BIMERR
RENOVATION 4.0

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DELIVERABLE D7.4
Life Cycle Cost/Assessment Module 2

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ACRONYMS

Acronym	Meaning
BIF	BIMERR Interoperability Framework
BIMERR	BIM-based holistic tools for Energy-driven Renovation of existing Residences
IFC	Industry Foundation Classes
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
RenoDSS	BIMERR Renovation Decision Support System

EXECUTIVE SUMMARY

This document describes the BIMERR Deliverable D7.4 "Life Cycle Cost/ Assessment Module 2" demonstrator and concludes the final iteration of the development activities in T7.2 "Renovation LCA/LCC module". This final release of the BIMERR LCA/LCC module provides 16 KPIs about the financial and sustainability impact of the renovation scenario under investigation. The relevant input data is extracted from the renovation scenario's IFC file. The IFC file is populated with sustainability data from the BIMERR Material and Component Database and project-specific financial data provided by the user via the BIMERR Renovation Support Tools user interface.

In the final release of the BIMERR LCA/LCC module we (i) implemented methods to check and complete missing energy- and LCA/LCC-related building material data, (ii) take project-specific energy costs, interest rates, environmental costs, and CO_2 emission rates at the KPI calculation into account, (iii) implemented the possibility to enter and visualize monetary units in renovation-project-specific currencies, (iv) implemented methods to extract and match IFC units with material units from the BIMERR Component and Material database, (v) implemented methods to calculate building element area and height measures using data provided in the IFC file, (vi) implemented the renovation scenario KPI calculation (e.g. life cycle cost) as described in D7.3 and (vii) evaluated if the integration of openLCA provides additional benefit to the RenoDSS user.

The BIMERR LCA/LCC module is based on state-of-the-art technologies and three layers: (i) the Presentation Layer, which allows the user to set his/her preferred data sources for sustainability data and project-specific financial data. The user interface is built upon Angular, Typescript, and NGRX Entity/Store, (ii) the Business Logic Layer which calculates the KPIs based on the IFC file and the financial and sustainability data for the building materials used in the renovation scenario, and (iii) the Data Layer that utilizes PostgreSQL to store preferred data sources, project-specific financial data, and calculated KPIs for faster access at later usage.

1. INTRODUCTION

The BIMERR LCA/LCC module provides information about the financial and sustainability impact of the renovation scenario under investigation. Cost is usually one of the most critical parameters in deciding whether to proceed with the renovation effort and needs to be seen on a long-term horizon to properly aid decision making. The LCA/LCC module takes project-specific **purchasing, installation, and maintenance costs** of renovation measures into account. It also aims at accurately estimating **yearly energy cost savings** based on potential renovation measures and the increased energy efficiency figures which are provided by the BIMERR Building Energy Performance module (D7.6). Besides costs, the LCA/LCC module provides **sustainability KPIs** to estimate and compare the overall sustainability impact of potential renovation scenarios.

1.1 Scope and Objectives of the Deliverable

D7.4 "Life Cycle Cost/ Assessment Module 2" reports the development activities in the context of Task T7.2 "Renovation LCA/LCC module" of WP7 "Renovation Decision Support System". It documents the final version of the BIMERR LCA/LCC module, which is responsible for providing 16 KPIs about the financial and sustainability impact of the renovation scenario under investigation.

The objective of this document is to give an overview and documentation of the final release of the BIMERR LCA/LCC module and describe:

- Functionalities of the BIMERR LCA/LCC module
- Technology stack
- Communication with the BIMERR data management module
- Assumptions and restrictions of the final release
- Installation instructions
- Usage walkthroughs
- Licensing

1.2 RELATION TO OTHER TASKS/DELIVERABLES

T7.2 "Renovation LCA/LCC module" and therefore D7.4 "Life Cycle Cost/ Assessment Module 2" are related to the following BIMERR deliverables:

- D3.1 "Stakeholder requirements for the BIMERR system": the business scenarios, use cases, and system requirements described in D3.1 are the basis for the development of the BIMERR LCA/LCC module.
- D3.3 "BIMERR evaluation methodology": economic and sustainability KPIs described in D3.3 are calculated by the LCA/LCC module.
- D3.6 "BIMERR system architecture final version": the final version of the BIMERR architecture provided an overview on the BIMERR components, how they communicate to each other and how the BIMERR LCA/LCC module is embedded in the BIMERR Renovation Support Tools.
- T7.1 "Building components database design and development" provides the BIMERR Material and Component Database which is used by the BIMERR LCA/LCC module as data source for sustainability figures of building materials and components used in the renovation scenarios.
- D7.3 "Life Cycle Cost/Assessment Module 1" provided the basis for the extensions developed in D7.4.
- T8.1 "External Information Availability and Sourcing": ensures that financial and sustainability data relevant for pre-validation and validation sites is available in the BIMERR Material and Component Database.

2. BIMERR LCA/LCC MODULE

2.1 OVERVIEW

The BIMERR LCA/LCC module provides information about the financial and sustainability impact of the renovation scenario under investigation. Based on D3.3 the following economic and sustainability KPIs are provided by the LCA/LCC module:

- Economic
    - Construction cost in €
    - Operation cost during period of analysis in €
    - Maintenance cost during period of analysis in €
    - End of life cost in €
    - Life cycle cost during period of analysis in €
    - Payback period in years
- Sustainability
    - Environmental cost indicator in €/m²
    - GWP100a total global warming potential in kg CO2-eq/m²
    - Acidification potential of soil and water (AP) in kg SO2-eq/m²
    - Depletion potential of the stratospheric ozone layer (ODP) in kg-CFC11/m²
    - Abiotic depletion potential for non-fossil resources (ADPE) in kg Sb-eq/m²
    - Eutrophication potential (EP) in kg PO4-3-eq/m²
    - Abiotic depletion potential for fossil resources (ADPF) in MJ/m²
    - Formation potential of tropospheric ozone (POCP) in (kg ethylene/m²)/m²
    - CO2 emission rate in kg CO2/m²
    - CO2 emissions reduction in %

The necessary input data to calculate these KPIs is obtained from the BIMERR Material and Component Database and project-specific financial/building-material data provided by the user. Please see D7.3 "Life Cycle Cost/Assessment Module 1" for a detailed description regarding (i) renovation measures supported by the LCA/LCC module, (ii) LCA/LCC KPI definitions and calculation formulas, (iii) how input data for the LCA/LCC KPI calculation is extracted from the IFC file, and (iii) KPI calculation formulas.

The final version of the BIMERR LCA/LCC module is embedded in BIMERR RenoDSS and available at[1]: https://renodss.xylem-technologies.com/

2.2 Architecture

Based on the final BIMERR architecture (D3.6), Figure 1 shows the architecture of RenoDSS and its modules. The main aim of RenoDSS is to put forward an intuitive and easy-to-use interface that illustrates the renovation options, evaluates their impact on the building performance and guides the user through various alternatives towards the optimal choice for given boundary constraints (such as size of intervention, budget, target energy savings, etc.). RenoDSS will offer to the user a renovation configurator that will allow her to explore alternative renovation interventions.

RenoDSS communicates via the RenoDSS Data Management Module with the BIMERR LCA/LCC module. The Data Management Module sends the IFC file, containing all relevant information about the renovation scenario to the LCA/LCC module, which returns the KPIs as listed in Section 2.1. The economic and environmental KPIs of the final renovation scenario are provided by the RenoDSS Data Management module to the BIF (BIMERR Interoperability Framework).

[1] Please send an email to support@xylem-technologies.com to request credentials.

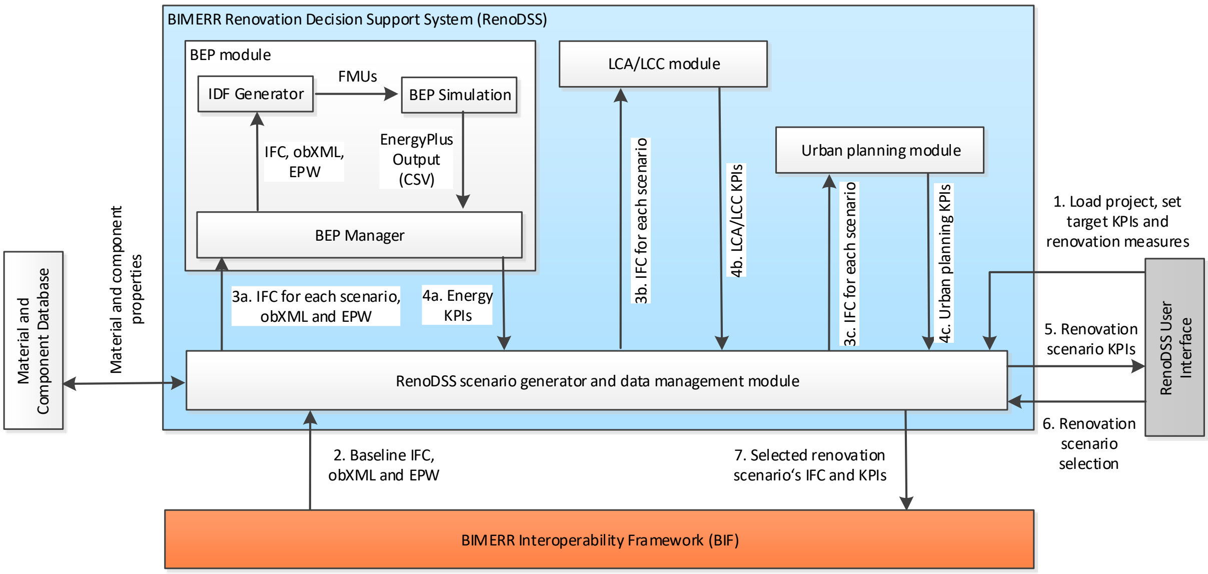

Figure 1: Architecture of the BIMERR Renovation Support Tools

2.3 Technology Stack and Implementation Tools

The BIMERR LCA/LCC module is based on state-of-the-art technologies and three layers:

- The Presentation Layer, which allows the user to set his/her preferred data sources for sustainability data and project-specific financial data. The user interface is built upon Angular, Typescript, and NGRX Entity/Store.
- The Business Logic Layer which calculates the KPIs based on the IFC file and the financial and sustainability data for the building materials used in the renovation scenario.
- The Data Layer that utilizes PostgreSQL to store preferred data sources, project-specific financial data, and calculated KPIs for faster access at later usage.

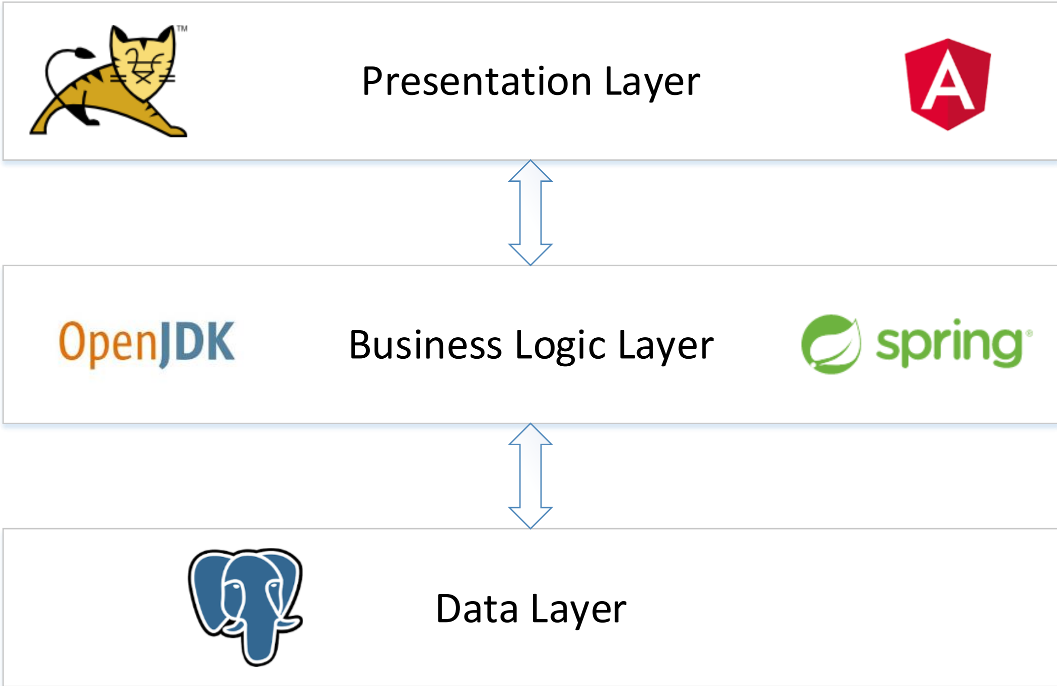

Figure 2: Architecture of the BIMERR LCA/LCC module

The BIMERR LCA/LCC modules utilizes the open source technologies and libraries as defined in the following table.

Table 1: Technologies and libraries used in BIMERR LCA/LCC module

Name of the technology/library	Version	License
Apache Tomcat	9	Apache License 2.0 license
Angular	8	MIT License
Typescript	3.5.3	Apache License 2.0 license
NGRX Entity/Store	8.5.2	MIT-style License
Java OpenJDK	11	GPLv2
Spring Boot	2.2.1	Apache License 2.0 license
PostgreSQL	9.5	PostgreSQL License (similar to BSD/MIT)
Hibernate	5.4.8	LGPL 2.1

In the following sections we describe the functionalities which were developed and released in the second and final BIMERR LCA/LCC module development iteration.

2.4 CHECK AND COMPLETE MISSING BUILDING MATERIAL DATA

To obtain all material- and project-specific data needed for KPI calculation, users are asked to provide missing parameters. On selecting a project in the project list the corresponding IFC file is sent to the .NET open source xbim Toolkit[2] Service. All relevant material and element data are extracted and checked for completeness. A form is provided to input missing data (see Figure 3).

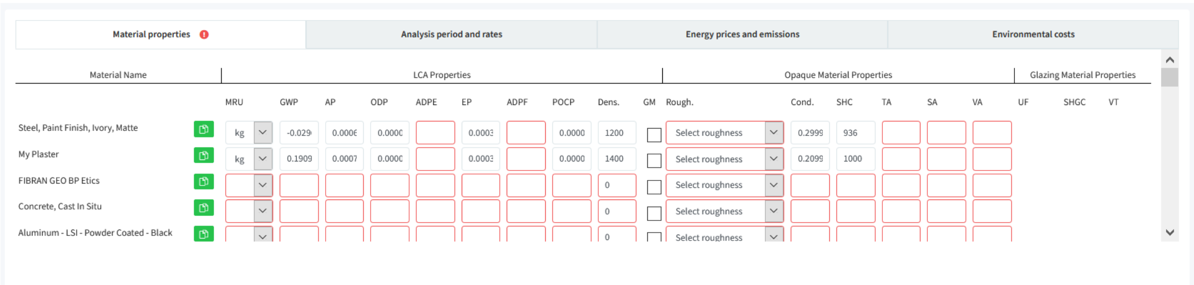

Figure 3: User interface for missing material data

The parameters are separated into different categories (LCA properties, opaque material properties, glazing properties, component properties, etc.). The category LCA Properties consists of parameters used for sustainability KPI calculation. If the user does not provide all required values a warning is issued describing the KPIs that will not be calculated due to missing data. For a detailed description of the KPI calculation parameters please refer to deliverable D7.3.

The user can choose to either input values manually or choose an equivalent material or component from the BIMERR Component and Material database to copy its values (see Figure 4).

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[2] https://docs.xbim.net/, last access: 25.11.2020

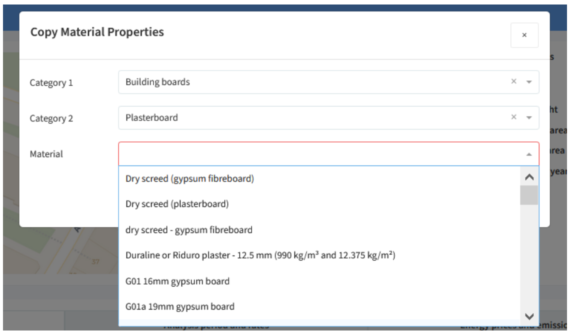

Figure 4: Copy values from existing materials

To calculate economic KPIs financial information about the materials/elements installed in the building are necessary and can be entered by the user using the form provided in the base data view (see Figure 5). Cost and lifetime data are prefilled with default values associated to the material of the layer. While default lifetime values for materials are provided by integrated third-party databases such as Oekobaudat, default cost values are derived from data which has been entered by other users for the same material in RenoDSS. If no user-entered cost data is available for the material, placeholder cost of "1" will be entered as default value into the cost input field. The installation year is prefilled with the construction year defined on project level.

Figure 5: User interface for missing building material data

The original IFC file as well as the building material data provided by the user are sent to the xbim Toolkit Service where the IFC file is extended with the values provided by the user using IfcMaterialProperties[3] to link the values to the corresponding material or layer. The old IFC File is replaced with the modified and extended IFC file. The

3 https://standards.buildingsmart.org/IFC/DEV/IFC4_2/FINAL/HTML/schema/ifcmaterialresource/lexical/ifcmaterialproperties.htm, last access: 11.05.2021

implementation of the IFC-file extension with the values described in the tables above is described in D7.10 – Integrated BIMERR Renovation Decision Support System 2.

2.5 Project-specific energy costs, interest rates, environmental costs, and CO2 emission rates

To calculate project specific LCA/LCC KPIs a user interface for setting energy costs, interest rates, environmental costs, and CO2 emission rates is provided in the base data screen. The initial values are based on region-specific or global values which are maintained by users associated to the administrator role. The values entered by the user are stored in the database in association to the project for later usage.

Those values are separated into 3 different categories: (i) analysis period and rates, (ii) energy prices and (iii) emissions and environmental costs:

<u>Analysis period and rates</u>

The following values can be defined by the user:

- Period of analysis in years describes the period for economic KPI analysis
- Expected discount rate describes the yearly discount rate that is expected for all costs
- Expected escalation rate for construction and maintenance cost per year
- Expected escalation rate for end-of-life cost describes the escalation rate for disposal cost per year

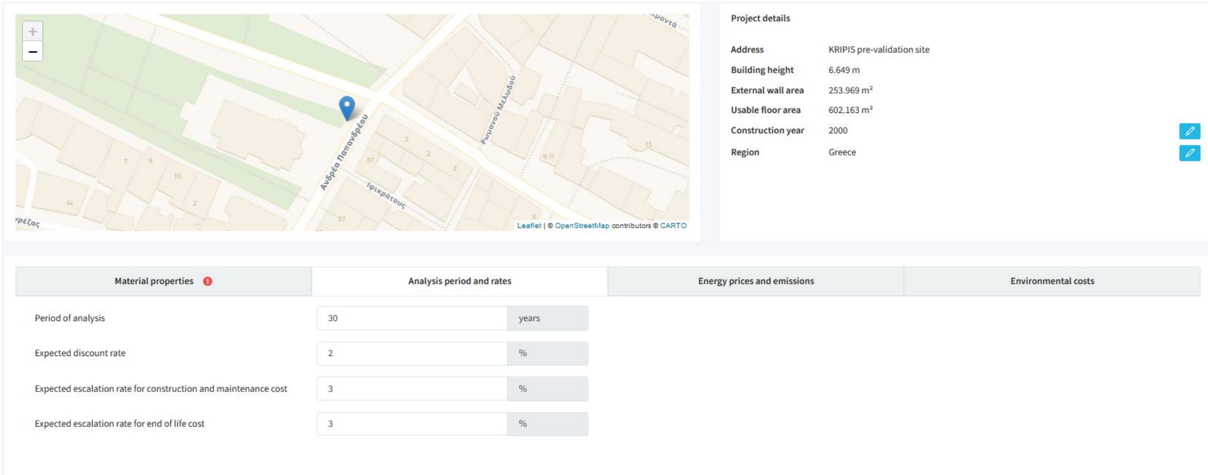

Figure 6: Project-specific values for KPI calculation – analysis period and rates

Energy prices and emissions:

For each energy carrier provided by users associated to the administration role the user can define the following values:

- Current energy price defines the current energy price for the carrier per kWh in project-specific currency
- Expected escalation rate for the energy price per year
- CO2 emission rate in kg/kWh

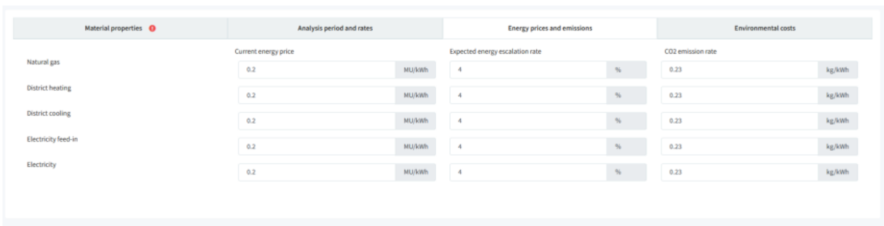

Figure 7: Project-specific values for KPI calculation – energy prices and emissions

Environmental costs:

To calculate a single environmental shadow price for the entire renovation scenario the impact in project-specific currency (e.g., Euro) of the following values can be defined:

- GWP: Global warming potential (price per kg CO2-eq)
- ODP: Depletion potential of the stratospheric ozone layer (price per kg CFC)

- EP: Eutrophication potential (price per kg PO4-3-eq)
- POCP: Formation potential of tropospheric ozone (price per kg C2H4-eq)
- AP: Acidification potential of soil and water (price per kg SO2-eq)
- ADPE: Abiotic depletion potential for non-fossil resources (price per kg Sb-eq)
- ADPF: Abiotic depletion potential for fossil resources (price per kg Sb-eq)

Figure 8: Project-specific values for KPI calculation – Environmental costs

2.6 Region- and project-specific currencies

User associated to the administrator role can change and define currencies for regions and the associated projects. This function is available in the "General" tab in the admin user view.

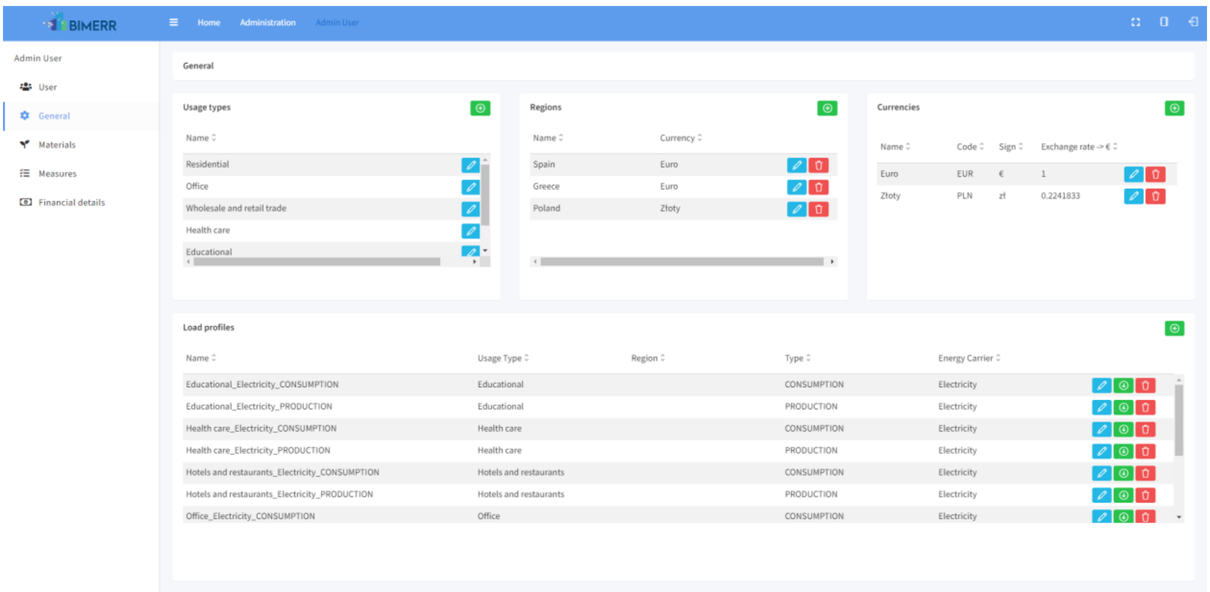

Figure 9: General administration view - currencies

A new currency and its exchange rate can be created by clicking the green “Add” button in the currencies section, which opens a modal with the appropriate input fields (see Figure 10).

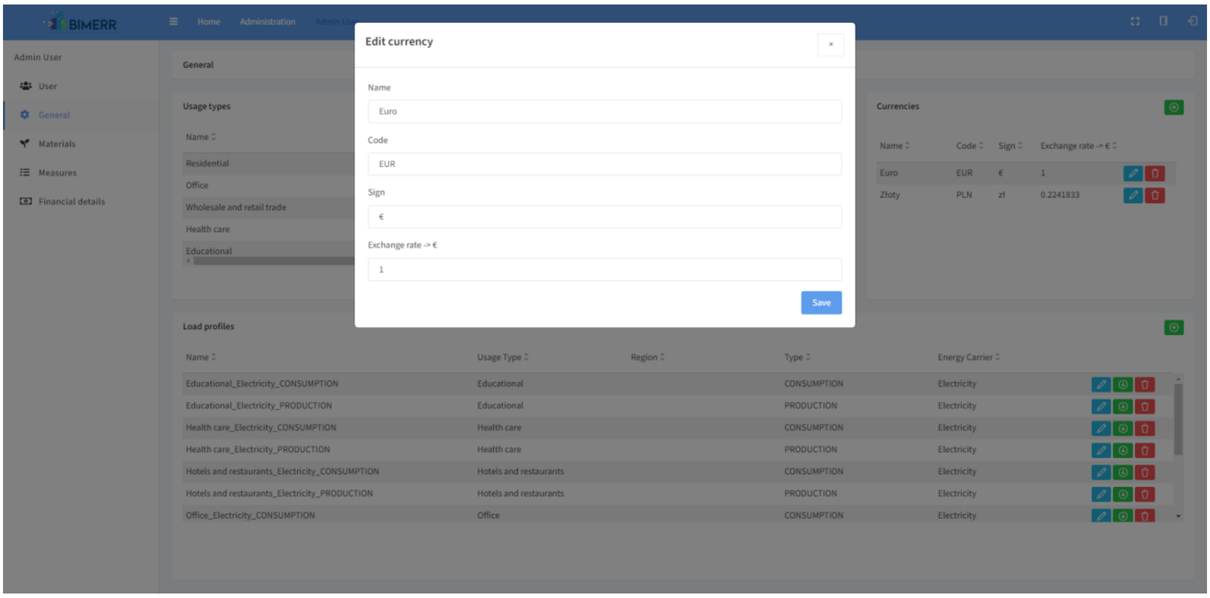

Figure 10: Create/edit currency modal

The exchange rate is defined as the price of 1 project-specific currency unit in Euros and not vice versa. Clicking the “Save” button will save the currency to the database and show it in the “Currencies” section of the page. For modifying a currency, the blue “Edit” button needs to be clicked. A delete functionality is available as well and can be accessed by clicking the red “Delete” button. After a currency is defined, it can be selected in the “Add”- or “Edit region” modal to assign it to a region (see Figure 11). The defined currency will be used in future projects assigned to this region.

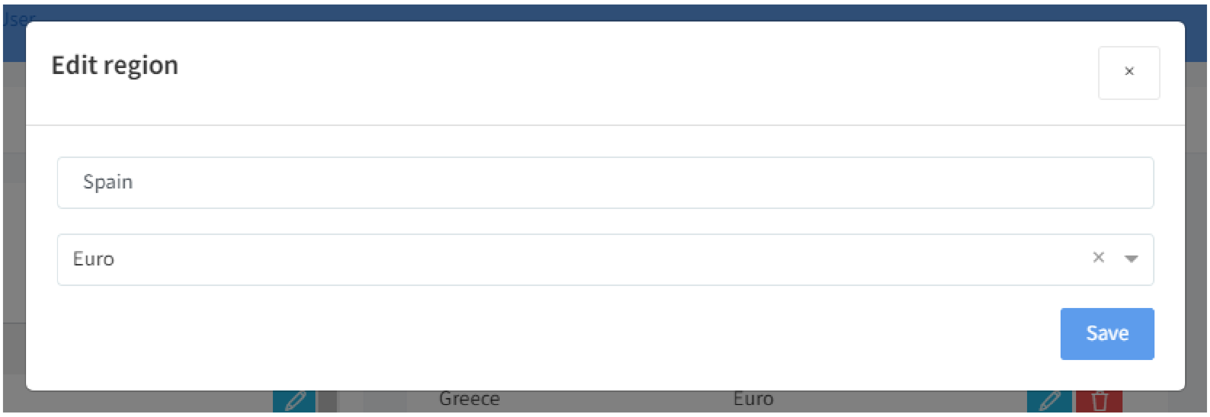

Figure 11: Assigning a currency to a region

Currencies can only be set at new projects. It is not possible to change the currency for existing projects. All globally defined monetary values (e.g., renovation measures) are stored in Euros and converted to the project-specific currency when used for the first time in the project. The project's currency is shown in the RenoDSS base data view (see Figure 12).

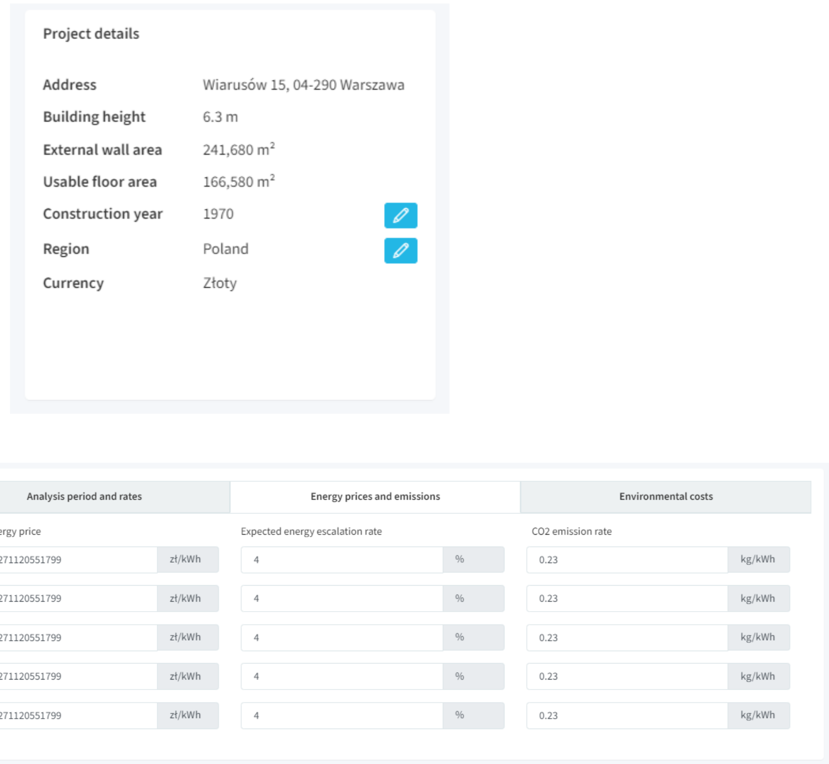

Figure 12: Project-specific currency in base data view

Economic KPIs are calculated in the project's currency and displayed accordingly (see Figure 13).

KPIs

Economic	Status quo	Target
Life cycle cost during period of analysis (in Złoty)	270,192,680	
Maintenance cost during period of analysis (in Złoty)	178,275,953	
Operation cost during period of analysis (in Złoty)	87,582,913	

Figure 13: KPIs in project-specific currency

Renovation measure costs are also stored in the project's currency and will be displayed as such. If costs are retrieved from globally defined construction layers they will be converted to the project-specific currency (see Figure 14).

Layers

Position	Layer name	Material	Thickness (mm)	Material cost (zł/m^2)	Installation cost (zł/m^2)	Maintenance cost (zł/m^2)	Disposal cost (zł/m^2)
1	Adhesive	Adhesives - synthetic resin adhesive	5	5.00	5.00	1.00	1.00
2	Insulation	Glass wool MW(GW)-PT 10 (90 kg/m^3)	50	12.00	12.00	12.00	2.00
2	Insulation	EPS-F (15.8 kg/m^3)	200	20.00	40.00	1.00	10.00
2	Insulation	EPS-F grey/black (15.8 kg/m^3)	50	12.00	12.00	12.00	1.00
3	Plaster	Single coat plaster mortar for exterior use C	2	2.00	2.00	6.00	3.00

Figure 14: Renovation measure cost in project-specific currency

2.7 Unit extraction and mapping

To match IFC units with material units from the BIMERR Component and Material database it is necessary to extract units used in the IFC file and send them to RenoDSS where the conversion factor to the reference unit of the material is calculated.

2.7.1 IFC file unit extraction and mapping

The .NET open source xbim Toolkit[4] Service is used to load and parse the IFC file as described in Section 2.5 of deliverable D7.3. To extract the units, the IFC file is parsed and all values that are defined as IfcSiUnit[5] or IfcUnit[6] and associated to the project via IfcUnitAssignment[7] are extracted and sent to RenoDSS in a JSON[8] structure. The following code snippets show an example for the IFC input and the JSON output.

```
#43=IFCSIUNIT(*,.LENGTHUNIT.,$,.METRE.);
#44=IFCSIUNIT(*,.AREAUNIT.,$,.SQUARE_METRE.);
#45=IFCSIUNIT(*,.VOLUMEUNIT.,$,.CUBIC_METRE.);
#51=IFCSIUNIT(*,.MASSUNIT.,.KILO.,.GRAM.);
```

```
[
   {
       "name": "KILOGRAM",
       "type": "MASSUNIT",
       "prefix": "KILO",
       "power": 1000,
       "symbol": "kg"
   },
   {
       "name": "CUBICMETRE",
       "type": "VOLUMEUNIT",
       "prefix": "",
       "power": 1,
       "symbol": "m³"
```

---

4 https://docs.xbim.net/, last access: 11.05.2021

5 https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD1/HTML/schema/ifcmeasureresource/lexical/ifcsiunit.htm, last access: 11.05.2021

6 https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2/HTML/schema/ifcmeasureresource/lexical/ifcunit.htm, last access: 11.05.2021

7 https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2/HTML/schema/ifcmeasureresource/lexical/ifcunitassignment.htm, last access: 11.05.2021

8 https://www.json.org, last access: 11.05.2021

```
    },
    {
        "name": "SQUAREMETRE",
        "type": "AREAUNIT",
        "prefix": "",
        "power": 1,
        "symbol": "m²"
    },
    {
        "name": "METRE",
        "type": "LENGTHUNIT",
        "prefix": "",
        "power": 1,
        "symbol": "m"
    }
]
```

2.7.2 Building material unit conversion

For each material, a reference unit (see Section 2.4) needs to be present to interpret all other values. If the reference unit does not correspond with the element unit (m, m^2, m^3), all data necessary for conversion such as area, thickness, density and unit of reference is sent to the unit conversion service where the conversion factor is calculated and sent back to the LCA/LCC Service for KPI calculation.

2.8 CALCULATION OF AREA AND LENGTH MEASURES

The IFC-Standard offers different approaches to extract measures of building elements. Measures can be defined using an IfcPropertySet[9] providing values for area and/or length measures. Example:

```
#468=
IFCPROPERTYSET('31gUPiJjz4Qvpt7MhCOGVg',#42,'Dimensions',$,(#450,#448,#449,#452,#451));
#448= IFCPROPERTYSINGLEVALUE('Area',$,IFCAREAMEASURE(15.53486704),$);
#451= IFCPROPERTYSINGLEVALUE('Unbounded Height',$,IFCLENGTHMEASURE(6.30479999999993),$);
#452= IFCPROPERTYSINGLEVALUE('Volume',$,IFCVOLUMEMEASURE(46.6046011199988),$);
```

9
https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/schema/ifckernel/lexical/ifcpropertyset.htm, last access: 11.05.2021

Another approach is to calculate these measures using the elements IfcShapeRepresentation [10] providing geometric data. This method can be further differentiated by the type of the representation. It can either contain an element describing a rectangle, in which case the area can be calculated by multiplying the provided x- and y-dimension, or an extruded body described by a polyline, in which case the polygon and extrusion depth are used for area calculation.

```
#1243= IFCRECTANGLEPROFILEDEF(.AREA.,$,#1242,2.5206,5.62700000000001);
#1244= IFCCARTESIANPOINT((0.68937984605084,-2.38662323422544,0.0));
#1246= IFCDIRECTION((7.1892860847411E-6,1.0,0.0));
#1248= IFCAXIS2PLACEMENT3D(#1244,#20,#1246);
#1249= IFCEXTRUDEDAREASOLID(#1243,#1248,#20,2.99999999999993);
#1250= IFCSHAPEREPRESENTATION(#102,'Body','SweptSolid',(#1249));
#1252= IFCPRODUCTDEFINITIONSHAPE($,$,(#1250));
```

```
#58=IFCPOLYLINE((#59,#60,#61,#62,#63));
#59=IFCCARTESIANPOINT((8000.,0.));
#60=IFCCARTESIANPOINT((9400.,0.));
#61=IFCCARTESIANPOINT((9400.,300.));
#62=IFCCARTESIANPOINT((8000.,300.));
#63=IFCCARTESIANPOINT((8000.,0.));
#64=IFCARBITRARYCLOSEDPROFILEDEF(.AREA.,$,#58);
#66=IFCEXTRUDEDAREASOLID(#64,#69,#67,1400.);
#67=IFCDIRECTION((0.,0.,1.));
#68=IFCCARTESIANPOINT((0.,0.,0.));
#69=IFCAXIS2PLACEMENT3D(#68,$,$);
#70=IFCSHAPEREPRESENTATION(#19,'Body','SweptSolid',(#66));
```

For a more generic calculation of areas the optional component Xbim.Geometry[11] is used. Each element is decomposed to its mesh representation using the triangulation methods of the component. The XbimFaceTriangulation[12] elements obtained are then filtered to only consider those representing the relevant side of the element. This is done by extracting the elements reference direction in context to the building and

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10 https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2/HTML/schema/ifcrepresentationresource/lexical/ifcshaperepresentation.htm, last access: 11.05.2021

11 http://docs.xbim.net/XbimDocs/html/9b028aea-ab0e-56cf-42c3-da6ac2758153.htm, last access: 11.05.2021

12 http://docs.xbim.net/XbimDocs/html/bdb35365-05aa-75f5-bb7a-d7cbd64942f6.htm, last access: 11.05.2021

comparing it to the faces normal vector. The areas of the remaining faces are then calculated using the cross product and summed up to obtain the area of the element.

2.9 Enhancement of IFC-file with project-specific renovation measure parameters

For each renovation measure the LCA/LCC module is served with material- and project-specific data needed for calculating the renovation measure's KPIs. For each renovation scenario the original IFC file as well as all modifications along with project-specific data described in Section 2.5 and values derived from the BIMERR Component and Material database are sent to the xbim Service, which integrates them as IFC property sets in the IFC file. For each renovation scenario a new IFC file containing all property sets relevant to the KPI calculation, is created, and stored. The following table shows the parameters, the corresponding KPIs, as well as the source they are derived of:

Table 2: Enhancement of IFC file for LCA/LCC module

Value	Source	KPI	Context
GWP	BIMERR Component and Material database	SU2	Material
AP	BIMERR Component and Material database	SU3	Material
ODP	BIMERR Component and Material database	SU4	Material
ADPE	BIMERR Component and Material database	SU5	Material
EP	BIMERR Component and Material database	SU6	Material
ADPF	BIMERR Component and Material database	SU7	Material
POCP	BIMERR Component and Material database	SU8	Material
Lifetime	BIMERR Component and Material database	EC3	Material/Layer

Material cost	RenoDSS – see Section 2.5	EC1, EC3	Layer
Installation cost	RenoDSS – see Section 2.5	EC1, EC3	Layer
Maintenance Cost	RenoDSS – see Section 2.5	EC3	Layer
Disposal cost	RenoDSS – see Section 2.5	EC1, EC3, EC4	Layer

The implementation of the IFC-file enhancement with the values described in the table above using IfcPropertySet[13] is described in detail in deliverable D7.10 – Integrated BIMERR Renovation Decision Support System 2.

2.10 Extended KPI Calculation

In addition to the KPI calculation described in D7.3 the user can get information about how the scenario solutions can be interpreted in relation to the original building values. A new KPI was introduced to show the Return of Investment. Please see the Annex of this deliverable for a full KPI list including their calculation formulas.

2.10.1 EC7 - Return on Investment (ROI)

The ROI is calculated by dividing the reduced operational costs by the overall investment costs.

$$ROI = \left(\frac{(ec2_{base} + ec3_{base}) - (ec2_{reno} + ec3_{reno})}{ec1_{reno}}\right) * 100$$

ROI	is the Return of Investment in %
$ec2_{base}$	is the energy running cost during the period of analysis for the baseline scenario
$ec2_{reno}$	is the energy running cost during the period of analysis for the renovation scenario with applied renovation measures

13 https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/schema/ifckernel/lexical/ifcpropertyset.htm, last access: 11.05.2021

$ec3_{base}$	is the maintenance cost during the period of analysis for the baseline scenario
$ec3_{reno}$	is the maintenance cost during the period of analysis for the renovation scenario with applied renovation measures
$ec1_{reno}$	are the construction cost of the renovation scenario

2.10.2 KPI deviation calculation

The UI as well as the API for renovation scenarios (see Deliverable D7.10) were enhanced to not only display absolute KPIs but to also show the absolute and relative deviation of the renovation scenario to the baseline scenario.

The user can select which values they want to see in the renovation scenario table by switching between the absolute, absolute deviation and relative deviation view. Per default the absolute values of the calculated KPIs are shown.

On mouseover all available values for this KPI are shown.

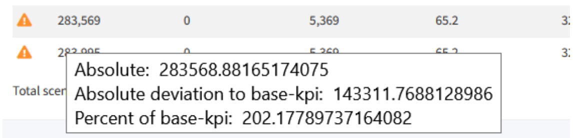

Figure 15: Tooltip KPI value

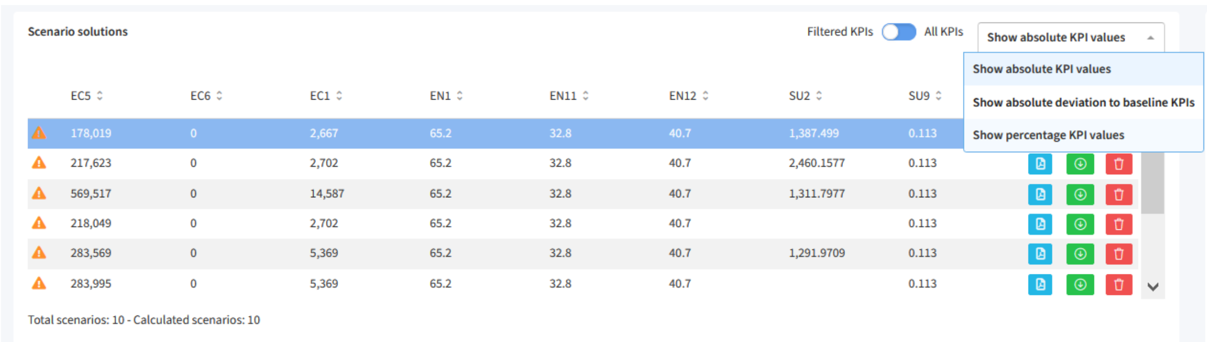

Figure 16: Selection of KPI value display

2.11 EVALUATION OF OPENLCA INTEGRATION

openLCA 1.10.3 is an open-source life cycle assessment tool capable of integrating chargeable and free of charge LCA databases. For the construction sector, the Ökobaudat database[14] is the most comprehensive free of charge LCA database and was therefore selected to support the BIMERR LCA/LCC module calculations. Ökobaudat can be imported into openLCA, but unlike other databases (e.g., GaBI, ecoinvent), Ökobaudat does not provide elementary flows or product and waste flows which can be used as input or outputs of construction processes. Instead, Ökobaudat provides "environmental impact categories, which show the aggregated contributions of a product or a process to relevant ecologic and economic aspects (indicators), such as emissions to soil, water and air, resource depletion or generation of solid wastes. These "indicator elementary flows" provide the means for expressing the environmental impact of the included construction products and services." [1]

Therefore, the definition of an openLCA process requires (i) an input flow by selecting the relevant building materials and indicating their quantity, and (ii) an output flow to describe the result and quantity of the construction process. The example shown in Figure 17 uses four different input materials to construct one square meter of a wall with exterior and interior painting. openLCA multiplies the quantities of each input material by the Ökobaudat impact indicators for that input material and summarizes the results to obtain the environmental impact indicators for the entire output element (e.g., one square meter wall given the stated input materials). Figure 18 shows the openLCA calculation results. For each environmental impact indicator (e.g., Acidification Potential) the distribution among the input materials is shown.

As the same functionality has been efficiently implemented with minimal system overhead into the BIMERR LCA/LCC module, the integration of openLCA currently provides no benefit to the BIMERR LCA/LCC module.

[14] https://www.oekobaudat.de/, last access: 11.05.2021

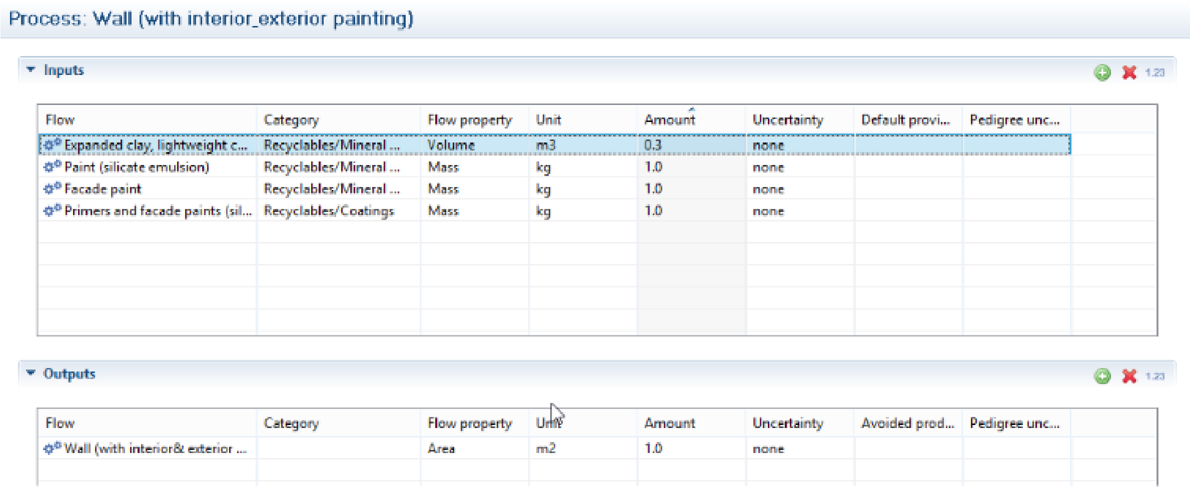

Figure 17: Input and output flows for constructing a wall [1]

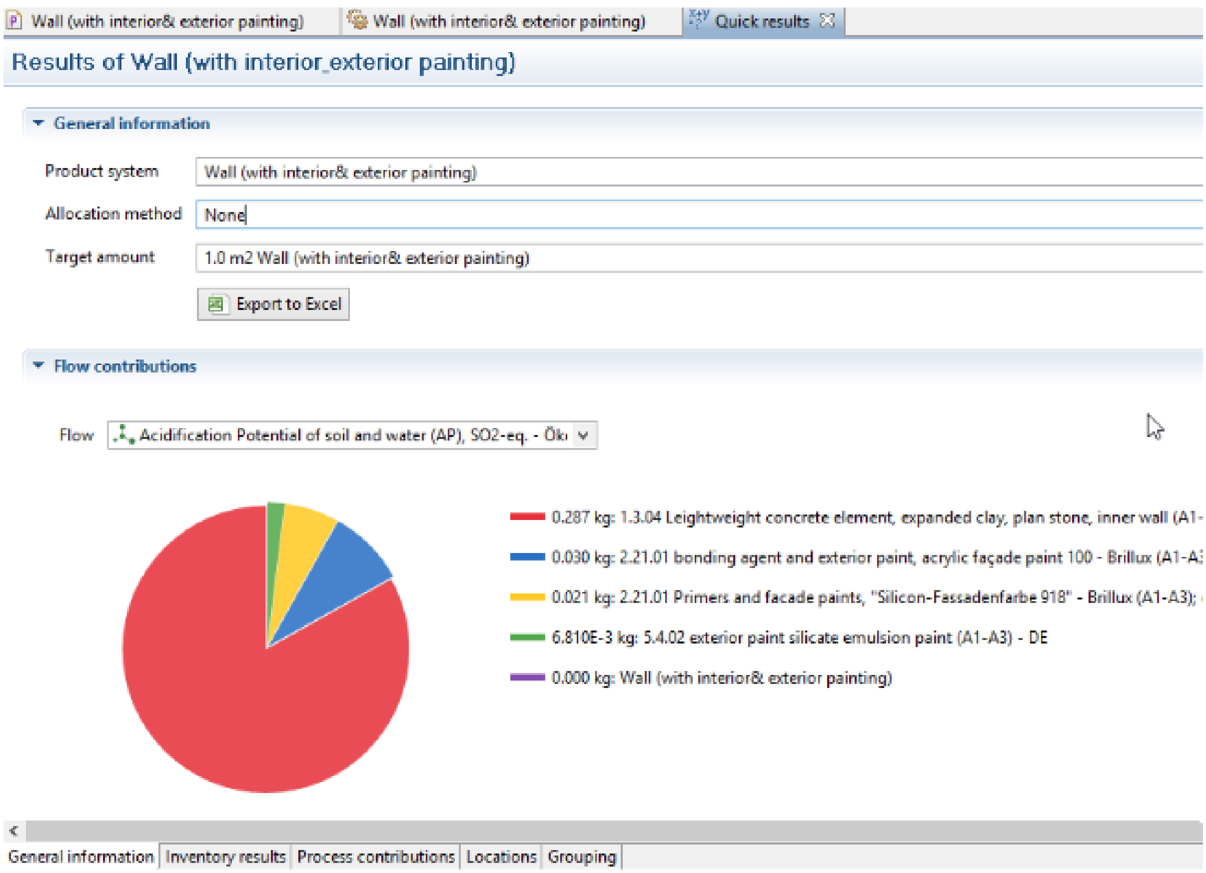

Figure 18: openLCA results based on Ökobaudat data [1]

2.12 API Documentation

The communication between the front end (RenoDSS UI) and the back end (LCA/LCC module) is typically through internal APIs. As they serve inter-subcomponent integration purposes they are not documented at this point in detail.

2.13 Assumptions and Restrictions

The final release of the BIMERR LCA/LCC module is based on the following assumptions/restrictions:

- KPIs are only calculated if all relevant input data for the specific KPI is available. If input data for a specific KPI is missing, a warning will be issued and the user can continue in the RenoDSS workflow without that specific KPI.

2.14 Installation Instructions

The BIMERR LCA/LCC module is part of BIMERR RenoDSS which is accessible via a web-based GUI, and therefore does not require installation or downloading of any component to use it.

2.15 Licensing

The KPI calculation schema is public. As parts of the BIMERR LCA/LCC module are based on and integrated into the Xylem business intelligence platform it is a closed source component.

3. END-TO-END USAGE WALKTHROUGH TO THE BIMERR LCA/LCC MODULE

This end-to-end usage walkthrough shows the BIMERR LCA/LCC module functionality in the context of the BIMERR RenoDSS system.

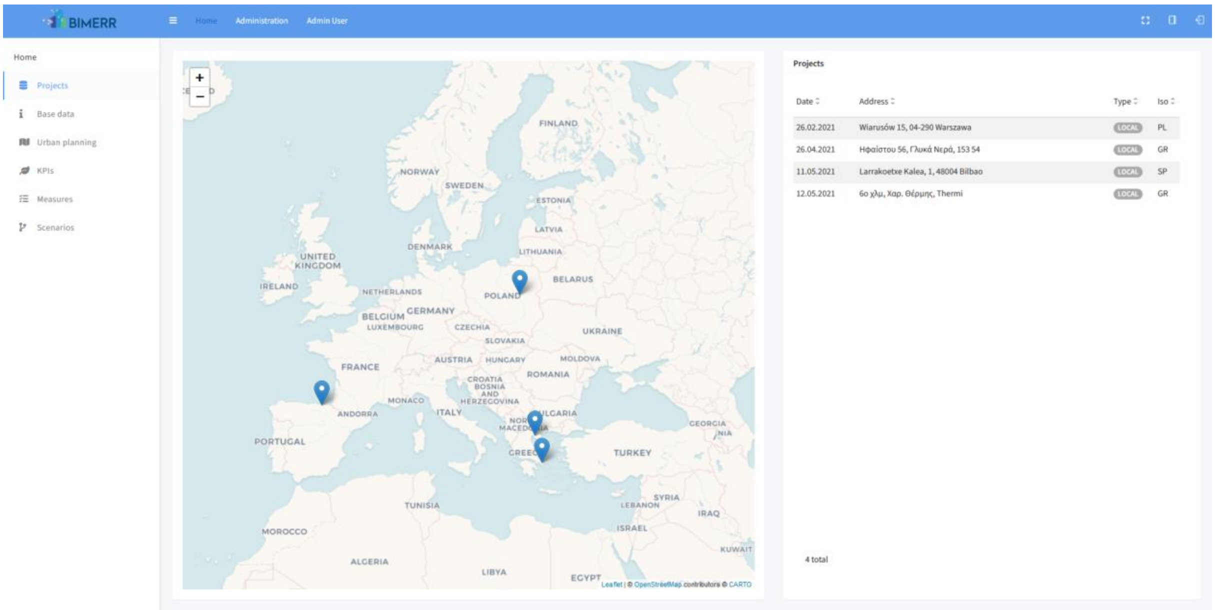

Figure 19: RenoDSS - project view

Figure 19 shows the project view of RenoDSS. By selecting a specific project, the corresponding IFC file is loaded and sent to the BIMERR LCA/LCC module which extracts building materials from construction layers present in the IFC file. By selecting a specific project, the following building view is loaded.

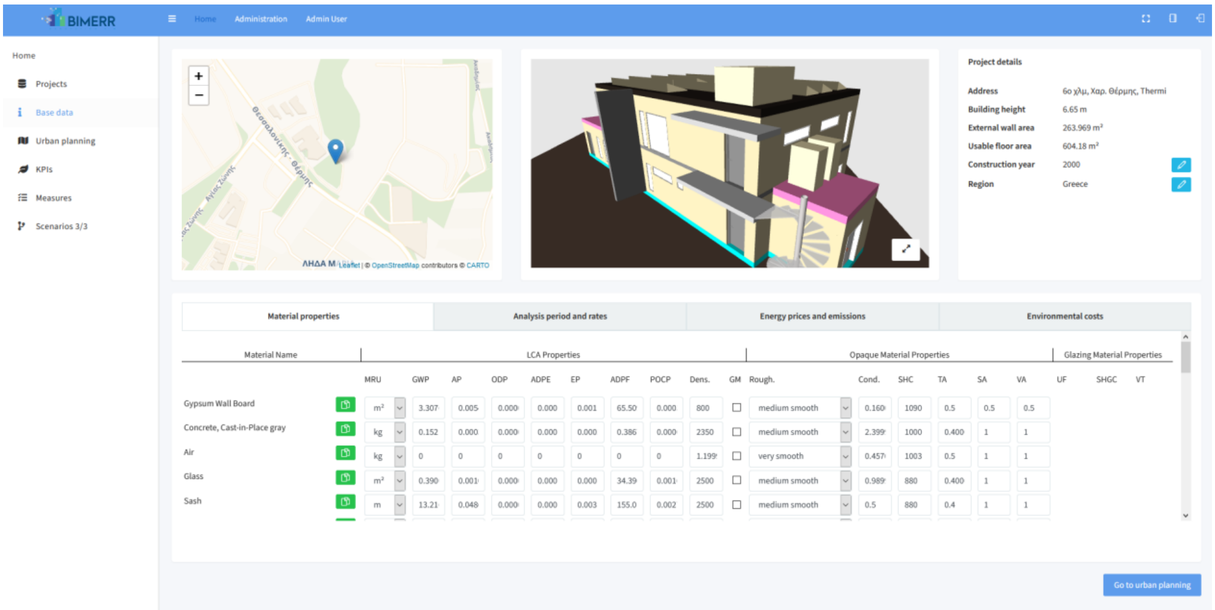

Figure 20: RenoDSS - base data view

Figure 20 shows, in the context of the Greek pre-validation site KRIPIS, the base data view which provides a user interface for setting material materials/component properties, currency and exchange rates, energy costs, interest rates, environmental costs, and CO2 emission rates. By clicking the "Show KPIs" button, the following KPI view is loaded.

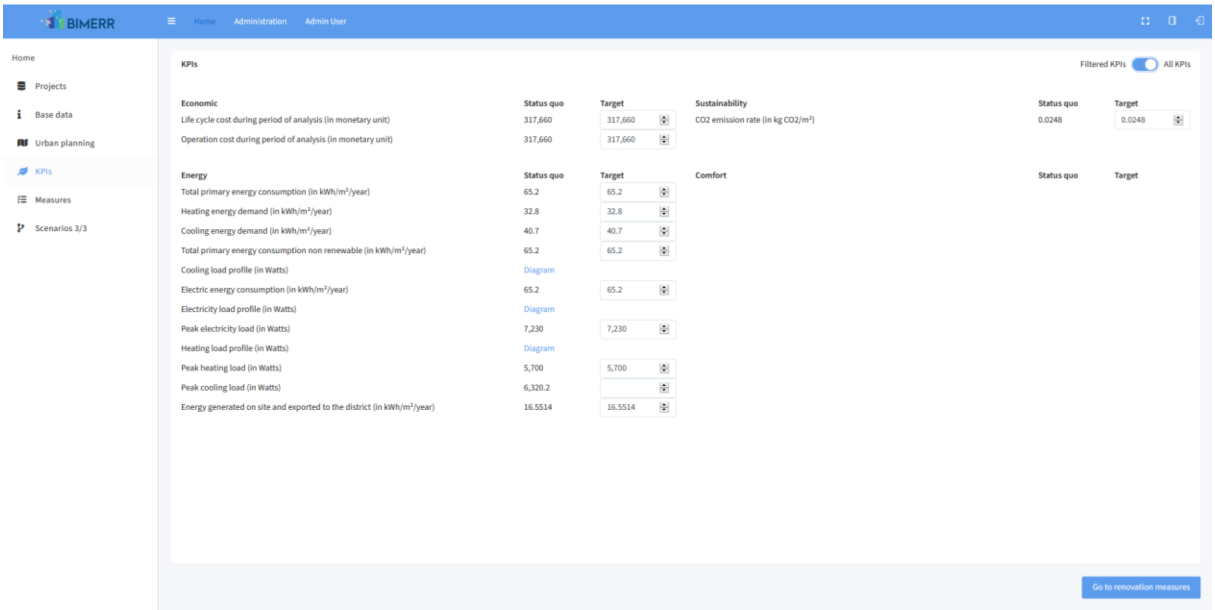

Figure 21: RenoDSS - KPI view

Figure 21 shows the calculated Economic, Sustainability, Energy, and Comfort KPIs. While the LCA/LCC module is responsible for calculating the economic and sustainability KPIs, the Building Energy Performance module is responsible for calculating the energy and comfort KPIs. The Status Quo column represent the calculation results for the baseline scenario, the Target column is used to set goals for the renovation scenarios (e.g., a specific energy performance).

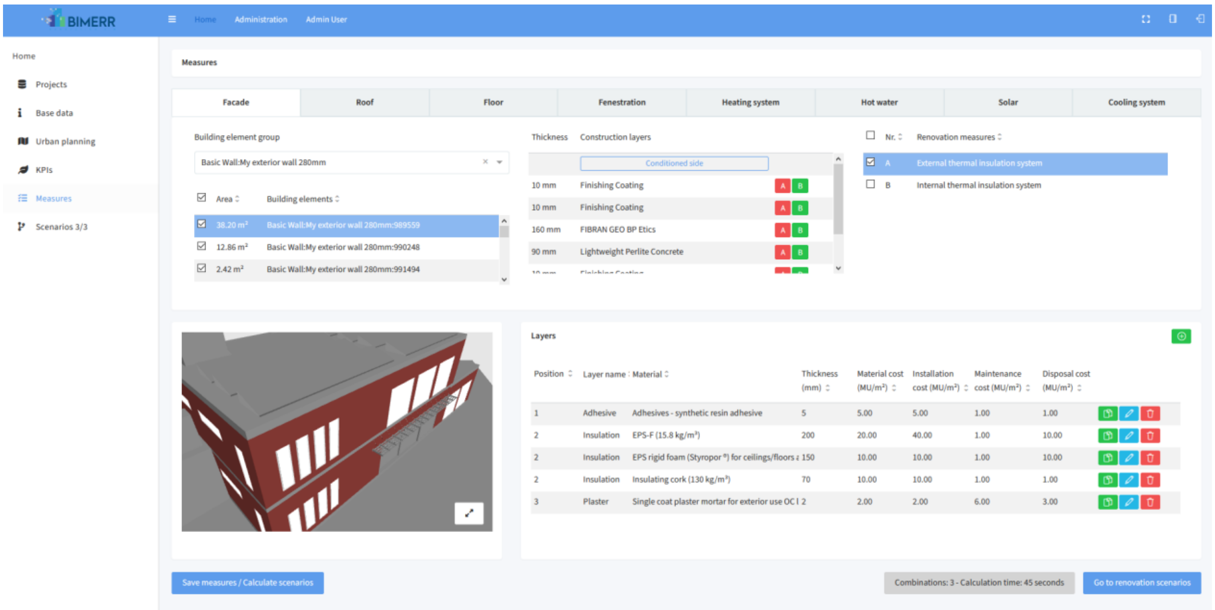

Figure 22: RenoDSS - setting potential renovation measures and their cost properties

Figure 22 shows how the user can set potential renovation measures and change the cost properties of each material layer. This data is required for the economic renovation scenario KPIs (e.g., life cycle cost). Please note that initially default cost are loaded which were set by the RenoDSS administrator role.

By clicking the “Explore renovation scenarios” button, the Scenario Generator module generates the renovation scenarios and sends each scenario to the LCA/LCC module for calculating the renovation scenario KPIs.

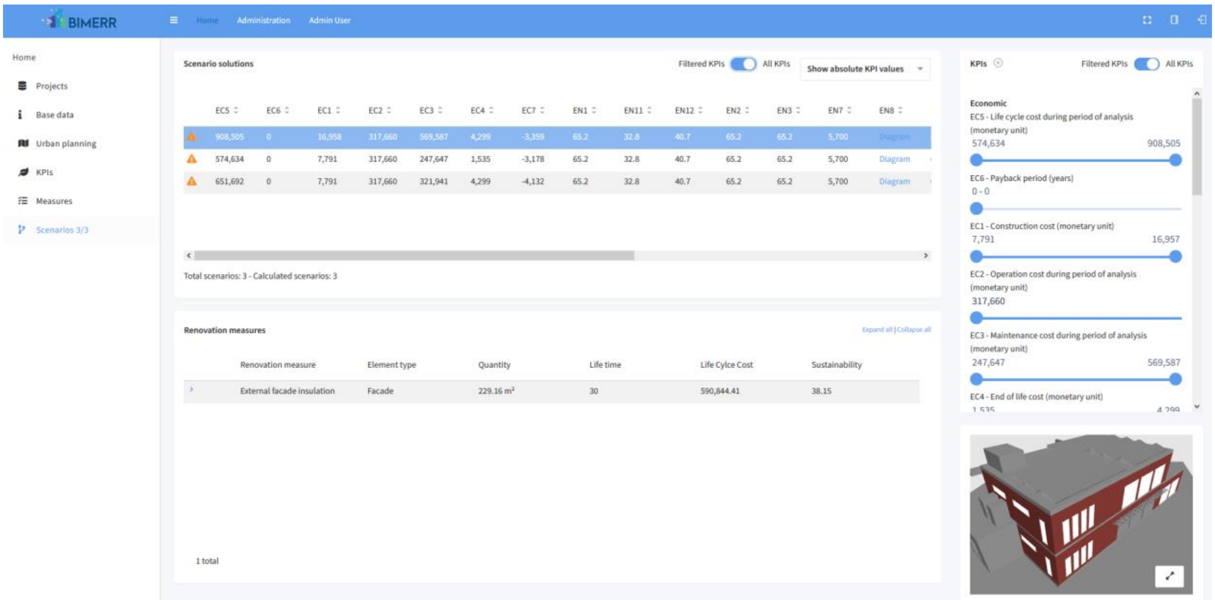

Figure 23: RenoDSS - renovation scenarios

Figure 23 shows the generated renovation scenarios. The selected line represents one potential renovation scenario. Each line shows the calculated KPIs of each scenario. The KPIs can be shown in absolute values, or as relative/absolute deviation from the baseline scenario. By using the sliders, the user can filter the scenarios depending on their KPIs. If the shown KPIs were calculated on an outdated IFC file version, a warning sign is presented in the renovation scenario line. By clicking on a renovation scenario, scenario specific LCA/LCC data (quantity, lifetime, lifecycle cost, sustainability of each renovation measure) is presented in the bottom area of the view.

4. CONCLUSIONS

The final BIMERR LCA/LCC module (i) calculates 17 KPIs about the financial and sustainability impact of the renovation scenario under investigation, (ii) provides methods to check and complete missing energy- and LCA/LCC-KPI-related building data, (iii) takes project-specific energy costs, interest/exchange rates, environmental costs, and CO_2 emission rates at the KPI calculation into account, (iv) provides the possibility to enter and visualize monetary units in renovation-project-specific currencies, (v) extracts and matches IFC units with material units from the BIMERR Component and Material database, (vi) calculates building element area and height measures using data provided in the IFC file, and (vii) provides renovation scenario KPIs in absolute values and absolute or relative deviation from the baseline scenario.

5. References

[1] Yasmine Emara, Andreas Ciroth, Kathleen Kiehl: The database ÖKOBAU.DAT in openLCA and SimaPro, online at: https://www.openlca.org/wp-content/uploads/2015/11/The-database-%C3%96KOBAUDAT_en_April2015.pdf

[2] D3.1 "Stakeholder requirements for the BIMERR system": the business scenarios, use cases, and system requirements described in D3.1 are the basis for the development of the BIMERR LCA/LCC module.

[3] D3.3 "BIMERR evaluation methodology": economic and sustainability KPIs described in D3.3 are calculated by the LCA/LCC module.

[4] D3.6 "BIMERR system architecture final version": the final version of the BIMERR architecture provided an overview on the BIMERR components, how they communicate to each other and how the BIMERR LCA/LCC module is embedded in the BIMERR Renovation Support Tools.

[5] D7.3 "Life Cycle Cost/Assessment Module 1" provided the basis for the extensions developed in D7.4.

[6] D7.10 – Integrated BIMERR Renovation Decision Support System 2.

6. ANNEX: KEY PERFORMANCE INDICATORS

This section describes how each economic and sustainability KPI is calculated, and which data sources are used.

6.1.1 EC1 - Construction cost in monetary unit

The construction costs of a renovation measure include the costs for (i) removing the old component or layers of the construction and (ii) purchasing and installing the new renovation measure (including taxes).

$$CC = \sum_{i=1}^{b} (DC_i + CC_i)$$

CC are the construction cost of the renovation measures

i is the current renovation measure

b is the number of renovation measures applied to the building

DC_i is the disposal cost which occur prior installing renovation measure i

CC_i is the construction cost for renovation measure i including material and installation

The costs are stored per reference unit of the renovation measure for each component or each layer of the construction. The reference unit (e.g., m^2 or m^3) of each layer is multiplied with the material and installation cost stored for this specific context-, scenario-, material- and thickness context in the cost and linking table.

Example: i=2, b=2, DC_1=20, CC_1=200, DC_2=10, CC_2=100

CC = 20+200+10+100 = 330

6.1.2 EC2 - Operation cost during period of analysis in monetary unit

Operation cost includes energy costs (including taxes) for heating and cooling the building. According to standard ISO 15686-5:2017 it takes expected the energy escalation rate and discount rate in terms of opportunity cost into account. Note that the energy costs are calculated for each energy carrier to take each one's escalation rate and consumption into account.

$$OC = \sum_{i=1}^{b} \sum_{n=0}^{a} \frac{EDi_n * EPi_0 * (1 + e_i)^n}{(1 + d)^n}$$

OC	are the present value operation cost during the period of analysis
b	is the number of energy carriers used in the building
i	is the current energy carrier
a	is the period of analysis (30 years per default)
n	is the number of years between the base data and the occurrence of the cost
EDi_n	is the energy demand of energy carrier i in year n
EPi_0	is the energy price of energy carrier i in year 0
e_i	is the expected energy escalation rate of energy carrier i
d	is the expected discount rate

Example: a=1, b=2, $ED1_0$=50, $ED1_1$=100, $EP1_0$=5, $ED2_0$=25, $ED2_1$=50, $EP2_0$=10, e_1=0,02, e_2=0,03, d=0,06

OC = 50*5 + (100*5*1,02)/1,06 + 25*10 + (50*10*1,02)/1,06 = 1462,26

6.1.3 EC3 - Maintenance cost during period of analysis in monetary unit

Maintenance cost includes costs that occur to maintain renovation measures and replace them after their lifetime during the period of analysis (including taxes). In case of constructions the maintenance costs include all renovated layers, in case of components the component itself.

$$MC = \sum_{i=1}^{b} \sum_{n=0}^{a} \frac{(MCi_0 + CCi_0) * (1 + e)^n}{(1 + d)^n}$$

MC	are the present value maintenance cost during the period of analysis
b	is the number of renovation measures applied to the building
i	is the current renovation measure

a is the period of analysis (30 years per default)

n is the number of years between the base data and the occurrence of the cost

MCi_n is the maintenance cost of renovation measure i in year n

CCi_n is the construction cost for replacing renovation measure i after its lifetime in year n

e is the expected escalation rate for construction and maintenance cost

d is the expected discount rate

Example: a=1, b=2, $MC1_0$=50, $MC2_0$=100, $CC1_0$=25, $CC2_0$=50, e=0,03, d=0,06

MC = 50+25 + (50+25*1,03)/1,06 + 100+50 + (100+50*1,03)/1,06 = 443,63

6.1.4 EC4 - End of life cost in monetary unit

End of life cost include disposal of the renovation measure after its lifetime (including taxes). Please note that this value can be negative if the residual value exceeds the cost of disposal.

End of life cost = sum of disposal cost for renovated construction layers or component

$$EoLC = \sum_{i=1}^{b} \frac{EoLCi_0 * (1+e)^n}{(1+d)^n}$$

EoLC are the present value end of life cost during the period of analysis

i is the current renovation measure

b is the number of renovation measures applied to the building

$EoLCi_0$ is the end of life cost of renovation measure i in year 0

e is the expected escalation rate for end of life cost

n the last year of the period of analysis (30 years per default)

d is the expected discount rate

Example: b=2, $EoLCi_0$=100, $EoLCi_1$=200, e=0,02, n=30

EoLC = $(100*1,02^{30})/1,06^{30}$+ $(200*1,02^{30})/1,06^{30}$ = 94,61

6.1.5 EC5 - Life cycle cost during period of analysis in monetary unit

Life cycle cost is the sum of the renovation measure's present value construction, operation, maintenance, and end of life costs. Note that the lifetime of renovation measures is not homogeneous and can be below or above the period of analysis.

6.1.6 EC6 - Payback period in years

According to ISO 15686-5:2017 the payback period is calculated as the number of years elapsed between the initial investment (construction cost), its subsequent operating cost and the time at which cumulative savings offset the investment. The payback period is the time it takes to recoup the initial investment of an alternative to the base case.

6.1.7 EC7 - Return on Investment (ROI)

The ROI is calculated by dividing the reduced operational costs by the overall investment costs.

$$ROI = \left(\frac{(ec2_{base} + ec3_{base}) - (ec2_{reno} + ec3_{reno})}{ec1_{reno}}\right) * 100$$

ROI	is the Return of Investment in %
$ec2_{base}$	is the energy running cost during the period of analysis for the baseline scenario
$ec2_{reno}$	is the energy running cost during the period of analysis for the renovation scenario with applied renovation measures
$ec3_{base}$	is the maintenance cost during the period of analysis for the baseline scenario
$ec3_{reno}$	is the maintenance cost during the period of analysis for the renovation scenario with applied renovation measures
$ec1_{reno}$	are the construction cost of the renovation scenario

6.1.8 SU1 - Environmental cost indicator in monetary unit/m²

Indicator that unites sustainability KPIs (SU2 to SU8) into a single score of environmental costs, representing the environmental shadow price of a product or project. Therefore, the output of SU2 to SU8 is multiplied by their monetary impact per unit as shown in the following table[15].

KPI	Unit	Monetary unit/unit
SU2 GWP100a total global warming potential	kg CO2-eq	0,05€
SU3 Acidification potential of soil and water (AP)	kg SO2-eq	4,00€
SU4 Depletion potential of the stratospheric ozone layer (ODP)	kg CFC	30,00€
SU5 Abiotic depletion potential for non-fossil resources (ADPE)	kg Sb-eq	0,16€
SU6 Eutrophication potential (EP)	kg PO4-3 eq	9,00€
SU7 Abiotic depletion potential for fossil resources (ADPF)	kg Sb-eq	0,16€
SU8 Formation potential of tropospheric ozone (POCP)	kg C2H4-eq	2,00€

6.1.9 SU2 - GWP100a total global warming potential in kg CO2-eq/m²

Describes how much heat a greenhouse gas traps in the atmosphere in 100 years relative to carbon dioxide. For example, the CO2 equivalent of methane over a period of 100 years is 28. I.e., one kilogram of methane contributes in the first 100 years to the greenhouse effect like 28 kilogram CO2.

GWP100a is provided for the life cycle of each building material and component used in the renovation measures by its reference unit. The total global warming potential per square meter floor area of a renovation measure is calculated by:

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[15] The monetary values have been taken from https://ecochain.com/knowledge/environmental-cost-indicator-eci/ and can be adjusted for every scenario of the renovation project.

$$GWP100a = \frac{\sum_{i=1}^{n} GWP100a_i * RU_i}{A}$$

GWP100a is the global warming potential of the renovation measure in kg CO2-eq
i is the current building material or component used in the renovation measure
n is the number of materials or components used in the renovation measure
$GWP100a_i$ is the global warming potential of material or component i per reference unit (e.g., 0,45 kg CO2-eq per m³)
RU_i is the amount of reference units of material or component I (e.g., 27 m³)
A is the floor area of the building

6.1.10 SU3 - Acidification potential of soil and water (AP) in kg SO2-eq/m²

Acidification potential describes the amount of acids emitted to the atmosphere and subsequently deposited in soil and water[16] in the context of the life cycle of materials and components used in the renovation measures per square meter floor area.

$$AP = \frac{\sum_{i=1}^{n} AP_i * RU_i}{A}$$

6.1.11 SU4 - Depletion potential of the stratospheric ozone layer (ODP) in kg CFC11-eq/m²

Is the relative amount of degradation to the ozone layer a chemical compound can cause, with CFC-11 fixed at an ODP of 1[17].

$$ODP = \frac{\sum_{i=1}^{n} ODP_i * RU_i}{A}$$

[16] https://www.sciencedirect.com/topics/engineering/acidification-potential

[17] https://en.wikipedia.org/wiki/Ozone_depletion_potential

6.1.12 SU5 - Abiotic depletion potential for non-fossil resources (ADPE) in kg Sb-eq/m²

Refers to the depletion of non-living (abiotic) non-fossil resources and is measured in kilograms of Antimony equivalents[18] per square meter floor area.

$$ADPE = \frac{\sum_{i=1}^{n} ADPE_i * RU_i}{A}$$

6.1.13 SU6 - Eutrophication potential (EP) in kg PO4-3-eq/m²

Eutrophication occurs when an ecosystem is saturated with essential non-organic nutrients such as nitrogen and phosphorus compounds, which under natural conditions would only normally be present in small concentrations. When released into water, these substances trigger outbreaks of algae and aquatic plants, which, in turn, leads to a shift in the biodiversity of the ecosystem[19]. The eutrophication potential of the nutrient input is specified in kg (PO4)3- -eq (phosphate equivalent) per square meter floor area.

$$EP = \frac{\sum_{i=1}^{n} EP_i * RU_i}{A}$$

6.1.14 SU7 - Abiotic depletion potential for fossil resources (ADPF) in MJ/m²

Refers to the depletion of non-living (abiotic) fossil resources and is measured in kilograms of Antimony equivalents[20] per square meter floor area.

$$ADPF = \frac{\sum_{i=1}^{n} ADPF_i * RU_i}{A}$$

[18] https://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf

[19] https://www.baubook.info/m/PHP/Fragezeichen.php?S_oekz_Typ=8&SW=16&oegpk2=n&lng=2

[20] https://www.leidenuniv.nl/cml/ssp/projects/lca2/report_abiotic_depletion_web.pdf

6.1.15 SU8 - Formation potential of tropospheric ozone (POCP) in (kg ethylene/m2)/m²

Quantifies the relative abilities of volatile organic compounds (VOCs) to produce ground level ozone[21]. Specified in kilograms ethylene per m² per square meter floor area.

$$POCP = \frac{\sum_{i=1}^{n} POCP_i * RU_i}{A}$$

6.1.16 SU9 - CO2 emission rate in kg CO2/m²

Refers to the CO2 emissions per square meter floor area caused by the energy consumption of the building during its operation.

$$CO2 = \frac{\sum_{i=1}^{n} CO2_i * EC_i}{A}$$

CO2 is the CO2 emission rate in kg CO2 per square meter floor area of the building
i is the current energy carrier (power, oil, gas, district heating, etc.)
n is the number of energy carriers used in the building
$CO2_i$ is the CO2 emission rate in kg of energy carrier i per kWh
EC_i is the energy consumption of the building regarding energy carrier i in kWh
A is the floor area of the building

6.1.17 SU10 – CO2 emissions reduction in %

Describes the CO2 emission reduction per square meter floor area caused by the lowered energy consumption because of implemented renovation measures. The reduction is calculated by comparing the renovation scenario to the baseline scenario in terms of CO2 emissions (SU9).

$$CO2_{red} = \left(1 - \frac{CO2_{reno}}{CO2_{base}}\right) * 100$$

[21] https://ui.adsabs.harvard.edu/abs/2017AtmEn.163..128J/abstract