles**, in order to optimize the building design to support lean and circular product material flows, including:
    - Quantification of construction products and materials used.
    - Planning, estimation and monitoring of circular outcomes for construction and demolition waste generated
    - Assessment and scoring of the potential for deconstruction in building designs as opposed to demolition.

3. **Efficient use of water resources,** particularly in areas with identified long term ore projected water stress.
4. **Healthy and comfortable spaces,** creating building spaces that are more comfortable, attractive and productive.
5. **Adaptation and resilience to the climate change.** The intention is to futureproof building performance as to:
    - Adapt to future climate changes that will impact thermal comfort.
    - Make buildings more resilient and resistant to extreme weather events
    - Improve the building design as to reduce the chances of pluvial/fluvial flood events in the local and downstream area.
6. **Optimized life cycle and value,** to gain a long -term view of the whole life costs and market value of more sustainable buildings.

Each of the 16 indicators, has been selected as to evaluate the performance and contribution of a building towards the specified macro-objective. An overview of the 16 key performance indicators and their respective units of measurement is presented in Table 2.

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TABLE 2 LEVEL(S) METHODOLOGY KEY PERFORMANCE INDICATORS

LEVEL(s) KEY PERFORMANCE INDICATORS			
1		Greenhouse gas emissions along a buildings' life cycle	i. Use stage energy performance [kWh/m^2/yr] ii. Life Cycle Global Warming Potential [CO_{2eq}/m^2/yr]
2		Resource efficient and circular material life cycles	i. Bill of quantities, materials, and lifespans. [Quantities mass+years] ii. Construction and demolition waste and materials. [kg of waste + materials/m^2] ii. Design for adaptability and renovation [Adaptability Score] v. Design and deconstruction, reuse and recycling [Deconstruction, reuse, recycling score]
3		Efficient use of water resources	i. Use stage water consumption [m^3/yr]
4		Healthy and comfortable spaces	i. Indoor air quality [Parameters for CO2 concentration, VOCs etc] ii. Time outside of thermal comfort range [% of time out of range during the heating and cooling period] ii. Lighting and visual comfort [Quality of artificial and natural light and associated with visual comfort] v. Acoustics and protection against noise [The capacity of building fabric to provide a comfortable acoustic environment for its occupants]
5		Adaptation and resilience to climate	i. Protection of occupier health and thermal comfort. ii. Increased risk of extreme weather events ii. Increased risk of flood events
6		Optimized life cycle and value	i. Life cycle costs (construction, operation, maintenance, refurbishment, and disposal [€/m2/yr] ii. Value creation and risk exposure – Encourage the integration of sustainability aspects into market value assessment and risk rating processes and ensure that this is done in as informed and transparent a way as possible

Once the macro-objectives and indicators have been selected, next step is to determine the "level" at which the project performance will be assessed. Design teams could utilize different levels for various indicators, using one or more levels for each indicator to follow the development of performance throughout the project. The ability to address multiple levels provides a more comprehensive understanding of the project's sustainability performance.

The Level(s) methodology, owes its name to the fact that it extends to three levels, at which the data related to the stakeholders' expertise, are introduced and processed. From LEVEL 1, which concerns the design through the assessment of reference data, to LEVEL 2 through the simulation of each case study, to LEVEL 3, as built and in-use, which corresponds to monitoring and values obtained from the detailed assessment. This three-stage methodology framework represents the following workflow of a design and construction of a building project.

LEVEL 1: CONCEPTUAL DESIGN ASSESSMENT.

At this stage of the methodology, qualitative assessments and early-stage reports are carried out on the concepts to be considered during the initial project definition and conceptual design phases. In this way, it is provided a simple structure that focuses on the most relevant aspects of sustainability of the indicators.

LEVEL 2: DETAILED DESIGN AND CONSTRUCTION ASSESSMENT.

Level 2 is an intermediate stage of the methodology, representing a quantitative assessment of the performance of the design, allowing comparison of estimates for different design options and monitoring of the construction, according to standardized measurements and methods.

LEVEL 3: AS-BUILT AND IN-USE.

Level 3 facilitates a comprehensive understanding of actual building performance estimating the on-going post occupancy monitoring of energy, comfort levels or other performance metrics. Essentially is the stage, which determines what works in practice compared with the buildings' models simulations.

5. Definition of KPIs

Following the process of the evaluation and the selection of the KPIs, as shown in the flowchart of Figure 2, an extensive list of KPIs was created and classified into the following 5 categories:

- Environmental performance.
- Comfort and Indoor Air Quality (Living Quality).
- Technical performance.
- Economics.
- Social and stakeholders' behaviour.

The comprehensive list of KPIs, 60 in total, is detailed in the Annex. This section provides specific information about the units of each KPI and the levels at which calculations are performed, whether at the material, SP, or demo building level. These KPIs are designed to be utilised throughout various project phases, including development, optimization, and evaluation tasks.

A final list of 20 KPIs was selected within each category using the Level(s) methodology, ensuring that all project needs are covered. These selected KPIs will serve to evaluate and subsequently monitor both direct aspects such as energy performance, economic impact, indoor comfort quality, as well as co-benefits including environmental performance, flexibility and adaptability on local value chains. For the calculation of each KPI, a common methodology is described. Table 3 presents the final list of the GreeNest KPIs.

TABLE 3: KPIS SELECTED FOR THE GREENEST SPS AND DEMO BUILDINGS

Category	KPI Number	Name	Symbol
Environmental	KPI01	Green-house gas Emissions	GHG
	KPI02	Global warming potential	GWP100
	KPI03	Embodied Carbon	ECE
	KPI04	Recyclability	REC
Comfort and IAQ	KPI05	Degree of thermal comfort	PMV/PPD
	KPI06	Thermal Comfort Availability	TCA
	KPI07	CO2 index	I_{CO2}
	KPI08	Volatile organic compounds	VOCs
	KPI09	Visual Comfort Availability	VCA
Energy	KPI10	Primary Energy consumption	PE_c
	KPI11	Produced on-site renewable energy	$E_{p,REonsite}$
	KPI12	Renewable Energy Ratio	RER
	KPI13	Smart Readiness indicator	SRI
Economics	KPI14	Investment Cost	IC
	KPI15	Operational Expenditures	OPEX
	KPI16	End-of-life () Costs	EoLC

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	KPI17	Financial Benefits for the locals	FB
Social	KPI18	Intangible Environmental benefits	EB
	KPI19	Intangible Social benefits	SB
	KPI20	Stakeholders Satisfaction	SS

5.1 Environmental KPIs (LCA)

New buildings, emit on average 50 tons of embodied CO_2, while the well-insulated make up for their high embodied energy costs through lower operational CO_2, although this compensation takes in most cases more than 50 years [3]. As the main objective of GreeNest is to provide solutions in the building sector that reduce GHG emissions and enhance carbon storage, prioritizing environmental considerations during the development, optimization, and manufacturing of SPs, as well as in the construction of demo buildings, is crucial. From the extensive list of KPIs, four have been selected as fundamental indicators for evaluating environmental impact through LCA activities.

5.1.1 Environmental - LCA KPIs Shortlist

The selected KPIs for the environmental aspect are the following:

- KPI01- Greenhouse Gas Emissions (GHG)
- KPI02- Global warming potential (GWP100)
- KPI03- Embodied Carbon (ECE)
- KPI04- Recyclability (REC)

5.1.2 Environmental -LCA- KPIs description

KPI01- Greenhouse gas Emissions (GHG)

Greenhouse Gas (GHG) Emissions are a critical measure of a building's environmental impact. Calculating these emissions focuses on operational emissions, which are the emissions resulting from the energy used to power the building. This includes heating, cooling, lighting, and running appliances and equipment. By understanding and quantifying these emissions, building managers and engineers can implement strategies to reduce the building's carbon footprint and improve overall sustainability.

Operational GHG emissions are influenced by various factors, including:

- Type of energy sources used (e.g. electricity, natural gas, heating oil)
- Efficiency of energy usage within the building
- Energy mix of the electricity grid (renewables vs. fossil fuels)
- Building design and insulation
- Occupant behaviour and usage patterns

KPI01- Green-house gas Emissions (GHG)					
Category	Environmental	Units	[$kgCO_{2eq}/m^2yr$]	Level	1-2
Description					
Greenhouse Gas (GHG) Emissions of a Building refers to the amount of greenhouse gases released into the atmosphere as a direct result of the energy a building uses annually. This is a simplified way to assess a building's environmental impact, focusing solely on its operational stage.					
Formula					
$GHG = \frac{TE_c \cdot GEF_T + EE_C \cdot GEF_E}{A}$					
Variables needed					
TE_c – Thermal energy consumption of an examined building [kWh/yr] GEF_T – Greenhouse gas emission factor for thermal energy weighted based on thermal energy production source [$kgCO_{2eq}/kWh$] EE_c – Electrical energy consumption of an examined building [kWh/yr] GEF_E – Greenhouse gas emission factor for electrical energy weighted based on electricity production source [$kgCO_{2eq}/kWh$]					
Standardized Package (SP)					
-					
Demo building					
DC#1	DC#2	DC#3	DC#4		

KPI02 - Global warming potential (GWP100)

GWP100 signifies the greenhouse gas (GHG) emissions associated with a building over its entire lifecycle, expressed in terms of its equivalent impact on global warming compared to CO_2 emissions over a 100-year period. ZeB buildings, aiming for net-zero energy balance, strive to minimize their environmental impact. GWP100 offers a quantifiable metric to assess such a building's performance in reducing its contribution to global warming.

GWP100 accounts for all GHG emissions associated with the building's lifecycle, including:

- Embodied emissions: GHGs emitted during the production, transportation, and construction of building materials.
- Operational emissions: GHGs from energy consumption for heating, cooling, lighting, and other building operations.
- End-of-life emissions: GHGs from the demolition, recycling, or disposal of building materials.

GWP100 is a valuable KPI for ZeB buildings as it compels engineers to consider the entire building lifecycle and make design choices that minimize the building's overall environmental impact.

<table>
<tr><th colspan="6">KPI02- Global warming potential (GWP100)</th></tr>
<tr><td>Category</td><td>Environmental</td><td>Units</td><td>$kg_{eq}CO_2$</td><td>Level</td><td>1-2</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">GWP is a metric used to compare the relative impact of different greenhouse gases on global warming. It quantifies the amount of heat a greenhouse gas traps in the atmosphere over a specific time horizon, typically 100 years for GWP100. Baseline model of 100 years of the IPCC [4]</td></tr>
<tr><td colspan="6">Formula</td></tr>
<tr><td colspan="6">$$GWP_{total} = GWP_{embodied} + GWP_{operational} + GWP_{end\text{-}of\text{-}life}$$
where:
$$GWP_{embodied} = \sum_{j=1}^{m} (M_j \times EF_j) \times GWP_{CO_2eq}$$
$$GWP_{operational} = \sum_{k=1}^{p} (E_k \times EF_k) \times GWP_{CO_2eq}$$
$$GWP_{end-of-life} = \sum_{l=1}^{q} (D_l \times EF_l) \times GWP_{CO_2eq}$$</td></tr>
<tr><td colspan="6">Variables needed</td></tr>
<tr><td colspan="6">M_j= Mass of material j [kg]
EF_j= Emission factor of material j [$kgCO_{2eq}$/kg of material]
m= Number of different materials used
GWP_{CO2eq}= GWP factor for CO_2 (which is 1)
E_k= Energy consumption of source k [kWh]
EF_k= Emission factor of energy source k [$kgCO_{2eq}$/kWh]
p= Number of different energy sources used
GWP_{CO2eq}= GWP factor for CO_2 (which is 1)
D_l= Amount of waste material l [kg]
EF_l= Emission factor for disposal method of material l [$kgCO_{2eq}$/kg of material]
q = Number of different waste materials considered
GWP_{CO2eq}= GWP factor for CO_2 (which is 1)</td></tr>
<tr><td colspan="6">Standardized Package (SP)</td></tr>
<tr><td colspan="6">-</td></tr>
<tr><td colspan="6">Demo building</td></tr>
<tr><td>DC#1</td><td>DC#2</td><td colspan="2">DC#3</td><td colspan="2">DC#4</td></tr>
</table>

KPI03 - Embodied Carbon emissions (ECE)

The embodied carbon of a product refers to the total greenhouse gas emissions associated with its entire lifecycle, including raw material extraction, manufacturing, transportation, use, and disposal. It encompasses emissions from various stages of the product's lifecycle, such as energy consumption, process emissions, and transportation-related emissions.

Calculating the embodied carbon involves assessing the emissions of various greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and converting them into CO_2 equivalents (CO_{2eq}).

Factors such as the choice of materials, manufacturing processes, energy sources, transportation methods, and end-of-life disposal options all contribute to the overall embodied carbon of a product.

Reducing the embodied carbon of a product involves implementing sustainable practices throughout its lifecycle, such as using renewable or low-carbon materials, optimizing manufacturing processes to minimize energy consumption and emissions, sourcing materials locally to reduce transportation emissions, designing products for durability and recyclability, and promoting circular economy principles to extend the product's lifespan and minimize waste generation.

<table>
<tr><th colspan="10">KPI03 - Embodied Carbon Emissions (ECE)</th></tr>
<tr><td colspan="2">Category</td><td colspan="2">Environmental</td><td>Units</td><td colspan="2">$[kgCO_{2eq}/m^3]$ or $[kgCO_{2eq}/m^2]$</td><td colspan="2">Level</td><td>1-2</td></tr>
<tr><td colspan="10">Description</td></tr>
<tr><td colspan="10">Carbon emitted in the production phase of products and materials, from mining and processing of natural resources, transport to processing sites, and the manufacturing phases.</td></tr>
<tr><td colspan="10">Formula</td></tr>
<tr><td colspan="10">$$\text{Embodied Carbon} = \frac{\text{Quantity of Material} \times \text{Carbon Factor}}{A}$$</td></tr>
<tr><td colspan="10">Variables needed</td></tr>
<tr><td colspan="10">• Quantity of Material: This refers to the amount of the specific material used in the product [kg].
• Carbon Factor: This represents the average CO_2 equivalent emissions associated with producing and delivering one kilogram of that material. It considers factors like raw material extraction, processing, assembly and transportation $[kg\ CO_{2eq}/kg]$.</td></tr>
<tr><td colspan="10">Standardized Package (SP)</td></tr>
<tr><td>SP1</td><td>SP2</td><td>SP3</td><td>SP9</td><td>SP10</td><td>SP11</td><td>SP12</td><td>SP13</td><td>SP14</td><td>SP15</td></tr>
<tr><td colspan="10">Demo building</td></tr>
<tr><td colspan="3">DC#1</td><td colspan="2">DC#2</td><td colspan="3">DC#3</td><td colspan="2">DC#4</td></tr>
</table>

KPI04 - Recyclability (REC)

Recyclability refers to the ability of a material or product to be collected, processed, and reused in the manufacturing of new products or materials. It involves the capacity for a material or product to undergo a recycling process effectively without losing its inherent properties or quality. The recyclability of a material depends on various factors, including its composition, physical properties, and the availability of recycling infrastructure and technologies. Materials that are easily separated, sorted, and processed into new products with minimal loss of quality are considered highly recyclable. Conversely, materials that are difficult to separate, contaminated, or degraded during the recycling process may have lower recyclability. Designing products and materials for recyclability involves considering factors such as material selection, ease of disassembly, labeling for identification, and compatibility with existing recycling processes. Promoting recyclability plays a crucial role in reducing waste generation, conserving natural resources, and minimizing environmental impacts associated with resource extraction, manufacturing, and disposal.

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KPI04- Recyclability (REC)					
Category	Environmental	Units	%	Level	2-3
Description					
Recyclability refers to the ability of a material or product to be collected, processed, and reused in the manufacturing of new products or materials. The calculation refers to as the percentage of material that is effectively recycled compared to the total material used.					
Formula					
$\text{Recyclability} = \frac{\text{Recovered Material}}{\text{Total Material}} \times 100\%$					
Variables needed					
• Recovered Material: refers to the amount of material that is successfully recycled or recovered from the waste stream. • Total Material: refers to the total amount of material generated or used.					
Standardized Package (SP)					
SP1, SP2, SP3, SP9, SP10, SP11, SP12, SP13, SP14, SP15					
Demo building					
DC#1, DC#2, DC#3, DC#4					

5.2 Comfort and IAQ KPIs (Living quality)

Residents, owners and investors will benefit directly from the GreeNest ecosystem. The occupants of the 4 new demonstration buildings will live in better indoor conditions, including thermal, visual and acoustic comfort, Indoor Air Quality (IAQ) and Indoor Environmental Quality (IEQ). Indoor environment is affected by a combination of the above conditions, therefore, the maintenance of each of these conditions withing prescribed and standardized ranges, by integrating IEQ strategies, contributes to the improvement of the overall IEQ and the satisfaction of the occupants.

Comfort Performance Indicators are metrics used to assess and measure occupant comfort and well-being in indoor environments. These indicators help to evaluate the quality of the indoor environment in terms of temperature, humidity, air quality etc, to ensure that occupants are provided with a comfortable and productive environment.

5.2.1 Comfort and IAQ KPIs shortlist

The selected KPIs for comfort and IAQ aspects are the following:

- KPI05- The degree of thermal comfort (PMV/PPD)
- KPI06 – Time Outside of comfort range – Discomfort hours
- KPI07- Indoor Air Quality – CO2 index
- KPI08 – Indoor Air Quality – Volatile organic compounds (VOCs)
- KPI09 – Visual Comfort – Visual Comfort Availability (VCA)

5.2.2 Comfort and IQA KPIs description

KPI05 - The degree of thermal comfort

The main KPI for the thermal comfort is considered according to EN 15251 "Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment lighting and acoustic" [5], ISO 7730 "Ergonomics of thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria" [6], and ASHRAE 55 "Thermal Environmental Conditions for Human Occupancy" [7]. To define the general requirements for indoor comfort conditions, data on building environmental parameters need to be collected. This will provide the necessary statistical data to accurately describe these conditions.

According to the technical standard EN 15251, discomfort time considers the sum of the discomfort hours with more than or as much as 10% dissatisfaction. Thermal comfort refers to PPD values lower than 10%.

KPI05 - The degree of thermal comfort					
Category	Living Quality	Units	[-]	Level	1-2-3
Description					
Comfort zone is defined by the combination of six major variables of thermal comfort, indoor thermal environmental factors and personal factors, that produce acceptable thermal environment conditions for the majority of the occupants within a space. Thermal comfort model is based on the Predicted Mean Vote/ Predicted Percentage of Dissatisfied (PMV/PPD) [8]					
Formula					
PMV: Predicted Mean Vote **PPD**: Percentage of people dissatisfied According to Fanger equations PMV is calculated as: $PMV=(0.303e^{-0.036M}+0.028) \times \{(M-W)-3.05\times10^{-3}\times[5733-6.99(M-W)-58.15]-1.7$ $\times10^{-5}M(5867-P_a)-0.0014M(34-t_a)-3.96\times10^{-8}f_{cl} \times [(t_{cl}+273)^4-(\bar{t}_r+273)^4]-f_{cl}h_C(t_{cl}-t_a)\}$ $t_{cl}=35.7-0.028(M-W)-I_{cl}\{3.96\times10^{-8}f_{cl}\times\left[(t_{cl}+273)^4-(\bar{t}_r+273)^4\right]+f_{cl}h_C(t_{cl}-t_a)\}$ $h_c=\begin{cases}2.38(t_{cl}-t_a)^{0.25} & \text{for } 2.38\times\lvert t_{cl}-t_a\rvert^{0.25}>12.1\sqrt{V_{ar}}\\ 12.1\sqrt{V_{ar}} & \text{for } 2.38\times\lvert t_{cl}-t_a\rvert^{0.25}<12.1\sqrt{V_{ar}}\end{cases}$ $f_{cl}=\begin{cases}1.00+1.290\times I_{cl} & \text{for } I_{cl}\leq0.078m^2K/W\\ 1.05+0.645\times I_{cl} & \text{for } I_{cl}>0.078m^2K/W\end{cases}$ With the PMV value determined, PPD index can be calculated using the following equation $PPD=100-95\cdot\exp\left(-0.03353\cdot PMV^4-0.2179\cdot PMV^2\right)$					
Variables needed					
M- the metabolic rate, (W/m^2) of the body surface area W- the effective mechanical power (W/m^2)					

I_{cl} – Thermal resistance of clothing, (m^2K/W) f_{cl} – is the clothing surface area factor t_a – is the air temperature, (°C) $\bar{t}_r$ - is the mean radiant temperature, (°C) v_{ar} – is the relative air velocity, (m/s) p_a – is the water vapour partial pressure, (Pa) h_c – is the convective heat transfer coefficient, [$W/(m^2K)$] t_{cl} – clothing surface temperature, (°C)
Standardized Package (SP)
SP15 / SP16
Demo building
DC#1 / DC#2 / DC#3 / DC#4 / VDC#1 / VDC#2

KPI06 – Thermal Comfort Availability (TCA)

Thermal Comfort Availability (TCA), is expressing the time when thermal comfort conditions are available in a thermal zone or a whole building/apartment, in a considered period of time.

KPI06 – Thermal Comfort Availability (TCA)					
Category	Living Quality	Units	hours	Level	1-2-3
Description					
Thermal comfort refers to PPD values, lower than 10% as suggested by the standard EN12251:2008 [5]. The fraction of time when thermal comfort conditions are available or not, can be expressed by the Thermal Comfort Availability indicator.					
Formula					
$TCA = \sum_{i=1}^{N_t} wf_i \cdot \frac{t}{T} \quad \in [0,1]$ $wf_i = \begin{cases} 0 & \text{if } PPD \geq PPD_{lim} \\ 1 & \text{if } PPD < PPD_{lim} \end{cases}$ When the examined whole building/apartment is divided into more than one thermal zones: $TCA = \sum_{i=1}^{n} \frac{TCA_i \times A_i}{A_i}$					
Variables needed					
PPD – Percentage of people dissatisfied PPD_{lim} – PPD values lower than 10% t- evaluation time step T – Reference period Nt – Total number of timesteps at period n= Number of thermal zones A_i = Area of each thermal zone [m^2]					
Standardized Package (SP)					
SP9			SP15		
Demo building					

DC#1	DC#2	DC#3	DC#4	VDC#1	VDC#2

KPI07 - Indoor Air Quality – Carbon dioxide (CO_2) concentration index

In residential buildings, indoor air quality depends on many parameters and sources, such as number of occupants and time of occupancy, emissions from activities. For this reason, the *Environmental Protection Agency* (EPA) developed the Air Quality Index (AQI) to assess the overall air quality of a space.

Carbon dioxide (CO_2) concentration index, is proposed to describe the indoor air quality of an occupied space, when occupants are assumed to be the only source of pollution. Taking into consideration the outside air CO_2 concentrations with a range of 300ppm to 500ppm, high levels of CO_2 about 700ppm above outdoor air levels, indicate a significant impact on occupants' comfort and productivity, even leading to fatigue and inability to concentrate. CO_2 concentrations above outdoor levels correspond to three categories: **A: 460ppm, B: 660ppm and C: 1190ppm** [9] **.** Increasing ventilation, helps on fresh air renewal as to dilute indoor airborne pollutants coming from indoor sources [10].

KPI07 – CO_2 concentration index					
Category	Living Quality	Units	ppm	Level	3
Description					
$I_t^{CO_2}$ index is equal to 1 when the values of CO_2 concentration is lower than the proposed limit, or else it is calculated as the relation between the monitored/simulated value via the threshold					
Formula					
$$I_t^{CO_2} = \frac{\sum_{i=1}^{N} I_{t,i}^{CO_2}}{N}$$ $$I_{t,i}^{CO_2} = \begin{cases} 1 \text{ if } CO_{2,t,i} \leq CO_2^{Thres} \\ \frac{CO_{2,t,i}}{CO_2^{Thre}} \text{ otherwise} \end{cases}$$ $I_t^{CO_2}$ - The average value of CO_2 level indexes in a mentioned ventilated area at the time t					
Variables needed					
$CO_{2,t,I}$ – Index of CO_2 for the sensor i at the time t CO_2^{thres} - CO_2 threshold					
Standardized Package (SP)					
SP9			SP15		
Demo building					
DC#1	DC#2	DC#3	DC#4		

KPI08- Indoor Air Quality – Volatile Organic Compounds Concentration (VOCs)

Volatile Organic Compounds (VOCs) in indoor air (μg/m^3, ppm), are a collection of more than 165 microscopic airborne chemical or organic substances. Cooking, smoking, cleaning, household appliances, furniture and pets are the most common indoor sources of VOCs There are no federally enforceable standards for VOCs in non-industrial environments. Current guidelines or recommendations for VOC concentrations from various organizations can be found at https://iaqscience.lbl.gov/.

KPI08 – VOCs concentration					
Category	Living Quality	Units	mg/m^3, ppm	Level	3
Description					
Volatile organic compounds (VOCs) are compounds that have a high vapour pressure and low solubility in water. Many VOCs are man-made chemicals used and produced in the manufacture of paints, pharmaceuticals and refrigerants.					
Formula					
-					
Variables needed					
VOCs concentration					
Standardized Package (SP)					
SP9	SP10	SP11	SP12	SP15	
Demo building					
DC#1	DC#2	DC#3	DC#4		

In the frame of the GreeNest project, the Carbon dioxide (CO_2) concentration index and Volatile Organic Compounds (VOCs) will identified based only on monitoring results, because both KPIs cannot be simulated (Level 3).

KPI09 – Visual Comfort – Visual Comfort Availability (VCA)

Visual Comfort Availability (VCA) is an indicator that expresses the availability of a sufficient visual comfort parameter in a considered period of time.

KPI09 – Visual Comfort Availability (VCA)					
Category	Living Quality	Units	-	Level	1-2-3
Description					
Visual comfort parameter that can be introduced refers to the Daylight Glare Index (DGI), that indicates whether a glare situation is acceptable or intolerable. The maximum acceptable value of DGI is 22 corresponding to glare that is referred as "acceptable" [11].					

Zone	Region	DGI
	intolerable	>28
Discomfort	Just intolerable	28
zone	uncomfortable	26
	Just uncomfortable	24
Comfort	***Acceptable***	***22***
Zone	Just acceptable	20
	noticeable	18

		Just perceptible	16		
Formula					
$VCA = \sum_{i=1}^{N_t} wf_i \cdot \frac{t}{T} \quad \in [0,1]$ $wf_i = \begin{cases} 0 & \text{if } DGI \geq DGI_{lim} \\ 1 & \text{if } DGI < DGI_{lim} \end{cases}$					
Variables needed					
DGI – Daylight Glare Index DGI_{lim} – Daylight Glare Index threshold t- evaluation time step T – Reference period Nt – Total number of timesteps at period T					
Standardized Package (SP)					
SP9	SP10	SP11	SP12	SP15	
Demo building					
DC#1	DC#2	DC#3	DC#4	VDC#1	VDC#2

5.3 Technical KPIs (Energy assessment)

5.3.1 Technical KPIs Shortlist

The selected KPIs for the technical (energy) aspect are the following:

- KPI10- Primary Energy consumption (PE_c)
- KPI11- Produced on-site renewable energy (RE_{onsite})
- KPI12- Renewable Energy Ratio (RER)
- KPI13- Smart Readiness indicator (SRI)

5.3.2 Technical KPIs description

KPI10- Primary Energy consumption (PE_c)

Primary Energy Consumption is a major metric within the Energy Performance of Buildings Directive (EPBD – Directive 2010/31/EU), and one of the most crucial indicators regarding the energy assessment of buildings. This KPI concerns the total energy that is consumed annually for heating, cooling, ventilation and domestic hot water. For its calculation, the relevant primary energy factors of the different fuel sources are necessary.

Primary energy factors vary across countries. For international comparison of buildings, there are two conventions for defining primary energy factors, according to prEN 15603 [12] .

a) Total primary energy factor. The conversion factors represent all the energy overheads of delivery to the point of use, i.e. the production outside the building system boundary transport, extraction.

b) Non-renewable primary energy factor. The conversion factors represent the energy overheads of delivery to the point of use but exclude the renewable energy component of primary energy.

Each country provides the values of Primary Energy factors, which are part of their National Standards. Indicatively, for the energy performance calculation, a default of primary energy factors choice is given in Table (following table)

Primary energy factors (f_p) [12]			
Energy carrier	**Non-renewable primary energy factor**	**Renewable primary energy factor**	**Total primary energy factor**
Delivered from distance	$f_{p,del,nren}$	$f_{p,del,ren}$	$f_{p,del,tot}$
Gas	1.05	0.00	1.05
Oil	1.05	0.00	1.05
Grid electricity	2.30	0.20	2.50
Grid electricity by hydraulic power plant	0.50	1.00	1.50
Liquid biomass and biogas	0.50	1.00	1.50
Delivered from nearby	$f_{p,del,nren}$	$f_{p,del,ren}$	$f_{p,del,tot}$
District heating	1.30	0.00	1.30
District cooling	1.30	0.00	1.30
Delivered from on site	$f_{p,del,nren}$	$f_{p,del,ren}$	$f_{p,del,tot}$
Solar PV on site	0.00	1.00	1.00
Thermal solar on site	0.00	1.00	1.00
Exported to the grid	$f_{p,exp,nren}$	$f_{p,exp,ren}$	$f_{p,exp,tot}$
Cogeneration unit electricity	1.60	0.00	1.60
PV electricity	1.60	0.00	1.60
Temporary exported and reimported later	$f_{p,del,nren}$	$f_{p,del,ren}$	$f_{p,del,tot}$
Cogeneration unit electricity	2.00	0.00	2.00
PV electricity	2.00	0.00	2.00
Exported for immediate use	$f_{p,del,nren}$	$f_{p,del,ren}$	$f_{p,del,tot}$
Cogeneration unit electricity	2.50	0.00	2.50
PV electricity	2.50	0.00	2.50

KPI10 - Primary Energy consumption (PE_c)					
Category	Energy	Units	kWh/m²yr	Level	1-2-3
Description					
The primary energy can be normalized per unit floor area [kWh/m²yr] and defined by the following equation. PE_c is the primary energy consumption in [kWh/m²yr] and E_P is the primary energy use in [kWh/yr], calculated as the balance of the delivered energy, required to meet the energy demands of considered end-uses of the building (heating, cooling, ventilation, DHW), and A_b is the total area of the building in					

[m²]. A derivation of the appropriate energy performance indicators is necessary because of the different fuel sources i.e. thermal and electrical energy consumption.					
Formula					
$PE_c = \frac{E_P}{A_b}$, where $E_p = \sum(f_{P,del} \cdot E_{del}) - \sum(f_{P,exp} \cdot E_{exp})$					
Variables needed					
E_{del} – The delivered energy for the energy carrier [kWh/yr] $f_{P,del}$ –Primary energy factor for the delivered energy carrier E_{exp} – The exported energy for the energy carrier [kWh/yr] $f_{P,exp}$ – Primary energy factor for the exported energy carrier A_b – The total area of the building [m²]					
Standardized Package (SP)					
-					
Demo building					
DC#1	DC#2	DC#3	DC#4	VDC#1	VDC#2

KPI11- Produced on-site Renewable Energy (RE_{onsite})

The energy from the renewable sources can be calculated by the difference between the total energy consumption and the non-renewable energy of the considered energy flow carrying renewable energy (thermal solar, photovoltaics, heat pumps).

KPI11 - Produced on-site renewable energy ($E_{p,REonsite}$)					
Category	Energy	Units	kWh/m²	Level	1-2-3
Description					
Power and Area of building integrated renewable energy systems					
Formula					
$E_{p,REonsite} = \frac{\sum(E_{p,tot} - E_{p,nren})}{A_b}$					
Variables needed					
$E_{p,tot}$ – The total primary energy calculated using total primary conversion factors $f_{P,del,tot}$ and $f_{P,exp,tot}$ [kWh] Ep,nren– The non-renewable primary energy calculated using non-renewable primary conversion factors $f_{P,del,nren}$ and $f_{P,exp,nren}$ [kWh] A_b – The total area of the building [m²]					
Standardized Package (SP)					
SP14 (BIPV/PV)					
Demo building					
DC#1	DC#2	DC#3	DC#4	VDC#1	VDC#2

KPI12- Renewable Energy Ratio (RER)

Renewable Energy Ratio (RER) is defined as the ratio of energy from Renewable Energy Systems (RES) to the energy consumption of the building or dwelling over a period of time. It can be calculated for thermal demand (heating and cooling) and electricity demand as a whole or separately.

KPI12- Renewable Energy Ratio (RER)					
Category	Energy	Units	%	Level	1-2-3
Description					
Formula					
$RER = \frac{E_{p,REonsite}}{E_{p,tot}}$					
Variables needed					
$E_{p,tot}$ – The total primary energy [kWh] $E_{p,REonsite}$ – The renewable energy produced on-site [kWh]					
Standardized Package (SP)					
SP14 (BIPV/PV)					
Demo building					
DC#1	DC#2	DC#3	DC#4	VDC#1	VDC#2

KPI13- Smart Readiness indicator (SRI)

Integration of smart technologies into buildings offers a cost-effective approach to reducing the energy consumption and carbon emissions on buildings while improving the comfort and living quality conditions. These technologies can also streamline the incorporation of renewable energy sources into future energy systems. The Energy Performance of Buildings Directive (EPBD), emphasizes leveraging this potential to smart technologies within the building sector. EPBD sets out provisions to establish a “Smart Readiness Indicator” (SRI) to assess buildings’ smart readiness.

KPI13- Smart Readiness Indicator (SRI)					
Category	Energy	Units	%	Level	1-2-3
Description					
The calculation methodology is structured in a flexible and modular multi-criteria assessment method on 9 technical domains and 7 impact criteria. For each of the services, several functionality levels are defined. Enhanced functionality refers to a “smarter” implementation of the service, resulting more beneficial impacts to building users or to the grid compared to services implemented at a lower functionality level [13]. The key smart readiness functionalities are composed by 9 technical domains: 1. Heating; 2. Cooling; 3. Domestic Hot Water; 4. Ventilation; 5. Lighting;					

6. Dynamic building envelope; 7. Electricity; 8. Electric vehicle charging; 9. Monitoring and control and 7 smart readiness impact criteria: 1. Energy efficiency; 2. Maintenance and fault prediction; 3. Comfort; 4. Convenience; 5. Health, well-being and accessibility; 6. Information to occupants; 7. Energy flexibility and storage					
Formula					
SRI assessment can be found upon request in this link https://ec.europa.eu/eusurvey/runner/SRI-assessment-package . It is a Spreadsheet that can be filled by the user and calculates the SRI degree.					
Variables needed					
Information regarding the building (use, location, etc) The overview of service list The functionality level for each technical domain					
Standardized Package (SP)					
-					
Demo building					
DC#1	DC#2	DC#3	DC#4	VDC#1	VDC#2

5.4 Economic KPIs (LCC)

Cost effectiveness is a crucial parameter in construction projects while Life Cycle Cost (LCC) analysis, provides a method to calculate total expenses of building structures over their expected lifetime, covering both operating and maintenance costs. A main advantage of LCC effectiveness is its evaluation at different phases of the building's lifecycle, more specifically in three stages including conceptual stage, acquisition stage and operational stage. LCC considers all the related costs required for construction, operational, maintenance and end of life costs of buildings. Moreover, it provides the stakeholders with the financial information to maintain, improve and construct facilities. Also, financial benefits associated with energy use can also be calculated using LCC analysis.

5.4.1 Economic KPIs Shortlist

The selected KPIs for the economic aspect are the following:

- KPI14- Investment Cost (IC)
- KPI15- Operational Expenditures (OPEX)
- KPI16- End-of-life (EoL) Costs
- KPI17- Financial Benefits for the locals

5.4.2 Economic KPIs description

KPI14- Investment Cost (IC)

KPI14 – Investment Cost (IC)									
Category	Economic	Units	€	Level	1-2				
Description									
Capital Expenditures describes the costs of contract purchase price of investments acquired, acquisition expenses, capital expenditures and other customarily capitalized costs but excludes acquisition fees									
Formula									
$IC = \sum investments$									
Variables needed									
Data available from the SPs and demo buildings partners/constructors									
Standarized Package (SP)									
SP1	SP2	SP3	SP9	SP10	SP11	SP12	SP13	SP14	SP15
Demo building									
DC#1	DC#2	DC#3	DC#4						

KPI15- Operating Expenses (OPEX)

KPI15 – Operating Expenses (OPEX)									
Category	Economic	Units	€/year	Level	1-2-3				
Description									
Operational Expenditures refers to all the ongoing costs associated with maintaining, operating and managing the building and the installed systems.									
Formula									
$OPEX = \sum \text{Building Operating Costs} + \sum \text{Energy System Operating Costs}$									
Variables needed									
Operating costs Utilities, maintenance, energy consumption, Monitoring and control, site, Energy management, HVAC systems, Lighting, RES, Energy management systems,									
Standardized Package (SP)									
SP1	SP2	SP3	SP9	SP10	SP11	SP12	SP13	SP14	SP15
Demo building									
DC#1	DC#2	DC#3	DC#4						

KPI16- End – of -life (EoL) Costs

KPI16 – End-of-life (EoL) Costs					
Category	Economic	Units	€	Level	1-2-3
Description					

End-of–life (EoL) costs, for buildings and their energy systems encompass a variety of expenses related to the decommissioning, demolition, and disposal of materials and systems, along with environmental and administrative expenses. These costs are key factors in the lifecycle management of the building sector.
Formula
-
Variables needed
• Decommissioning and Demolition Costs: labour, equipment, permits and compliance) • Disposal and recycling Costs: Waste management – recycling – Landfill Fees • Environmental Costs: Carbon Footprint – Sustainability Initiatives • Energy Systems Costs: Dismantling Energy Systems – Hazardous Material Handling - Recycling of Energy Components • Administrative and Legal Costs: Project Management – Documentation and Reporting • Future use and Land Reclamation: Site Restoration
Standardized Package (SP)

SP1	SP2	SP3	SP9	SP10	SP11	SP12	SP13	SP14	SP15

Demo building			
DC#1	DC#2	DC#3	DC#4

KPI17- Financial benefits for the locals

KPI17 – Financial benefits for the locals					
Category	Economic	Units	€	Level	1-2-3
Description					
Availability of local resources: • Attractive to the local workmanship. The concept is based and/or is fully adoptable with /to the traditional building techniques, minimising their training and special skill need. Moreover, the ease of use increases the productivity, leading to lower labor cost. • Increasing job opportunities in the local community, thereby providing income to people in the region. Also, eco-friendly materials lead to construction projects with priority to sourcing materials locally, creating business opportunities for the local suppliers and manufacturers. (Sustainable Development Goal 8)					
Formula					
-					
Variables needed					
-					
Standardized Package (SP)					
-					
Demo building					

DC#1	DC#2	DC#3	DC#4

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5.5 Social KPIs (CBA)

Social KPIs for Zero emission Buildings and innovative energy system packages, are essential for assessing how effectively these fulfil the diverse needs and expectations of various stakeholders. This encompasses occupants, investors, employees, the local community and regulatory bodies. The social KPIs will be calculated within the Cost Benefit Analysis (CBA) of each demo case.

5.5.1 Shortlist of Social KPIs

The selected KPIs for the social aspect are the following:

- KPI18- Intangible Environmental benefits
- KPI19- Intangible Social benefits
- KPI20- Stakeholders Satisfaction

5.5.2 Social KPIs description

KPI18- Intangible Environmental benefits

<table>
<tr><th colspan="6">KPI18 – Environmental benefits</th></tr>
<tr><td>Category</td><td>Social - CBA</td><td>Units</td><td>Scale 1-5</td><td>Level</td><td>1-2-3</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">Environmental benefits refer to:
• Reduction in Greenhouse Gas Emissions and lower air pollution. These can improve the microclimate and make the area more attractive (Goal 11) [1]
• Enhanced Biodiversity. The use of green roofs, living walls, and sustainable landscaping in ZeBs, supports urban biodiversity by providing habitats for plants, birds, and insects.
• Energy poverty tackling. The combination of the energy efficient systems with the on-site energy production by renewable system.</td></tr>
<tr><td colspan="6">Formula</td></tr>
<tr><td colspan="6">Qualitative Assessment: In this case can be used qualitative measures for non-quantifiable factors. These can be scored or ranked based on their perceived importance. To integrate quality variables effectively, assign weights to each factor based on its importance to the overall objectives. The considered variables will be classified into levels (from 1 to 5) using questionnaires.</td></tr>
<tr><td colspan="6">Variables needed</td></tr>
<tr><td colspan="6">A questionnaire will likely be developed.</td></tr>
<tr><td colspan="6">Standardized Package (SP)</td></tr>
<tr><td colspan="6">-</td></tr>
<tr><td colspan="6">Demo building</td></tr>
<tr><td>DC#1</td><td colspan="2">DC#2</td><td>DC#3</td><td colspan="2">DC#4</td></tr>
</table>

KPI19- Intangible Social benefits

KPI19 – Social benefits					
Category	Social - CBA	Units	-	Level	1-2-3
Description					
Social benefits include qualitative variables such as: • Diminishment of health - related costs e.g. absenteeism and sick leave, hospitalization and morbidity (Goal 3). • Public awareness – sensitization. • Socialization. • Comfortable and attractive facilities with well organized activities (Goal 11) [1].					
Formula					
Qualitative Assessment: In this case can be used qualitative measures for non-quantifiable factors. These can be scored or ranked based on their perceived importance. To integrate quality variables effectively, assign weights to each factor based on its importance to the overall objectives. The considered variables will be classified into levels (from 1 to 5) using questionnaires.					
Variables needed					
A questionnaire will be probably created.					
Standardized Package (SP)					
-					
Demo building					
DC#1	DC#2	DC#3	DC#4		

KPI20- Stakeholders Satisfaction

KPI20 - Stakeholders Satisfaction															
Category	Social - CBA	Units	Scale 1-5	Level	3										
Description															
Scale 1-5 with 1 being “Not Suitable” and 5 “Very Suitable”															
Variables needed															
• Occupant Satisfaction regarding Indoor Air Quality, Thermal Comfort and Lighting Quality, space utilization • Community impact evaluating the effectiveness of the building’s impact on the local community • Investor and regulatory satisfaction in relation to cost savings from energy efficiency and reduced maintenance cost.															
Standardized Package (SP)															
SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10	SP11	SP12	SP13	SP14	SP15	SP16
Demo building															
DC#1	DC#2	DC#3	DC#4												

6. Conclusions

This report presents the process and steps followed in the GreeNest project for the definition of the Key Performance Indicators (KPIs), analyzing the methodology that leads to the selection of a list of indicators that address the main objectives of the project. For this purpose, a detailed approach has been developed leading to the selection of the most representative KPIs for the GreeNest project. The initial compilation of an extensive list of KPIs, related to the Level(s) framework and SDGs 7,9,10 and 11, is then refined, ensuring alignment with the project's specific objectives and goals, which are based on established reports and standards within EU and national regulations.

The current report provides a comprehensive list of KPIs for evaluating integrated solutions based on a digitised platform for a unified ecosystem incorporating both abiotic and biotic solutions, enabling rapid and widespread adoption of Zero emission Buildings. The selected KPIs support the comprehensive evaluation of the GreeNest ecosystem, assessing the SPs and demo buildings in terms of environmental impact, living quality (comfort), energy efficiency, economic performance, and social aspects. Additionally, an extensive list of KPIs is presented for evaluating individual technologies and specific cases.

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7. Annex

The following table presents the extended list of KPIs from which the indicators, relevant to the GreeNest objectives, were selected following the methodology that was described in the corresponding chapter of this report.

	KPIs	Symbol	Units	Component
Technical	Thermal conductivity	k	[W/(mK)]	SP/Material level
	Thermal Transmittance / Resistance of a wall system	U-value / R-value	W/m^2K	Building element / Building level
	Thermal Transmittance of windows	U_w	W/m^2K	Windows systems
	Solar heat gain coefficient	g-value or SHGC		Windows systems
	Visible Transmittance	$T_{vis\text{-}glass}$		Windows systems
	Final energy use	FE_{use}	kWh/yr	Building level
	Primary energy Demand/consumption	PE_d/PE_c	kWh/m^2yr	Building level
	Non- Renewable primary energy	E_{p_nren}	kWh	Building level
	Renewable Energy Ratio	RER	kWh/m^2yr	Building level
	Thermal Energy demand	TE_d	kWh/m^2yr	Building level
	Thermal Energy consumption	TE_c	kWh/m^2yr	Building level
	Electric consumption of mechanical ventilation	E_{fan}	kWh/m^2	Building level
	Energy consumption for Domestic Hot Water	E_{DHW}	kWh/m^2yr	Building level
	Energy from solar panels DHW	$E_{sol,DHW}$	kWh/m^2yr	Building level
	Energy needs for lighting	E_{LIGHT}	kWh/m^2yr	Building level
	Seasonal performance factor	SPF	-	SPs level
	Seasonal Coefficient of Performance	SCOP	-	SPs level
	Building integrated renewable energy supply	BIRES	kWh	Building level
	Produced on-site renewable energy	$E_{p,REonsite}$	$[kW/m^2]$	Building level
	Renewable Energy Ratio	RER	kWh/m^2yr	Building level
	Energy self-sufficiency from renewable energy	-	[%]	Building level
	Automation controls for heating/Cooling (EN 15232:2007)	-	Scale 1-4	Building level
	Automation controls for lighting	-	Scale 1-3	Building level
	Smart readiness indicator	SRI	%	Building level
Environmental-LCA	Global Warming Potential	GWP100	$kgCO_{2eq}$	Building/SPs level
	Green House Gas emissions	GGE	$kgCO_{2eq}/m^2yr$	Building/SPs level

	Embodied Carbon (Upfront carbon)	ECE	[$kgCO_{2eq}/m^3$] or [$kgCO_{2eq}/m^2$]	Building/SPs level
	Recyclability	REC	%	Building/SPs level
	Carbon storage	CCS	$kgCO_{2eq}/m^3$	SPs level
	Avoid Emissions	AE	$kgCO_{2eq}$]	Building/SPs level
Comfort and IAQs	PMV: Predicted Mean Vote or PPD: Predicted Percentage of Dissatisfied	PMV/ PPD Or DH_{exc}	-	building level / Thermal zone
	Thermal comfort Availability	TCA	hr	Building level
	Overheating hours	OH	hr	
	Daylight Factor	DF	%	Building level
	Daylight Glare Index	DGI	-	Building level
	Visual Comfort Availability	VCA	hr	Building level
	Indoor Air Quality	I^{CO2}	ppm	Building level
	Acoustic Performance/Comfort	AC	dBA	Building level
Economic	Investment Costs	IC	€	Building/SPs level
	Operational & Maintenance Costs	OPEX	€/yr	Building/SPs level
	End-of-life Costs	EoL Costs	€	Building/SPs level
	Cost of potential risks	-	€	Building level/ energy system
	Direct financial benefits		€/yr	Building/SPs level
	Financial benefits for the locals	-	€	Building/SPs level
Social	Acceptance from local communities	-	Custom scale	Building/SPs level
	Accessibility for people with specific needs	-	Custom scale	Building/SPs level
	View from local authorities	-	Custom scale	Building/SPs level
	Stakeholders' satisfaction	-	Custom scale	Building/SPs level
	Functionality	-	Custom scale	Building/SPs level
	Environmental benefits	-	$kgCO_{2eq}/m^2yr$	Building/SPs level
	Social benefits	-	-	Building/SPs level

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