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The BIMERR project consortium is composed of:			
FIT	Fraunhofer Gesellschaft Zur Foerderung Der Angewandten Forschung E.V.	Germany	
CERTH	Ethniko Kentro Erevnas Kai Technologikis Anaptyxis	Greece	
UPM	Universidad Politecnica De Madrid	Spain	
UBITECH	Ubitech Limited	Cyprus	
SUITE5	Suite5 Data Intelligence Solutions Limited	Cyprus	
HYPERTECH	Hypertech (Chaipertek) Anonymos Viomichaniki Emporiki Etaireia Pliroforikis Kai Neon Technologion	Greece	
MERIT	Merit Consulting House Sprl	Belgium	
XYLEM	Xylem Science and Technology Management GmbH	Austria	
CONKAT	Anonymos Etaireia Kataskevon Technikon Ergon, Emporikon Viomichanikonkai Nautiliakon Epicheiriseon Kon'kat	Greece	
BOC	Boc Asset Management GmbH	Austria	
вх	Budimex S.A.	Poland	
UOP	University of Peloponnese	Greece	
UEDIN	University of Edinburgh	United Kingdom	
UCL	University College London	United Kingdom	
NT	Novitech As	Slovakia	
FER	Ferrovial Agroman S.A.	Spain	

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AUTHORS LIST

Leading Author (Editor)						
	Surname First Name Beneficiary Contact email					
	Fenz	Stefan	Xylem	fenz@ylem.tech		
	Co-authors (in alphabetic order)					
#	Surname	First Name	Beneficiary	Contact email		
1	Bergmayr	Julia	Xylem	bergmayr@xylem.tech		
2	Heurix	Johannes	Xylem	<u>heurix@xylem.tech</u>		
3	Neubauer	Thomas	Xylem	neubauer@xylem.tech		
4	Tsakiris	Thanos	CERTH	<u>atsakir@iti.gr</u>		
5	Wachter	Christoph	Xylem	wachter@xylem.tech		
6	Wellner	Florian	Xylem	wellner@xylem.tech		
7	Wlasak	Lech	BX	lech.wlasak@budimex.pl		

REVIEWERS LIST

List of Reviewers (in alphabetic order)				
#	Surname	First Name	Beneficiary	Contact email
1	Hanel	Tobias	FER	<u>thanel@ferrovial.com</u>
2	Lucerski	Maciej	BX	<u>maciej.lucerski@budimex.pl</u>

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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 CO₂ 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
 - o GWP100a total global warming potential in kg CO2-eq/m²
 - o Acidification potential of soil and water (AP) in kg SO2-eq/m²
 - o 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
 - o 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 at¹: <u>https://renodss.xylem-technologies.com/</u>

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 <u>support@xylem-technologies.com</u> 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, projectspecific 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.

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

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

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 Toolkit² Service. All relevant material and element data are extracted and checked for completeness. A form is provided to input missing data (see Figure 3).

Material propertie	s 🕕					Ar	nalysis peri	iod and rates					Energy prices and	emissi	ons				Em	rironment	al costs		
Material Name							LCA Prope	erties						(Opaque Mat	terial Prope	rties			Gla	zing Materia	Properties	^
		MRU		GWP	AP	ODP	ADPE	EP	ADPF	POCP	Dens.	GM	Rough.		Cond.	SHC	TA	SA	VA	UF	SHGC	VT	
Steel, Paint Finish, Ivory, Matte	۵	kg	\sim	-0.029	0.000€	0.0000		0.0003		0.0000	1200		Select roughness	\sim	0.2999	936				ן			
My Plaster	Ø	kg	~	0.1909	0.0007	0.0000		0.0003		0.0000	1400		Select roughness	~	0.2099	1000			j 🕅	j			
FIBRAN GEO BP Etics	۵		\sim								0		Select roughness	\sim]			
Concrete, Cast In Situ	Ø		\sim) 🕅			0		Select roughness	\sim					j 📃	j			
Aluminum - LSI - Powder Coated - Black	۵		\sim					רחו			0		Select roughness	\sim	\square					7			~

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).

² <u>https://docs.xbim.net/</u>, last access: 25.11.2020

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Category 1	Building boards	×
Category 2	Plasterboard	×
Material		
	Dry screed (gypsum fibreboard)	1
	Dry screed (plasterboard)	
margher / V/	dry screed - gypsum fibreboard	
	Duraline or Riduro plaster - 12.5 mm (990 kg/m² and 12.375 kg/m²)	
	COLUMN THE REAL PROPERTY AND A	

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.

Material properties 0	Analysis period an	id rates		E	nergy prices and	emissions				Environm	ental costs		
Element Name	1	Installation Year	Lifetime		Material Cost		Installation Cost	t	Maintenance	Cost	Removal Cost		^
Basic Wall:My exterior wall 280mm with paint: 0.1cm Steel, Paint Finish, Ivo	y, Matte	2000	30	Years	1	MU/m ²	1	MU/m^2	0.05	MU/m²/a	1	MU/m ²	
Basic Wall:My exterior wall 280mm with paint: 1cm My Plaster		2000	30	Years	1	MU/m ²	1	MU/m ²	0.05	MU/m²/a	1	MU/m ²	
Basic Wall:My exterior wall 280mm with paint: 1cm My Plaster		2000	30	Years	1	MU/m ²	1	MU/m ²	0.05	MU/m²/a	1	MU/m ²	
Basic Wall:My exterior wall 280mm with paint: 16cm FIBRAN GEO BP Etics		2000	30	Years	1	MU/m ²	1	MU/m ²	0.05	MU/m²/a	1	MU/m ²	
Basic Wall: My exterior wall 280mm with paint: 0.5cm My Plaster		2000	30	Years	1	MU/m ²	1	MU/m ²	0.05	MU/m²/a	1	MU/m ²	
Basic Wall: My exterior wall 280mm with paint: 9cm Concrete, Cast In Situ		2000	30	Years	1	MU/m ²	1	MU/m ²	0.05	MU/m²/a	1	MU/m ²	
													~

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 IfcMaterialProperties³ 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:

Analysis period and rates

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



7 8 10 7 8 10 7 8 10	9 9 9	Leafler 0 CpenSteer	Mape construints & CARTO	Project details Address Building height External wall area Usable floor area Construction year Region	KRIPIS pre-validation site 6.649 m 253.969 m ² 602.163 m ² 2000 Greece		0
Material properties 0	Analysis period and rate	'S	Energ	gy prices and emissions		Environmental costs	
Period of analysis	30	years					
Expected discount rate	2	%					
Expected escalation rate for construction and maintenance cost	3	%					
Expected escalation rate for end of life cost	3	%					

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

Material properties 0	Analysis period and rates		Energy prices and emissions		Environmental costs		
	Current energy price		Expected energy escalation rate		CO2 emission rate		
Natural gas	0.2	MU/kwh	-4	%	0.23	kg/kWh	
District heating	0.2	NU/kWh	4	5	0.23	kg/kWh	
District cooling	0.2	MU/kWh	4	. %	0.23	kg/kWh	
Electricity feed-in	0.2	NU/kWh	4	. 5	0.23	kg/kWh	
Electricity	0.2	MU/kWh	4	. %	0.23	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) Deliverable D7.4**=** 06/2021 **=** Xylem



- 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)

Material properties 🧿	Analysis period and	d rates	Energy prices and emissions	Envir	ronmental costs
GWP100a total global warming potential	0.05	MU/kg CO2-eq	Acidification potential of soil and water (AP)	4	MU/kg SO2-eq
Depletion potential of the strategobaric enous laws (ODD)	20	Million CDC	Abiatic daplation potential for non-forsil resources (ADE)	0.16	MII/ka Shiea
oepreuwr poreniuar or nie susioosprienic ozonie rayer (o'or)	30	moregore	новак, акриеван ракентан на постозан незантоез (нал с.)	0.10	moly R soved
Eutrophication potential (EP)	9	MU/kg PO4-3 eq	Abiotic depletion potential for fossil resources (ADPF)	0.16	MU/kg Sb-eq
Enzymation potential of transsolveric graphs (POCP)	2	Millike C204.en			

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.

dmin User User User Ceneral Usage types Ceneral Usage types Ceneral Usage types Ceneral Usage types Ceneral Ce				
B User Usage types Image types				
Central Uage types Image Sector Pagions Materials Name C Name C Name C Messures Office Image Sector Spain Office Image Sector Image Sector Spain Office Image Sector Image Sector Spain Image Sector Image Sector Im				
Mare iala Masares Financial details Amage is a series of the series of		⊕ Currenci	ies	
Measures Residential Image: Spain Gence Gence Image: Spain	Currency 0	Name 🤇	Code Code Sign C	Exchange rate -> € ≎
Office Image: Construction of the subscription of the su	Euro	C Euro	FUR €	1
Iniancial details Wholesale and retail trade Health care Educational Health care Health care Educational Educational Health care Hedels and restaurants_Electricity_CONSUMPTION Hotels and restaurants	Euro	Ztoty	PLN zł	0.2241833
Health care	Złoty	2 0		
Educational Image Type 1 Loid profiles Usage Type 2 Educational Educational Educational_Electricity_CONSUMPTION Educational Health care_Electricity_CONSUMPTION Health care Health care_Electricity_CONSUMPTION Health care Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants				
Lead profiles Usage Type C Name C Usage Type C Educational_Electricity_CONSUMPTION Educational Educational_Electricity_CONSUMPTION Educational Health care_Electricity_ROOUCTION Health care Health care_Electricity_ROOUCTION Health care Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants		,		
Name : Usage Type : Educational_Electricity_CONSUMPTION Educational Educational_Electricity_PRODUCTION Educational Health care_Electricity_CONSUMPTION Health care Health care_Electricity_CONSUMPTION Health care Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants				
Educational_Electricity_CONSUMPTION Educational Educational_Electricity_PRODUCTION Educational Health care_Electricity_CONSUMPTION Health care Health care_Electricity_CONSUMPTION Health care Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants	Region 0	Type 🗘	Energy Carrier 0	
Educational_Electricity_PRODUCTION Educational Health care_Electricity_CONSUMPTION Health care Health care_Electricity_PRODUCTION Health care Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants		CONSUMPTION	Electricity	 Image: Open set of the set of t
Health care_Electricity_CONSUMPTION Health care Health care_Electricity_PRODUCTION Health care Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants		PRODUCTION	Electricity	 Image: Image: Ima
Health care_Electricity_PRODUCTION Health care Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants		CONSUMPTION	Electricity	2 0
Hotels and restaurants_Electricity_CONSUMPTION Hotels and restaurants		PRODUCTION	Electricity	 Ø Ø
		CONSUMPTION	Electricity	🖉 🕑 🗘
Hotels and restaurants_Electricity_PRODUCTION Hotels and restaurants		PRODUCTION	Electricity	🖉 🕑 🗊
Office_Electricity_CONSUMPTION Office		CONSUMPTION	Electricity	1 🕑 🚺

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).

BIMERR		r									
Admin User		Edit currency			×						
🚢 User	General	Name									
the Connect	Usage types	Euro				Currencies					⊙
General	Name 0	Code									
Y Materials	Residential	FUR				Name 0	Code 0	Sign ≎	Exchange rate -> €		
f≡ Measures	Office	LON				Euro	EUR	¢	1	0	
Financial details	Wholesale and retail trade	Sign				Złoty	PLN	zt	0.2241833	0	
	Health care	e									
	Educational	Exchange rate -> €									
		1									
					Save						
	Load profiles										
	House &			Device 1							
	name -		Usage type v	Region -	lype -		Energy Carrie				
	Educational_Electricity_CONSUMPTION		Educational		CONSUMPTION		Electricity		2	0	
	Educational_Electricity_PRODUCTION		Educational		PRODUCTION		Electricity		2	0 0	
	Health care_Electricity_CONSUMPTION		Health care		PRODUCTION		Electricity				
	Hotels and restaurants Electricity CONSUL	IPTION	Hotels and restaurants		CONSUMPTION						
	Hotels and restaurants Electricity_PRODUC	TION			PRODUCTION		Electricity				
	Office_Electricity_CONSUMPTION		Office		CONSUMPTION		Electricity				

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.



Edit region						×
Spain						
Euro						× •
						Save
	0	Greece	E	uro	0	Û

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).

Project details	
Address	Wiarusów 15, 04-290 Warszawa
Building height	6.3 m
External wall area	241,680 m ²
Usable floor area	166,580 m²
Construction year	1970
Region	Poland 🖉
Currency	Złoty

Material properties ()	Analysis period and rates		Energy prices and emissions		Environmental costs	
	Current energy price		Expected energy escalation rate		CO2 emission rate	
Natural gas	0.8921271120551799	zł/kWh	4	96	0.23	kg/kWh
District heating	0.8921271120551799	zł/kWh	4	96	0.23	kg/kWh
District cooling	0.8921271120551799	zł/kWh	4	96	0.23	kg/kWh
Electricity feed-in	0.8921271120551799	zt/kWh	4	%	0.23	kg/kWh
Electricity	0.8921271120551799	zł/kWh	4	96	0.23	kg/kWh

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).

ayers									€
Position 🗘	Layer name	Material 🗘	Thickness (mm) ≎	Material cost (zł/m²) ≎	Installation cost (zł/m ²) $\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$	Maintenance cost (zł/m²) ≎	Disposal cost (zł/m²) \$		
1	Adhesive	Adhesives - synthetic resin adhesive	5	5.00	5.00	1.00	1.00	10 🖉 🗘	
2	Insulation	Glass wool MW(GW)-PT 10 (90 $kg/m^3)$	50	12.00	12.00	12.00	2.00	D 🖉 Ū	
2	Insulation	EPS-F (15.8 kg/m ³)	200	20.00	40.00	1.00	10.00	D 🖉 Û	
2	Insulation	EPS-F grey/black (15.8 kg/m ³)	50	12.00	12.00	12.00	1.00	D 🖉 Ū	
3	Plaster	Single coat plaster mortar for exterior use 0	2	2.00	2.00	6.00	3.00	በ / በ	

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 Toolkit⁴ 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 IfcSiUnit⁵ or IfcUnit⁶ and associated to the project via IfcUnitAssignment⁷ are extracted and sent to RenoDSS in a JSON⁸ 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 <u>https://docs.xbim.net/</u>, 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

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

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, m², m³), 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 IfcPropertySet⁹ 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 IfcShapeRepresentation¹⁰ 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.,$,#1242,2.5206,5.62700000000001);
#1244= IFCCARTESIANPOINT((0.68937984605084,-2.38662323422544,0.0));
#1246= IFCDIRECTION((7.1892860847411E-6,1.0,0.0));
#1248= IFCAXIS2PLACEMENT3D(#1244,#20,#1246);
#1249= IFCEXTRUDEDAREASOLID(#1243,#1248,#20,2.99999999999999);
#1250= IFCSHAPEREPRESENTATION(#102,'Body','SweptSolid',(#1249));
#1252= IFCPRODUCTDEFINITIONSHAPE($,$,(#1250));
```

```
#58=IFCPOLYLINE((#59,#60,#61,#62,#63));
#59=IFCCARTESIANPOINT((8000.,0.));
#60=IFCCARTESIANPOINT((9400.,300.));
#61=IFCCARTESIANPOINT((9400.,300.));
#63=IFCCARTESIANPOINT((8000.,0.));
#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.Geometry¹¹ is used. Each element is decomposed to its mesh representation using the triangulation methods of the component. The XbimFaceTriangulation¹² 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

10

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

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

¹² <u>http://docs.xbim.net/XbimDocs/html/bdb35365-05aa-75f5-bb7a-d7cbd64942f6.htm</u>, 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 projectspecific 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:

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

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



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

The implementation of the IFC-file enhancement with the values described in the table above using IfcPropertySet¹³ 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.

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

ROIis the Return of Investment in %ec2_{base}is the energy running cost during the period of analysis for the baseline
scenarioec2_{reno}is the energy running cost during the period of analysis for the renovation
scenario with applied renovation measures

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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.

▲ 2	83,569	0	5,369	65.2	3
▲ 2 Total scen	Absolute: 28 Absolute dev Percent of ba		220 075 pi: 143311.7688 89737164082	3128986	3:

Scena	ario solutions						Filtered KPIs	All KPI	Show absolute KPI values
									Show absolute KPI values
	EC5 ¢	EC6 ¢	EC1 0	EN1 0	EN11 0	EN12 \$	SU2 ¢	SU9 0	Show absolute deviation to baseline KPIs
									Show percentage KPI values
▲	217,623	0	2,702	65.2	32.8	40.7	2,460.1577	0.113	
▲	569,517	0	14,587	65.2	32.8	40.7	1,311.7977	0.113	Image:
▲	218,049	0	2,702	65.2	32.8	40.7		0.113	Image:
	283,569	0	5,369	65.2	32.8	40.7	1,291.9709	0.113	Image:
▲	283,995	0	5,369	65.2	32.8	40.7		0.113	🕒 💿 🚺 🗸
Total	scenarios: 10 - C	Calculated scenarios: 10							

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 database¹⁴ 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 <u>https://www.oekobaudat.de/</u>, last access: 11.05.2021

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Process: Wall (with interior_exterior painting)

Flow	Category	Flow property	Unit	Amount	Uncertainty	Default provi	Pedigree unc	
Expanded clay, lightweight c	Recyclables/Mineral	Volume	m3	0.3	none			
Paint (silicate emulsion)	Recyclables/Mineral	Mass	kg	1.0	none			
⁹ Facade paint	Recyclables/Mineral	Mass	kg	1.0	none			
[©] Primers and facade paints (sil	Recyclables/Coatings	Mass	kg	1.0	none			
utputs								01
low	Category	Flow property	Unite	Amount	Uncertainty	Avoided prod	Pedigree unc	
Q Mail (with interior®) enterior		Area		10	0008		-	

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

Wall (with interior&	exterior painting) 🛛 🏶 Wall (with in	nterior& exterior painting)	💥 Quick results 🖾	
Results of Wall	(with interi	ior_exterior pair	nting)		
▼ General informa	ation				
Product system	Wall (with int	terior& exterior paintin	g)		
Allocation method	d None				
Target amount	1.0 m2 Wall (with interior& exterior	painting)		
	🖲 Export to	Excel			
 Flow contribution 	005				
Flow Acidi	fication Potentia	l of soil and water (AP)	, SO2-eq Öki 🔻		
			0.287 kg: 1.3.04	Leightweight concrete element, expander 1 bonding agent and exterior paint, acrylic	d clay, plan stone, inner wall (A1- c façade paint 100 - Brillux (A1-A3
			0.021 kg: 2.21.0	1 Primers and facade paints, "Silicon-Fass	adenfarbe 918" - Brillux (A1-A3);
			6.810E-3 kg: 5.4	l.02 exterior paint silicate emulsion paint (/	A1-A3) - DE
			—— 0.000 kg: Wall (with interior& exterior painting)	
¢					
General information In	wentory results	Process contributions	Locations Grouping		

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 webbased 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.



BIMERR		dmin User																			0
				Avail						_		-				P	roject de	tails			
cts	+			ophok						-							ddress		60 xX	μ, Χαρ. Θέρι	μης, Thermi
lata	e l							P								E	uilding h	eight	6.65 r	m	
	Petro				2											E	xternal w	all area	263.9	69 m²	
planning	a second s	0			abop.								1			U	Isable flo	or area	604.1	8 m²	
	inter of												<u>14</u>			c	onstructi	ion year	2000		
	AF	A M Leaflet @ Ope	StreetMap contr	ributors © CAR	то									7	•						
	Material pro	perties			Ana	alysis perio	d and rate	5				Energy prices and	emissio	ns				Envi	ronmental	l costs	
	Material pro Material Name	perties			Ana	alysis perio LCA Proper	d and rates	5				Energy prices and	emissio Oj	ns paque Ma	terial Prope	erties		Envi	ronmental Glazi	l costs	Properties
	Material pro Material Name	perties	GWP	AP	Ana	alysis perio LCA Proper ADPE	d and rates rties EP	s ADPF	POCP	Dens.	GM	Energy prices and Rough.	emissio Ol	ns paque Ma Cond.	terial Prope SHC	erties TA	SA	Envi	Glazi UF	l costs ing Material i SHGC	Properties VT
	Material pro Material Name Gypsum Wall Board	perties	GWP	AP 7 0.005	An: ODP 0.000	ADPE	d and rates rties EP	ADPF 65.50	P0CP	Dens.	GM	Energy prices and a Rough.	emissio Oj	ns paque Ma Cond. 0.160	SHC	TA 0.5	SA 0.5	Envi VA 0.5	Glazi UF	ing Material SHGC	Properties VT
	Material pro Material Name Cypsum Wall Board Concrete, Cast-in-Place gray	perties MRU D m ²	GWP	AP 7 0.005 2 0.000	An: ODP 0.000	ADPE	d and rates rties EP 0.001	ADPF 65.50 0.386	POCP 0.000	Dens. 800 2350	GM	Energy prices and Rough. medium smooth medium smooth	emissio Ol	ns paque Ma Cond. 0.160 2.399	SHC 1090	TA 0.5 0.400	SA 0.5	Envi VA 0.5	Glazi UF	ing Material SHGC	Properties VT
	Material pro Material Name Gypsum Wall Board Concrete, Cast-in-Place gray Air	perties MRU (1) m ² (2) kg (1) kg	GWP	AP 7 0.005 2 0.000	An: ODP 0.000 0.000	ADPE	d and rates ttles EP 0.001 0.000	ADPF 65.50 0.386	POCP 0.000 0.000	Dens. 800 2350	GM	Energy prices and of Rough.	emissio Ol	ns paque Ma Cond. 0.160 2.399:	terial Prope SHC 1090 1000	TA 0.5 0.400	SA 0.5	VA 0.5	UF	ing Material SHGC	Properties VT
	Material pro Material Name Gypsum Wall Board Concrete, Cast-in-Place gray Air	perties MRU D m ² b kg b kg	GWP	AP 7 0.005 2 0.000 0	An: ODP 0.000 0	Alysis perio	d and rates tries EP 0.001 0.000 0	ADPF 65.50 0.386 0	POCP 0.000 0.000 0	Dens. 800 2350 1.199	GМ	Energy prices and a compared of the second s		ns paque Ma Cond. 0.160 2.399 0.457	Eerial Prope SHC 1090 1000 1003	erties TA 0.5 0.400 0.5	SA 0.5 1	VA 0.5 1 1	UF	I costs ing Material SHGC	Properties VT
	Material pro Material Name Gyppum Wall Board Concrete, Cast-in-Place gray Air Glass	perties MRU (1) kg (1) kg (1) kg (1) m	GWP	AP 7 0.005 2 0.000 0 0.001	An: ODP 0.000 0.000 0 0.000	Alysis perio LCA Proper ADPE 0.000 0.000 0.000	d and rates EP 0.001 0.000 0 0.000	ADPF 65.50 0.386 0 34.39	POCP 0.000 0.000 0 0.001	Dens. 800 2350 1.199 2500	GM	Energy prices and Rough. medium smooth medium smooth wery smooth medium smooth		ns paque Ma Cond. 0.160 2.399 0.457 0.989	SHC 1090 1000 1003 880	erties TA 0.5 0.400 0.5 0.400	SA 0.5 1 1	VA 0.5 1 1 1	UF	i costs ing Material I	Properties VT

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.

BIMERR	E Home Administration Admin User						0 0 0
Home	KPIs					Filterec	
Projects							-
	Economic	Status quo	Target		Sustainability	Status quo	Target
i Base data	Life cycle cost during period of analysis (in monetary unit)	317,660	317,660	٥	CO2 emission rate (in kg CO2/m ²)	0.0248	0.0248
NU Urban planning	Operation cost during period of analysis (in monetary unit)	317,660	317,660	۲			
🥖 KPIs	Energy	Status quo	Target		Comfort	Status quo	Target
(=) Harrison	Total primary energy consumption (in kWh/m²/year)	65.2	65.2	٠			
T Measures	Heating energy demand (in kWh/m²/year)	32.8	32.8	٥			
Scenarios 3/3	Cooling energy demand (in kWh/m²/year)	40.7	40.7	۲			
	Total primary energy consumption non renewable (in kWh/m²/year)	65.2	65.2	٥			
	Cooling load profile (in Watts)	Diagram					
	Electric energy consumption (in kWh/m ² /year)	65.2	65.2	٢			
	Electricity load profile (in Watts)	Diagram					
	Peak electricity load (in Watts)	7,230	7,230	٥			
	Heating load profile (in Watts)	Diagram					
	Peak heating load (in Watts)	5,700	5,700	٥			
	Peak cooling load (in Watts)	6,320.2		٢			
	Energy generated on site and exported to the district (in kWh/m²/year)	16.5514	16.5514	٢			
						Gol	to renovation measures





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).

BIMERR	■ Home	Administration	Admin User											D	0 O
Home	Measures														
Projects	F	acade	Roof	Floor		Fenestral	tion	Heating system		Hot water		Solar		Cooling system	
Urban planning	Building	element group			Thickness	Construction I	ayers			□ Nr.≎	Renovation m	easures 0			
💋 KPIs	Basic W	/all:My exterior wall	280mm	× v			Conditioned sid		^	M A	External then	nal insulation system			
E Measures	Are	a C Building	elements 0		10 mm	Finishing Coat	ing	A	в	В	Internal therr	nal insulation syster	n		
9 Scenarios 2/2	38.	20 m² Basic Wa	II:Mv exterior wall 280mm:989559	^	10 mm	Finishing Coat	ing	Δ.	в						
e scenarios 3/3	✓ 12.	I2.86 m ² Basic Wall: My exterior wall 280mm: 990248			160 mm	Lightweight B	r Etics	A	8						
	2.4	2 m ² Basic Wa	ll:My exterior wall 280mm:991494		10 mm	Finishing Cost			· ·						
				Ŷ											
		-			Layers Position 0	Layer name :	Material 0		Thickness (mm) 0	Material cost (MU/m²) ≎	Installation cost (MU/m ²)	Maintenance cost (MU/m ²) c	Disposal cost (MU/m ²) 0		•
					1	Adhesive	Adhesives - synthe	tic resin adhesive	5	5.00	5.00	1.00	1.00		
					2	Insulation	EPS rigid foam (Sty	ropor °) for ceilings/floors	: 150	10.00	10.00	1.00	10.00		
					2	Insulation	Insulating cork (13	0 kg/m ^a)	70	10.00	10.00	1.00	1.00	0 / 0	
					3	Plaster	Single coat plaster	mortar for exterior use OC	12	2.00	2.00	6.00	3.00	0 0	
	Save measur	res / Calculate scena	arios							Con	binations: 3 - C	alculation time: 45 s	econds	Go to renovation sce	enarios

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.



BIMERR	🗮 Home Administration Admin User			
Home	Scenario solutions		Filtered KPIs All KPIs Show absolute KPI values *	KPIS 💿 Filtered KPIS 🂽 All KPIS
 Projects Base data Urban planning KPIs KPIs Measures 	ECS : EC6 : EC1 : NOLIDO 0 16,958 S74,634 0 7,791 651,662 0 7,791	EC2: EC3: EC4: EC7: EN1: EN1:1: 117.660 563.537 4.538 -3.359 65.2 22.8 317.660 227.647 1.535 -3.178 65.2 22.8 317.660 321.941 4,299 -4,132 65.2 32.8	BH2 BH2 BH3 BH3 BH3 BH5 40.7 45.3 45.2 5.700 Degram 40.7 65.2 5.700 Degram	Economic A ECS-Life cycle cost during period of analysis (moretary units) 908,505 574,634 908,505 ECS-Pugback period (years) 0
Scenarios 3/3	 Total scenarios: 3 - Calculated scenarios: 3 Renovation measures Renovation measure 	Element trose Quantity Life time	> Life (vice Cost Sustainability	EC1 - Construction cost (monetary unit) 7,791 16,957 EC2 - Operation cost during period of analysis (monetary unit) 247,647 569,557
	> External facade insulation 1 total	Facade 229.16 m ² 30	590,844.41 28,15	E2-E2 dd life cost (nonetary unit) 1 < C 2 300 V

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 CO₂ 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: <u>https://www.openlca.org/wp-content/uploads/2015/11/The-database-%C3%96KOBAUDAT_en_April2015.pdf</u>

[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., m² or m³) 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, DC1=20, CC1=200, DC2=10, CC2=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

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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
- EPi₀ is the energy price of energy carrier i in year 0
- ei is the expected energy escalation rate of energy carrier i
- d is the expected discount rate

Example: a=1, b=2, ED1₀=50, ED1₁=100, EP1₀=5, ED2₀=25, ED2₁=50, EP2₀=10, e₁=0,02, e₂=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

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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

 $MCi_n \quad \mbox{is the maintenance cost of renovation measure i in year n}$

 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, MC1₀=50, MC2₀=100, CC1₀=25, CC2₀=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, EoLCi₀=100, EoLCi₁=200, e=0,02, n=30

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

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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 table¹⁵.

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

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:

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



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

GWP100ais the global warming potential of the renovation measure in kg CO2-eqiis the current building material or component used in the renovationmeasureis the number of materials or components used in the renovationmeasureGWP100aiGWP100aiis the global warming potential of material or component i per referenceunit (e.g., 0,45 kg CO2-eq per m³)RUiis the amount of reference units of material or component I (e.g., 27 m³)Ais 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 water¹⁶ 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 CFC11eq/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} .

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

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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 equivalents¹⁸ 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 ecosystem¹⁹. 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 equivalents²⁰ 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&Ing=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 ozone²¹. 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

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