D9.3

Life Cycle Assessment report of the demonstrations

SINFONIA

"Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions"

CONTRACT NUMBER	609019	INSTRUMENT	COLLABORATIVE PROJECT
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Publishable executive summary

Life-cycle assessment (LCA, also known as life-cycle analysis) is a technique to assess environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service, e.g., in the case of a manufactured product, from raw material extraction and processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave).

Deliverable D9.3 has three main objectives:

- To present the methodology, hypotheses and outcomes of the Life Cycle Analysis of the energy saving measures implemented in selected buildings in Bolzano (Italy) and in Innsbruck (Austria), based on the input data provided by the building owners, members of the SINFONIA consortium (analysis performed by DOWEL) .
- To present the methodology, hypotheses and outcomes of the Life Cycle Analysis of the measures carried out on the district heating networks in Bolzano and in Innsbruck, based on the input data provided by the local utilities Alperia and IKB, members of the SINFONIA consortium (analysis performed by RISE).
- To explore the applicability of LCA at the district scale.

Results

At building scale:

The comparison of the environmental impacts of the two scenarios (with / without renovation) for the whole life cycle and all contributors demonstrates that:

- For 5 of the 8 indicators shown, the environmental profile is substantially improved by the renovation for all buildings: Energy use indicators, Global warming potential (GWP), and acidification potential (AP), Formation potential of tropospheric ozone (POCP) are clearly lower in the case of the renovated building.
- The 3 remaining indicators (Use of net fresh water, Hazardous and Non-Hazardous Waste) show either a relatively similar profile in both scenarios or, for some buildings, are deteriorated by the renovation:
    - For via Cagliari and via Passeggiata dei Castani, the installation of solar thermal collectors and corresponding heating system negatively impacts the indicator “Hazardous waste disposed” (however the impact on the energy use indicators is positive)
    - For Sebastian Scheel Strasse, the need for a new foundation with a gravel layer has an impact on the indicator “Non-hazardous waste disposed”. For the other buildings, the amount of new materials is so small in comparison to the existing ones (structural materials in particular) that their negative impact is largely offset by the avoided non-hazardous waste from the energy use.

In conclusion, the Life Cycle Assessments performed on the studied buildings confirm that **the renovation substantially reduces the environmental impact of a building** and **decreases in particular its Global Warming Potential.** This conclusion is valid both for Innsbruck and Bolzano.

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The Life Cycle Assessments demonstrate that the deep renovation of buildings brings multiple environmental co-benefits, in addition to the CO_2 indicator which is the most commonly used. As already mentioned in Deliverable 9.2 (Economic analyses of the demonstrations), the non-financial benefits of energy renovation measures, such as improvement of comfort, health, well-being and accessibility, green property value, environmental benefits, tackling fuel poverty, should be taken into account when assessing the benefits of renovation, to go beyond the 'kWh' and 'payback' rationale. Those benefits are however difficult to monetise, and more research is needed to be able to internalise them into a financial analysis.

Green certificates (based on the Emission Trading Scheme) could here provide an interesting option as they would enable to integrate the CO_2 cost into the financial equation and thereby decrease the payback time by a few years (the payback time of deep renovation being often above 25 years).

For District Heating:

- **Bolzano**

With the system boundaries and assumptions made for the analysis of the district heating system in Bolzano, it can be seen that the mixing of hydrogen into the CHP reduces the CO_2 emissions with 38.6 g CO_2/kWh_{heat}. The carbon intensity of the district heating system will be reduced with this solution as long as the production of hydrogen keep the emission factor below 215 g CO_2/kWh_{H2}.
The optimisation of the district heating network reduces the carbon intensity with 18.2 g CO_2/kWh_{heat} with the system of 2018. There is a small increase in carbon intensity with 0.051 g CO_2/kWh_{heat} with the district heating expansion in 2024 and the assumed operation of the different plants.

- **Innsbruck**

All three demonstrations in Innsbruck evaluated in this analysis reduce the carbon intensity of heat generation, although it is only powerhouse Rossau that is connected to the district heating network. Both the demonstration at UW Mitte and power to heat Amras only affect the heat generated at those sites.
The carbon intensity decreases by 107 g CO_2/kWh_{heat} by implementing heat pumps at the transformer station of UW Mitte.
The emission intensity decreases by 57 g CO_2/kWh_{heat} by implementing power to heat Amras. This might be a conservative number since it is calculated with average emission factor of electricity generation, while the aim is to operate the electric heating element while the electricity prices are low, which indicate that the emission level is lower as well.
Powerhouse Rossau is the only measure out of the three studied in Innsbruck with affects the emission intensity of the district heating system. Between 2016 and 2019, the carbon intensity of the district heat decreased by 47.74 g $CO_2/kWh_{heat.}$ However, this reduction is not due to the implementation of powerhouse Rossau only and the comparison when the district heating system is kept constant except from the implementation of powerhouse Rossau shows a reduction of carbon intensity of the district heat with 2.86 g CO_2/kWh_{heat}.

District scale

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Could LCA type approaches support the decision making on planning issues towards sustainable cities? Studies of environmental impacts at the level of a district or a city by urban planners could be carried out to identify impacts of options such as building types, urban density, morphology of urban fabrics, retrofit or new constructions. Such use remains limited for the time being, but it could play a role of target setting, monitoring and assessing sustainable urban environment programs in the general context of the integration of climate strategies.

The simple analysis carried out in Bolzano demonstrates that improving both the performance of buildings and of the district heating network has a synergistic effect which enables reaching a substantial impact (e.g. for Via Cagliari in Bolzano: Use of primary energy over the whole life cycle reduced by 51%, and GWP reduced by 57%).

Conclusion & recommendations

As a general conclusion, a Life Cycle Approach is instrumental when developing a long-term urban plan and can be used to make informed decisions. When it comes to energy efficient renovation (of buildings or district heating), the LCA usually provides positive results, and in that case **it is recommended to use it *ex ante* to compare different options, and *ex post* to confirm the impacts (once real measures are available).**

The availability and quality of data is essential: in the present report, simplified analyses have been carried out as some data were missing (for instance on the waste generated during the renovation works). Different hypotheses were also made on the structural materials, and on the consumption per energy carrier before renovation. So as to ensure the quality of the LCA done at building level, detailed datasets should therefore be made available on:

- The energy consumption before renovation (per energy carrier), based on real measurements or energy bills
- The energy consumption after renovation (per energy carrier), based on real measurements or energy bills
- The materials already in place before the renovation, and those removed during the renovation works
- The materials and equipment installed during the renovation (with information on their lifetime)
- Ideally, the water consumption

Finally, **the use of LCA at district scale brings an interesting added value – although it seems to be better suited for new constructions** (or for very ambitious operations such as Positive Energy Districts/ Building Blocks) than for punctual renovations as in SINFONIA.

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GLOSSARY

Abbreviation	Explanation
ADP	Abiotic Depletion Potential
ADPE	Abiotic Resource Depletion Potential for elements
ADPF	Abiotic Resource Depletion Potential of fossil fuels
AP	Acidification Potential
AIP	Air pollution
BLBSB	Benefits and Loads Beyond the System Boundary
CML	Centrum voor Milieukunde, Leiden (NL)
CPD	Construction Products Directive
CRU	Components for re-use
EE	Exported energy per energy carrier
EP	Eutrophication Potential
EPD	Environmental Product Declaration
ESL	Estimated service life
FW	Use of net fresh water
GWP	Global Warming Potential
HQE	Haute qualite' environmentale (French Sustainable Building Council)
HWD	Hazardous waste disposed
IBU	Institut Bauen und Umwelt e.V.
ILCD	International Reference Life Cycle Data System
IWD	Inert wastes disposed
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCC	Life Cycle Costing
MER	Materials for energy recovery
MFR	Materials for recycling
NRSF	Use of non-renewable secondary fuels
NHWD	Non-hazardous waste disposed
ODP	Ozone Layer Depletion Potential
PE	Total use of primary energy
PENRT	Total use of non-renewable primary energy resources
PERT	Total use of renewable primary energy resources
PCR	Product Category Rules
POCP	Photochemical Ozone Creation Potential
ReqSL	Required Service Life
RSF	Use of renewable secondary fuels
RSL	Reference Service Life
RSP	Reference Study Period
RWD	Radioactive waste disposed

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SM	Use of secondary material
VIP	Vacuum insulation panel
WP	Water pollution

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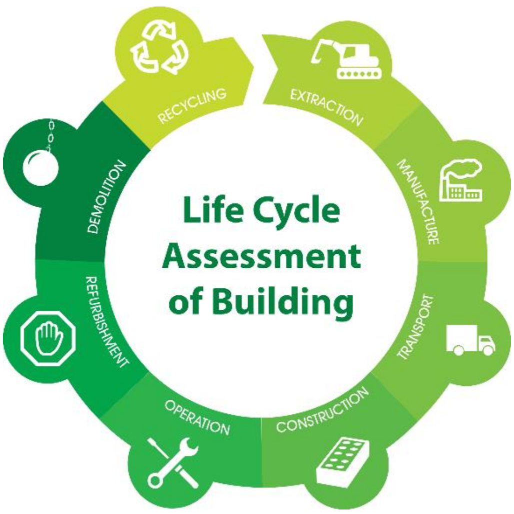
1. INTRODUCTION

This document synthesizes the life cycle assessment results obtained for the demonstrations (incl. buildings and district heating) carried out in Innsbruck and Bolzano.

1.1 SHORT INTRODUCTION TO LIFE CYCLE ASSESSMENT

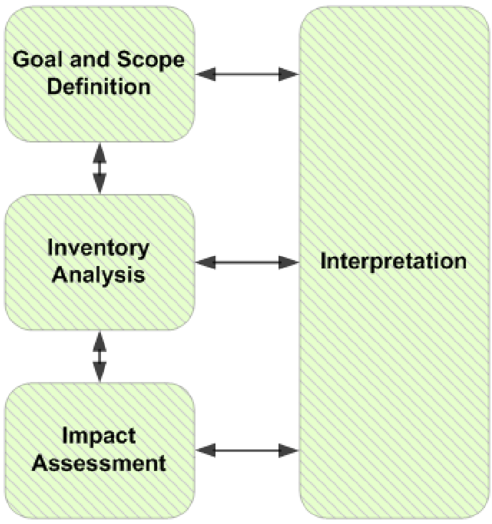
Life-cycle assessment (LCA, also known as life-cycle analysis) is a technique to assess environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service, e.g., in the case of a manufactured product, from raw material extraction and processing (cradle), through the product's manufacture, distribution and use, to the recycling or final disposal of the materials composing it (grave).



More specifically, the term is applied to the techniques and methods by which the overall environmental impact of the product, process, or service is determined, through a thorough inventory of the energy and materials that are brought into each, and the energy and materials related to each that are released into the environment.
The LCA methodology is standardized in ISO 14040 and ISO 14044 where principles and framework for LCA are described. However the standards do not describe the main phases in detail nor be prescriptive of the application.

Four main phases have to be considered in an LCA:

- **Definition of the goal and the scope of application**. In particular the limits of the system and the goal of the study have to be specified.
- **Inventory analysis** where raw materials, all inwards/outwards energy flows of the system during the whole life cycle as well emissions to air, water and soil are quantified. The use of relevant database and/or Environmental Product Declarations is considered during this phase
- **Impact analysis** is the 3rd step in which the inventory data are classified and evaluated in a series of impact categories
- **Interpretation** finally allows to assess the results of the study with respect to the initial goal and scope.



1.2 REPORT CONTENT

The present document contains:

- *Simplified LCA reports of the studied items (buildings and district heating)*

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- *An explaratory note on LCA at district scale, with Bolzano example, bringing together the results at district heating network and building levels*
- *Conclusions & Recommendations*

1.3 TOOL USED TO PERFORM THE ANALYSIS

Different tools & software exist to carry out LCAs:

Name	**Building specific?**	**Comment**
Simapro	NO	SimaPro has been a world's leading life cycle assessment (LCA) software package for 25 years. SimaPro supports LCA and EPD and always includes a variety of LCI databases, such as ecoinvent v3, the sector-specific Agri-footprint database and ELCD.
GaBi	NO	A world leader since 25 years too, GaBi combines Life Cycle Assessment (LCA) modelling and reporting software, content databases with intuitive data collection and reporting tools. It offers its own databases + ecoinvent and US specific databases.
Umberto	NO	Umberto is first an Effiency Software (i.e. analyzes the material and energy efficiency of a production and identifies potentials for optimization), but it also offers LCA functionalities .Umberto uses both ecoinvent and GaBi databases.
OpenLCA	NO	Open Source LCA software. Requires to buy the ecoinvent database
ELODIE	YES	Building specific web-based tool developed and commercialised by CSTB
ProCasaClima	YES	ProCasaClima is an Excel based tool elaborated by Energy Agency of Province of Bolzano CasaClima. In this region, it is mandatory to use this tool for the energy performance certificates' elaboration. ProCasaClima is able to perform LCA and economical assessment of buildings.

As CSTB is one of the project partners, and involved in T9.3 in particular, it was decided to use the ELODIE software to perform the LCA of buildings. The fact that it is web-based and collaborative (i.e. possibility to share projects between different members) was also a strong advantage.
Another approach was used to carry out the LCA of the district heating measures. GEMIS[1] a life cycle and material flow analysis model and database were used for the emission factors for the fuels used in the district heating system in Bolzano and Innsbruck.

[1] IINAS. *GEMIS - Global Emissions Model for integrated Systems*. 2014; Available from: http://iinas.org/gemis.html.

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2. LCA AT BUILDING LEVEL

2.1 GOAL OF THE STUDY

The LCA at building level provides a comparative analysis for existing buildings of a state without renovation and a state with renovation. The objective is to quantify the impacts and benefits of renovation on the life cycle performance of the building.

2.2 SCOPE

The studies conducted at building scale follow the provisions and guidelines developed by the EeBGuide research project funded by the European Commission (FP7)[2]. The present report is based on the template report provided by the EeBGuide Website.

The present document presents simplified LCA reports of the following buildings:

Bolzano	**Innsbruck**
Via Cagliari	Sebastian-Scheel-Straße 18, 18a, 18b
Via Aslago	Elementary school Angergaße
Via Passeggiata dei Castani (A&B)	Elementary school Siegmairstraße 1
	Osw.-Redlichstr. 7, 9, 11

Not all renovated buildings were studied, primarily because the data collection process took overall more than 2.5 years (for data availability and data confidentiality issues) and only datasets for those 7 buildings (out of the 18) were received on time. This study provides nevertheless a good basis to analyse the impacts of the project as a whole.

Forewords and warning:

- The present LCA report describes a simplified approach. While the study is based on EN 15978 standard, a number of hypotheses and data used do not strictly follow the standard's requirements.
- All LCAs were performed *ex ante*, i.e. with theoretical values on the energy consumption, as no real data on energy consumption after renovation were received to perform *ex post* analyses and complete the report in due time.

The studies have been carried out by DOWEL Management and CSTB.

2.3 FUNCTIONAL EQUIVALENT

The objects of the assessment are entire residential buildings (from cradle to grave). Infrastructures located on the building site (e.g. road, park, etc.) are not included within the boundaries. The assessment is done for the non-renovated building and for the renovated building.

[2] EeBGuide : Operational Guidance for Life Cycle Assessment Studies of the Energy Efficient Buildings Initiative - http://www.eebguide.eu/

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The numbers of tenants are derived from the information provided in the BEST sheets. A typical reference study period of 50 years has been chosen.

Functional unit		BOLZANO			INNSBRUCK			
		Via Cagliari	Via Passeggiata dei Castani	Via Aslago	Sebastian-Scheel Str.	Fennerstraße & Oswald-Redlich-Str.	School Angergasse	Siegmair school
	Reference unit:	1 building	2 buildings	1 building	1 building	2 buildings	1 building	1 building
	Type of building	Residential	Residential	Residential	Residential	Residential	School	School
	Number of dwellings	106 (384 tenants)	72 (108 tenants)	70 (174 tenants)	34	84	NA	NA
	required service life	50 years	50 years	50 years	50 years	50 years	50 years	50 years
	Other services provided within the building (shops, …)	/	/	/	/	/	/	/

2.4 SYSTEM BOUNDARIES: LIFE CYCLE STAGES AND CONTRIBUTORS

The study encompasses:

- The production, transport, implementation, use phase and end of life of building products and systems that are implemented during the retrofitting (new materials);
- The end of life of products that are kept during the retrofitting: hypotheses have been made on the structural materials of the buildings (which are the materials with the highest impact, given the volumes and weight at stakes).
- When known, the replacements that are carried out during the reference study period (i.e. change of windows at the end of their service life);
- The energy use during the reference study period for the following services: heating, cooling, domestic hot water production, ventilation and lighting;
- The energy produced during the reference study period (Photovoltaic or Solar heating).

The system boundary includes all stages of the life cycle, from the acquisition of raw materials to their disposal (or to the point where materials exit the system boundary) but exclude system extension (module 'D': reuse, recovery, recycling potential).

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Included lifecycle stages			
Product Stage	☑	A1	Raw Materials Supply
	☑	A2	Transport
	☑	A3	Manufacturing
Construction Process	☑	A4	Transport
	☑	A5	Construction- Installation process
Use Stage	☑	B1	Use
	☑	B2	Maintenance
	☐	B3	Repair
	☑	B4	Replacement
	☐	B5	Refurbishment
	☑	B6	Operational Energy Use
	☑	B7	Operational Water Use
End of Life Stage	☑	C1	Deconstruction
	☑	C2	Transport
	☑	C3	Waste process for reuse, recovery or/ and recycling
	☑	C4	Disposal
Benefits and loads beyond the system boundary	☐	D	Reuse- Recovery- Recyclingpotential

These different phases, and the included contributors, are illustrated below:

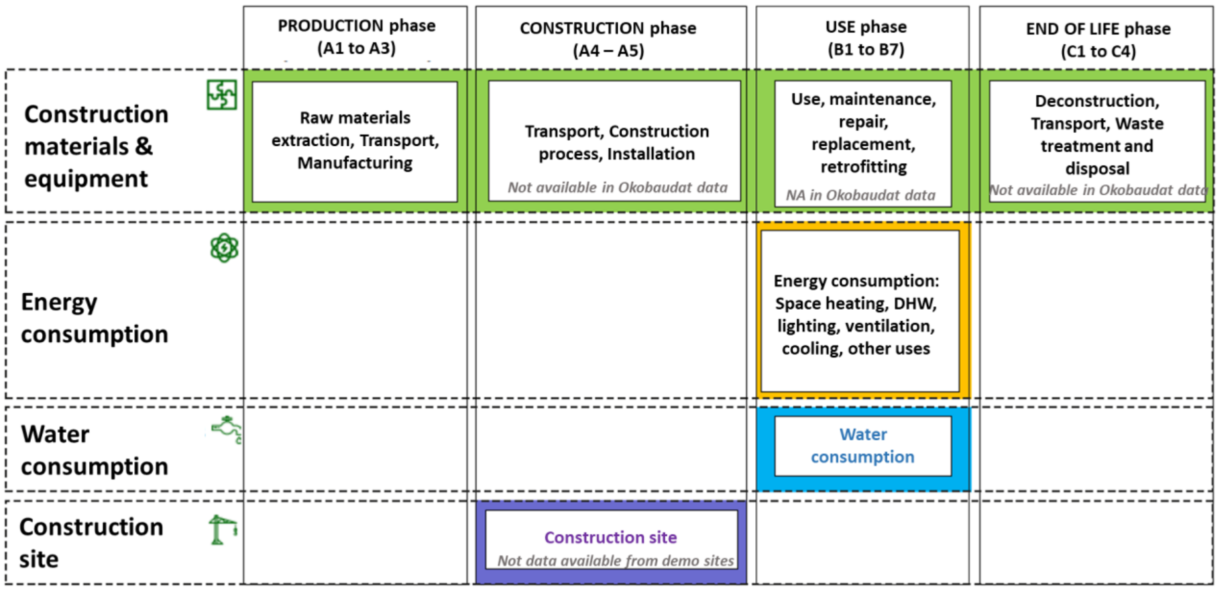

FIGURE 1: LCA PHASES AND CONTRIBUTORS

The tool used to collate all the data related to these stages is ELODIE, the LCA software developed and distributed by CSTB.

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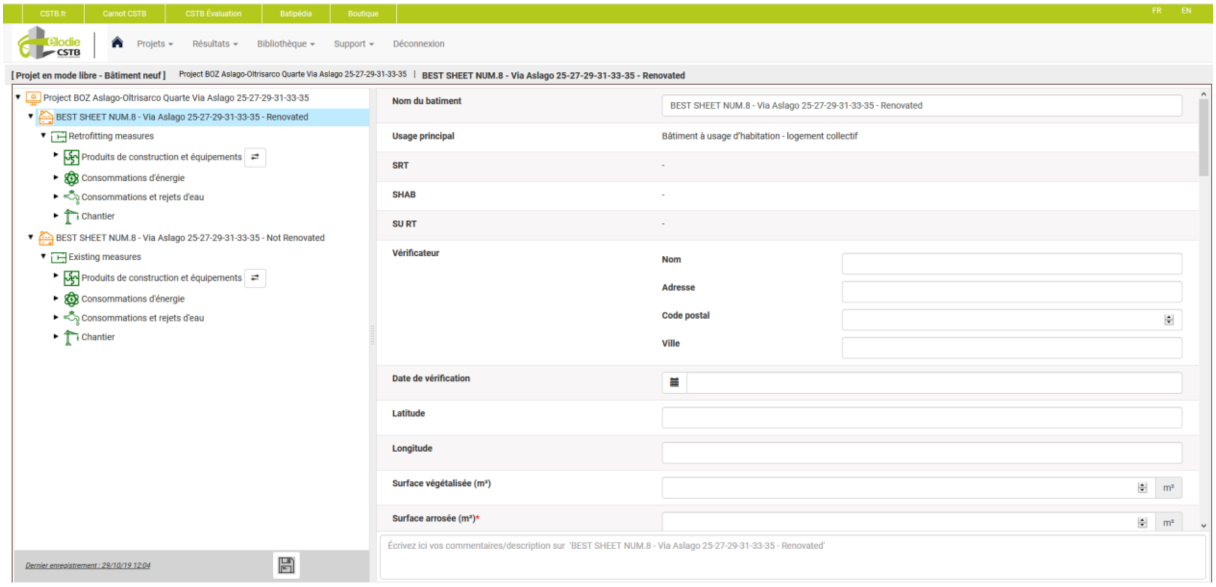

FIGURE 2 SCREENSHOT FROM THE ELODIE V3 SOFTWARE

2.5 DESCRIPTION OF THE STUDIED BUILDINGS

The studied buildings have the following general characteristics:

TABLE 1: BUILDING CHARACTERISTICS (SOURCE: BEST SHEETS)

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City	BOLZANO			INNSBRUCK			
Best sheet number	**1**	**7**	**8**	**3**	**11**	**18**	**17**
Building Characteristics	**IPES via Cagliari**	**BOZ via Passeggiata dei Castani**	**BOZ via Aslago**	**IIG Sebastian Scheel Strasse**	**NHT Fennerstrasse**	**IIG Angergasse**	**IIG Siegmairstrasse**
total area	9402 (+ vertical extension)	7364,8	5796	2115	6994	5139	3786
category	residential	residential	residential	residential	residential	school	school
building age	**1954**	**1996**	**1960**	1941	1958	1955	1960
Final energy consumption before (kWh/m².year)							
Space heating	185,66	201,71	228,59	**216,9**	**116**	**156,5**	**154,4**
Ventilation							
lighting	14,43	14,43	14,43	12	12	30	30
DHW	20,69	20,01	21,27	17,4	26,8	9,2	6,5
other						30	30
Total	**220,78**	**236,15**	**264,29**	246,3	154,8	225,7	220,9
Appliances	21,25	21,25	21,25	50	50		
Final energy consumption after (kWh/m².year)							
Space heating	23,89	23,89	23,89	23,2	20	30,3	81,5
Ventilation	5,42	5,42	5,42	3,3	3,3	4,7	4,6
lighting	12,41	12,41	12,41	7	7	20	20
DHW	19,29	18,65	19,83	15,4	20	6,00	9,40
other				1,4	1,4	18	18
Total	**61,01**	**60,37**	**61,55**	**50,30**	**51,70**	**79,00**	**133,50**
Appliances	21,25	21,25	21,25	30	30	21,25	22,25
Production	12,48	37,85	35,36	9,00	6,20	4,75	0,00
Global building energy use (kWh/m².year)	**48,53**	**22,52**	**26,19**	**41,30**	**45,50**	**74,25**	**133,50**
Label before renovation	G	G	G	E	D	D	D
Heating system	DH	Before: Gas. After: Geothermal HP	Before: Gas. After: Pellet boiler	Elec+gas	Elec+gas	Elec+gas	Elec+gas

2.6 LIFE CYCLE INVENTORY

2.6.1 DATA COLLECTION AND CALCULATION PROCEDURES

Data collection follows the guidance provided in **ISO 14044**, clause 4.3.2. The calculation procedures described in **ISO 14044** are applied consistently throughout the study.

According to the definition of the scope of the study, all relevant inputs and outputs related to the building are identified and quantified.

Data were provided by:

- CasaClima for buildings owned by the municipality of Bolzano and IPES
- IIG for Sebastian Scheel Strasse and the 2 schools
- NHT for Fennerstrasse

2.6.2 SELECTION OF DATA/ BACKGROUND DATA

For life cycle modelling of the building, ELODIE LCA software has been used. Some preliminary calculations involved the use of the SimaPro LCA software (v 7.3.3).

Life cycles of new products were considered using data from **ÖKOBAUDAT** (see table 17 in Annex for more details).

Additional data used during the studies were taken directly from the INIES Database and from the **Ecoinvent Database (v2.2)**.

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Impacts related to electrical energy uses are representative of the Austrian and Italian electric mixes (based on Ecoinvent 2.2 data).
For the District Heating in particular, the methodology used is presented below.

2.6.3 SPECIFIC METHODOLOGY FOR THE USE OF HEAT FROM DISTRICT HEATING

The environment impact indicators which have been calculated for District Heating are presented in Table 2.

TABLE 2: ENVIRONMENT IMPACT INDICATORS

Global Warming	kg $CO_{2\ eq}$	There is no data available on INIES database to calculate this indicator. It has been calculated on another way detailed in the §I.B
Ozone Depletion	kg $CFC^{-11}{}_{eq}$	These indicators have been calculated, thanks to data available on the INIES database. The calculation in detailed in §I.A.
Acidification for soil and water	kg $SO_{2\ eq}$	
Eutrophication	kg $PO4^{3-}{}_{eq}$	
Photochemical ozone creation	kg $C_2H_{4\ eq}$	
Depletion of abiotic resources -elements	kg Sb_{eq}	
Depletion of abiotic resources -fossil	MJ, net CV	
Water pollution	m^3	
Air pollution	m^3	
Renewable primary energy excl. RM	MJ, net CV	
Total renewable primary energy	MJ, net CV	
Non renewable primary energy excl. RM	MJ, net CV	
Total non renewable primary energy	MJ, net CV	
Net use of fresh water	m^3	
Hazardous waste disposed	kg	
Non hazardous waste disposed	kg	
Radioactive waste disposed	kg	

2.6.3.1 ENVIRONMENT IMPACT INDICATORS (EXCEPT GWP)

Data used for the study (coming from INIES database) are presented in Table 3.

TABLE 3 : DATA AVAILABLE ON INIES DATABASE

Input fuel	Data available on INIES[3]	Id INIES	Data used in
Biogas (CHP)	Mise à disposition de chaleur par réseau de chaleur type cogénération biogaz (hors contenu CO2)	5934	Innsbruck case study
Biomass	Mise à disposition de chaleur par réseau de chaleur type biomasse (hors contenu CO2)	5927	Innsbruck case study
Excess heat*	-	-	Innsbruck case study
Natural gas	Mise à disposition de chaleur par réseau de chaleur type gaz naturel (hors contenu CO2)	5929	Innsbruck case study and Bolzano case study

[3] https://www.base-inies.fr/iniesV4/dist/consultation.html

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Natural gas (CHP)	Mise à disposition de chaleur par réseau de chaleur type cogénération gaz naturel (hors contenu CO2)	5931	Bolzano case study
Oil	Mise à disposition de chaleur par réseau de chaleur type fioul (hors contenu CO2)	5928	Innsbruck case study
Waste*	-	-	Bolzano case study

*For excess heat and recovery energy, a conversion factor of 0 is assumed, considering that emissions would have been emitted anyway.

The following formula is used to calculate the environment impact indicators (except GWP):

$$indicator = \frac{\sum_i E_{fuel_i} \times F_{fuel_i}}{Heat\ produced}$$

- E_{fuel_i}: amount of fuel i
- F_{fuel_i}: conversion factor for the fuel i
- $Heat\ produced$: heat produced

The Combined Heat and Power (CHP) aspect is already included in the data, that is why it is not included in the formula.

2.6.3.2 GWP

Figure 3 presents the LCA scope which is considered to calculate district heating's GWP.

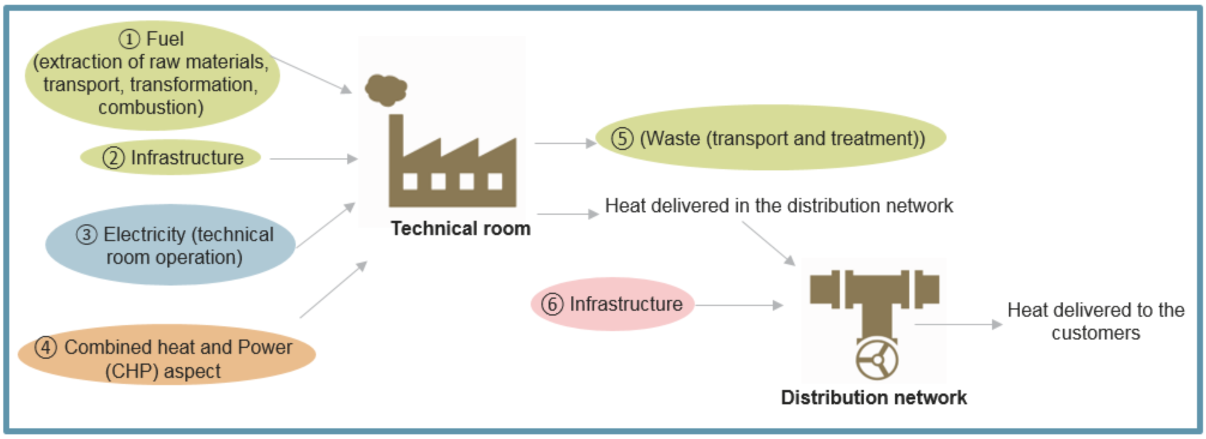

FIGURE 3: LCA SCOPE FOR DISTRICT HEATING

The scope is divided in 6 steps:

- ① Fuel: this part takes account of the extraction of raw materials (biomass, gas…), its transport, its transformation and its combustion to produce the heat.
- ② Infrastructure: infrastructure of the technical room.
- ③ Electricity for the technical room operation.
- ④ Combined Heat and Power aspect: this aspect is considered in the calculation formula.
- ⑤ Waste: waste (ash) produced during the combustion for biomass fuel.
- ⑥ Infrastructure: infrastructure of the distribution network.

Table 4 describes the conversion factor used for each step.

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TABLE 4: CO_2 CONVERSION FACTOR

	GWP (gCO_{2eq}/kWh)			
Input fuel	**Fuel + Infrastructure + Waste[4]**	**Electricity (central heat operation)** [5]**	**Infrastructure[5]**	**Data used in**
Biogas	80	Innsbruck case study: 5.89 Bolzano case study: 8.02	2.89	Innsbruck case study
Biomass	16			Innsbruck case study
Excess heat*	0			Innsbruck case study
Natural gas	274			Bolzano and Innsbruck case studies
Oil	314			Innsbruck case study
Waste*	0			Bolzano case study

* For excess heat and recovery energy, a CO_2 conversion factor of 0 is assumed, considering that emissions would have been emitted anyway

** 0.019kWh used in the technical room/kWh delivered. The GWP for 1 kWh depends on the electricity mix of the country. That is why, this value is different for Austria and Italy. Detailed calculation is presented in Table 5** Fel! Hittar inte referenskälla.**.

TABLE 5: CALCULATION FOR STEP «ELECTRICITY (CENTRAL HEAT OPERATION)**

	GWP for 1 kWh electricity (from SimaPro)	GWP for 0.019 kWh electricity
Austria (Innsbruck)	310 gCO_{2eq}/kWh	5.89 gCO_{2eq}/kWh
Italy (Bolzano)	422 gCO_{2eq}/kWh	8.02 gCO_{2eq}/kWh

The following formula was used to determine district heating's GWP.

$$GWP = \frac{\sum_i E_{fuel_i} \times F_{fuel_i} \times (1 - \%_{CHP,fuel} \times \%_{power\ produced})}{Heat\ produced}$$

- GWP: district heating's global warming potential [gCO_{2eq}/kWh]
- E_{fuel_i}: amount of fuel i [kWh]
- F_{fuel_i}: conversion factor for the fuel i [gCO_{2eq}/kWh]
- $\%_{CHP,fuel}$: percentage of fuel used for Combinated Heat and Power (CHP)
- $\%_{power\ produced}$: percentage of GWP linked to the power production during CHP. $\%_{power\ produced} = \frac{P_{CHP,heat}}{P_{CHP,heat} + P_{CHP,power} \times \frac{Ref_{Hr}}{Ref_{Er}}}$
- $P_{CHP,heat}$: amount of heat produced during CHP [kWh]
- $P_{CHP,power}$: amount of power produced during CHP [kWh]
- Ref_{Hr}: efficiency reference value for separate production of electricity and heat[6]

[4] Excel PEBN_toutes_energies_v1.20, RDC Environnement

[5] Development of Universal Calculation Model and Calculation Tool for Primary Energy Factors and CO Equivalents in District Heating and Cooling including CHP, IEA-DHC, Annex X Summary Final Report Universal Calculation Model Tool Date: 014-09-10 + associated Excel

[6] COMMISSION DELEGATED REGULATION (EU) 2015/2402 of 12 October 2015 reviewing harmonised efficiency reference values for separate production of electricity and heat in application of Directive 2012/27/EU of the European Parliament and of the Council and repealing Commission Implementing Decision 2011/877/EU

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- Ref_{Er}: efficiency reference value for separate production of electricity and heat[6]
- $Heat\ produced$: heat produced

This formula removes the GWP part linked to the power production from the total GWP (heat and power electricity).

2.6.4 PRODUCT AND MATERIAL CONTRIBUTOR

Data provided by the building owners were processed to identify the existing products and materials, and the new ones.

- **Existing products**: the focus was put on the main contributors, i.e. structural materials in particular, as they have the biggest impact in the building life cycle compared to other materials and pieces of equipment used in the dwellings themselves
- **New products and materials installed during the renovation**: this includes new windows and openings, new insulating materials, new heating systems and pipes, PV panels and solar thermal collectors
- **Existing products and materials discarded during the renovation**: unfortunately no data was available about the wastes generated by the works

All identify materials & products were then associated to the corresponding item in the Okobaudat database (which turned out to be a time-consuming process).

The **aggregated quantities of materials** for each studied building are provided in the table below (this list does not include windows, heating systems, PV panels and solar thermal collectors as those are kept at component level and corresponding data on number of units / areas were directly fed to ELODIE).

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City	BOLZANO				INNSBRUCK				
Best sheet number	1	7		8	3	11		18	17
Building	IPES via Cagliari	BOZ via Passeggiata dei Castani (A)	BOZ via Passeggiata dei Castani (B)	BOZ via Aslago	IIG Sebastian Scheel Strasse	NHT Fenner-strasse	NHT Oswald	IIG Angergasse	IIG Siegmair strasse
Existing materials (kept during renovation) - kg [Main contributors only]									
Lime-cement plaster	289 866			184 453	47 957	136 100	28 615		33 967
Gypsum plaster	134 581	268 029	236 420	93 980	66 060	155 347	126 175	137 800	39 417
Synthetic resin plaster						35 908	16 659		
Ceramic tiles and glue	25 508	67 466	64 834	50 342					
Concrete screed	209 856	372 061	360 460	216 091		268 619	151 081	169 350	247 761
Laminated wood				171 829					
Solid wood						778 180	353 905		4 348
Insulation cork						12 673	5 880	39	
Wood wool - Tektalan						13 538	5 034	23 388	29 440
Reinforced concrete		414 804	373 300	729 936	301 680	6 682	3 254	2 446 275	4 425 979
Slabs (beams and concrete)	827 185	2 167 609	2 089 241	115 830					
Masonry (concrete)				5 038 014				82 973	23 838
Bricks	774 491	1 058 566	1 049 690	265 680	420 670	531 421	36 329		
Bituminous membrane		16 133	15 504						
New materials - kg								110	
gypsum plaster	109 660	34 125	35 219	74 017	8 190	8 341	11 715	15 022	
lime-cement plaster				1 256					
gypsum plasterboards	17 739	744	948	27 270	189	324		2 233	
adhesive	66 930				47 360	23 508	6 956	49 872	
glasswool		13 209	12 994		804	371	174		
rockwool	15 587			2 587				1 848	
stone wool facade	51 567								
Wood wool + cement- Tektalan					16 642	5 324	2 662		
standard glued laminated wood	163 392			59 994					
Wood fibre insulation panel	417	14 941	14 313		1 529	2 200	1 245	3 898	10 631
Cellulose					9 950			5 068	8 443
perforated bricks				25 128					
extruded polystyrene panel XPS				1 467	369			2 255	5 500
polyiso foam sandwich panel		21 686	21 108						
rigid polyurethane foam panel PUR	1 201				1 426				
EPS insulation			102	39 762	5 445	13 526	6 627	8 086	
PVC waterproofing		1 159	1 134					140	
concrete screed			8 890	38 610				1 163	
reinforced concrete	25 690							4 152	
Slabs (beams and concrete)			76 810						
bituminous membrane	6 535								3 974
ceramic tiles			2 921					129	

2.6.5 OPERATIONAL ENERGY USE

Data on the final energy used by each building in its existing state (not renovated) and after renovation, and by type of energy carrier, have been derived from the BEST sheets and information provided by CasaClima, IIG and NHT (e.g. in the “Energieausweis”), as well as complementary data where required (e.g. split of the energy systems in each flat for Sebastian Scheel Strasse).

A specific datasheet is then attributed in ELODIE to each energy carrier:

- Use of electricity for the use phase (operational energy) uses country specific energy mixes, based on Ecoinvent data (including imports from other countries).
- Use of gas for heating has been modeled as “Natural gas, burned in boiler condensing modulating <100kW/RER U” for all the studies (median value for Europe).
- District heating in Bolzano has been modelled according to the methodology described in .

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City	BOLZANO				INNSBRUCK				
Best sheet number	**1**	**7**		**8**	**3**	**11**		**18**	**17**
FINAL CONSUMPTION	**IPES via Cagliari**	**BOZ via Passeggiata dei Castani (A)**	**BOZ via Passeggiata dei Castani (B)**	**BOZ via Aslago**	**IIG Sebastian Scheel Strasse**	**NHT Fenner-strasse**	**NHT Oswald**	**IIG Angergasse**	**IIG Siegmair-strasse**
Existing	**source: BEST sheet**				**Source: BEST sheets & Energieausweis provided by IIG and NHT**				
SPACE HEATING									
Natural gas		201,71	201,71	228,59	55,23	70,50	71,90	143,92	159,50
District heating	185,66								
Heating oil					154,48				
Electricity					7,18				
DHW									
Natural gas		20,01	20,01	21,27	4,45				
District heating	20,69								
Heating oil					5,09				
Electricity					7,86	12,78	12,70	6,33	6,54
Other uses (ventilation, lighting)									
Electricity	14,43	14,43	14,43	14,43	12,00	16,43	16,33	24,63	24,00
After renovation	**Source: CasaClima**				**Source: Energieausweis provided by IIG and NHT**				
SPACE HEATING & COOLING									
Natural gas					3,43	26,34	26,14	17,81	72,57
District heating	24,31								
Electricity		23,89	23,89		7,17				
Biomass (pellet)				35,11					
DHW									
Natural gas		1,95	1,91		7,11				
District heating	4,41								
Electricity					14,86	12,78	12,77	7,01	6,26
Solar thermal	14,88	19,12	18,08						
Biomass (pellet)				20,34					
Other uses (ventilation, lighting	***Source: BEST sheet***				**Source: Energieausweis provided by IIG and NHT**				
Electricity	17,83	17,83	17,83	17,83	19,34	18,72	19,46	13,96	14,00
PRODUCTION	**Source: CasaClima**				**Source: Energieausweis provided by IIG and NHT**				
PV	2,15	7,27	7,24	4,18	6,23	5,69	6,52	16,25	0,00

2.6.6 INDICATORS FOR THE LIFE CYCLE INVENTORY ANALYSIS

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TABLE 6 USED INDICATORS

Used indicators		
	☑	1. Global warming potential
	☑	2. Acidification Potential
	☐	3. Eutrophication Potential
	☑	4. Photochemical Ozone Creation Potential
	☑	5. Total use of renewable primary energy
	☑	6. Total use of non-renewable primary energy
	☐	7. Use of renewable primary energy excluding renewable primary energy resources used as raw materials
	☐	8. Use of renewable primary energy resources used as raw materials
	☐	9. Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials
	☐	10. Use of non renewable primary energy resources used as raw materials
	☐	11. Depletion potential of the stratospheric ozone layer
	☐	12. Abiotic Resource Depletion Potential for elements
	☐	13. Abiotic Resource Depletion Potential of fossil fuels
	☐	14. Secondary Materials
	☐	15. Secondary fuels - renewable
	☐	16. Secondary fuels – non renewable
	☑	17. Net Fresh Water
	☑	18. Hazardous Waste
	☑	19. Non Hazardous Waste
	☐	20. Radioactive Waste
	☐	21. Components for Re-Use
	☐	22. Materials for Recycling
	☐	23. Materials for Energy Recovery
	☐	24. Exported Energy

Some of the environmental indicators calculated are based on CML. Others, such as Eutrophication and Formation of photochemical ozone are calculated with a similar approach but with different boundaries or characterizations factors. Overall results are presented in Table 22.

TABLE 7 DETAILS OF THE CALCULATED INDICATORS AND RELATIONS WITH CML

	Unit	Method
Total primary energy	MJ	∑ of flows
Renewable energy	MJ	∑ of flows
Non-renewable energy	MJ	∑ of flows
Resource depletion (ADP)	kg Sb-equivalent	**CML (ADP tot.)**
Total water consumption	m^3	∑ of flows
Dangerous waste	kg	∑ of flows
Non dangerous waste	kg	∑ of flows
Inert waste	kg	∑ of flows
Radioactive waste	kg	∑ of flows
Climate change	kg CO2 equ.	**CML (GWP 100)**
Atmospheric acidification	kg SO2 equ.	**CML**
Destruction of the stratospheric ozone layer	kg eq. CFC-11	**CML**
Formation of photochemical ozone	kg ethylene equivalent	**Derived from CML**[‡‡]

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Eutrophication	kg PO4-- equivalent	Derived from CML†
‡ The fictive volume of air or water in m3 by which it would dilute each inventory flow to conform to the threshold of the order, and to the sum of the notional volumes thus calculated on the basis of the order of 2 February 1998. ‡‡ Based on hydrocarbons only † Similar to CML but based only on water compartment.		

2.7 SYNTHESIS OF RESULTS FOR BOLZANO

The diagrams presented in the following section summarise visually the key results of the Life Cycle Assessment. The same diagrams are provided for each building:

- The first one provides an overall comparison of the LCA results for the renovated building versus the non-renovated one. 8 indicators are described:
  - Total use of primary energy
  - Total use of non-renewable primary energy
  - Global warming potential
  - Use of net fresh water
  - Hazardous waste disposed
  - Non-hazardous waste disposed
  - Acidification potential
  - Formation potential of tropospheric ozone

  Relative values are pictured, i.e. the state (i.e. renovated or non-renovated) scoring the highest over its whole life cycle is set at 100%.
- The 4 other diagrams focus on
  - Total use of non-renewable primary energy
  - Global warming potential
  - Hazardous waste disposed
  - Non-hazardous waste disposed

  Absolute values are provided (renovated on the left, non-renovated on the right), and the respective contributions of each contributor (water use / energy use / materials) are detailed. Water and energy use correspond to the use phase, while materials correspond mostly to the production, construction and end-of-life phases.

Please note that the scales vary from one indicator to another, and from one studied building to the other.

Key conclusions are given at the end.

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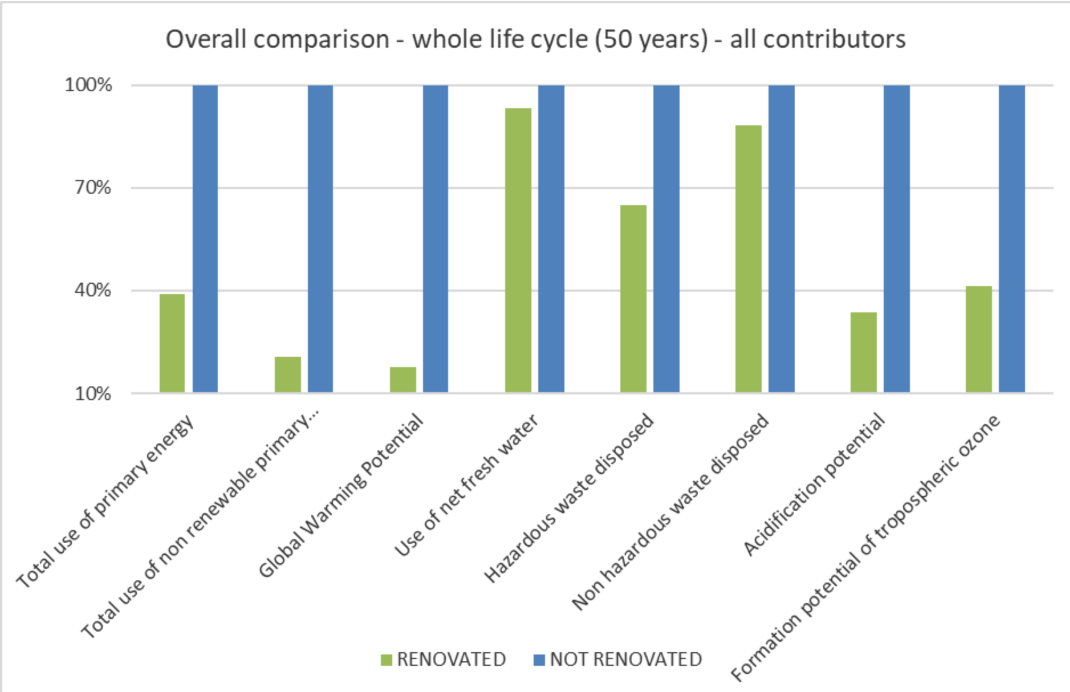
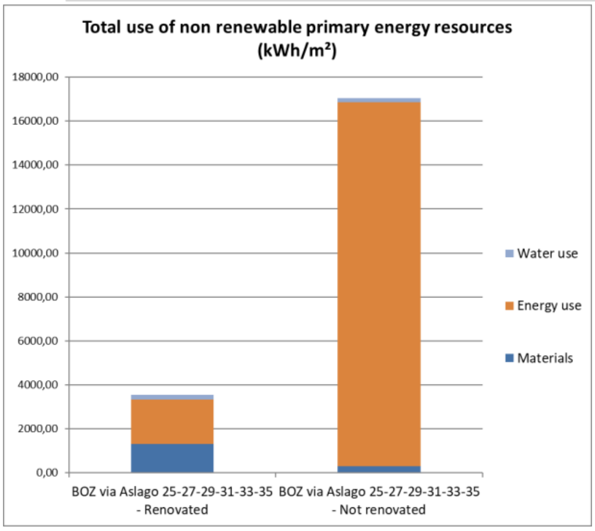
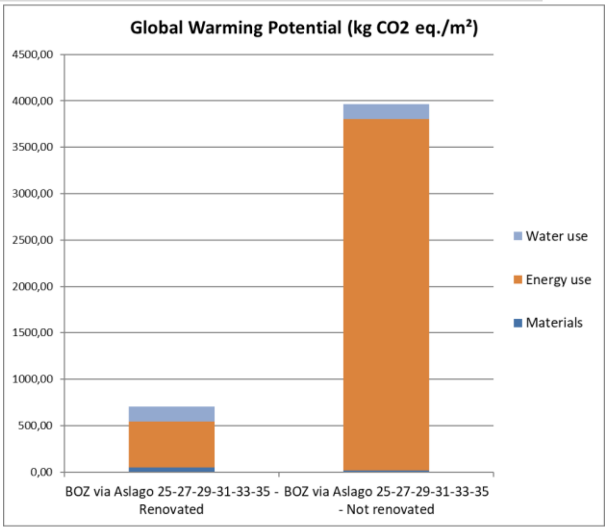
2.7.1 **VIA ASLAGO**







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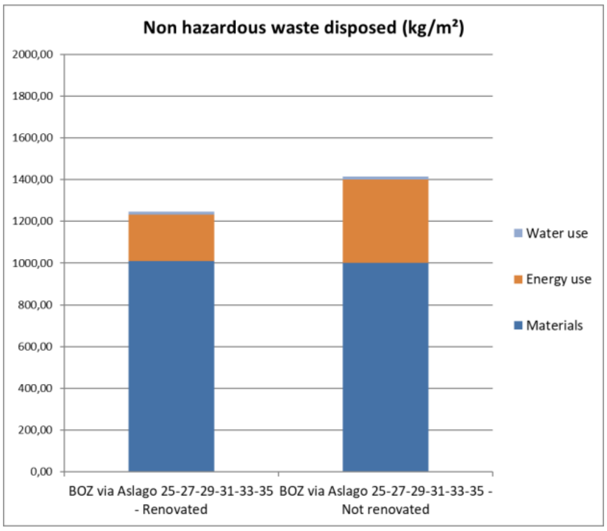
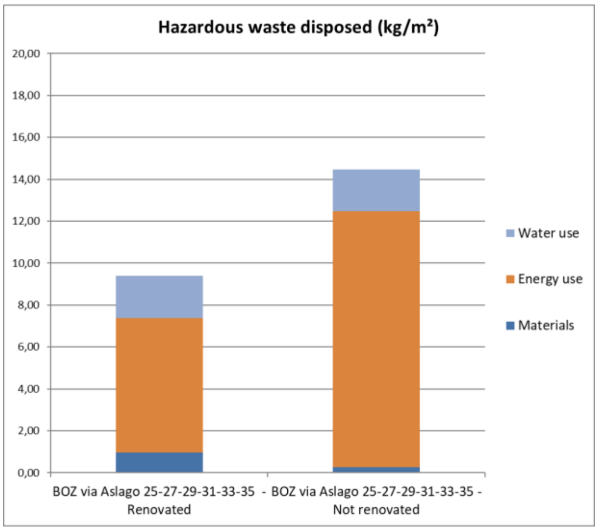
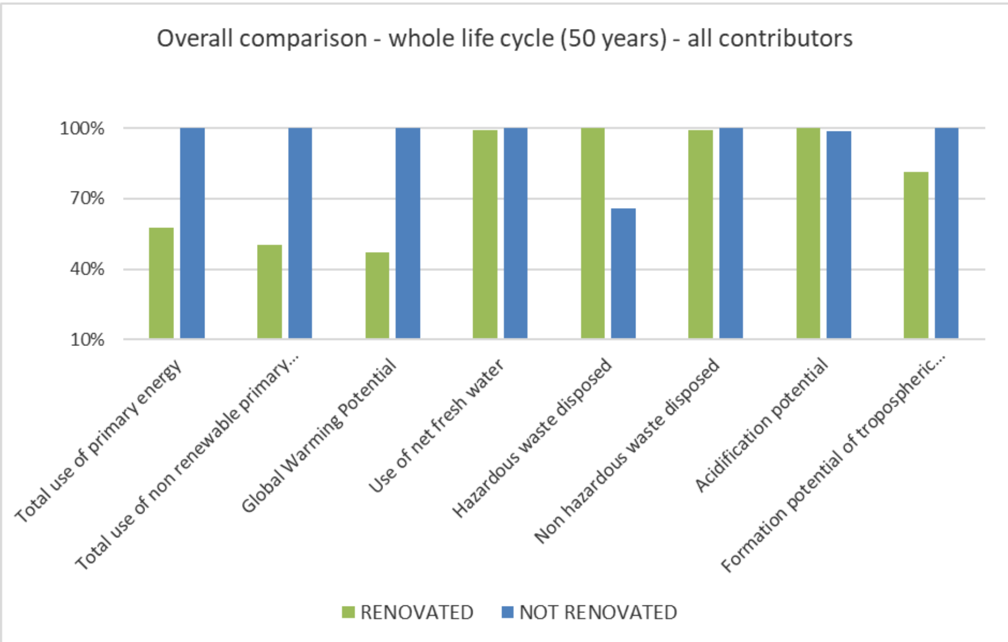




2.7.2 VIA CAGLIARI



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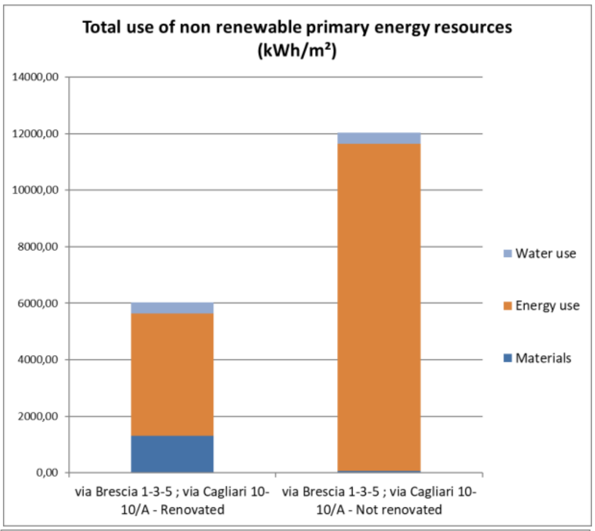

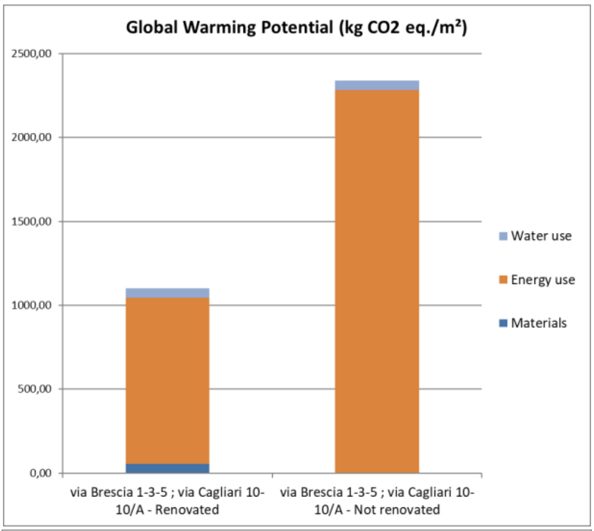

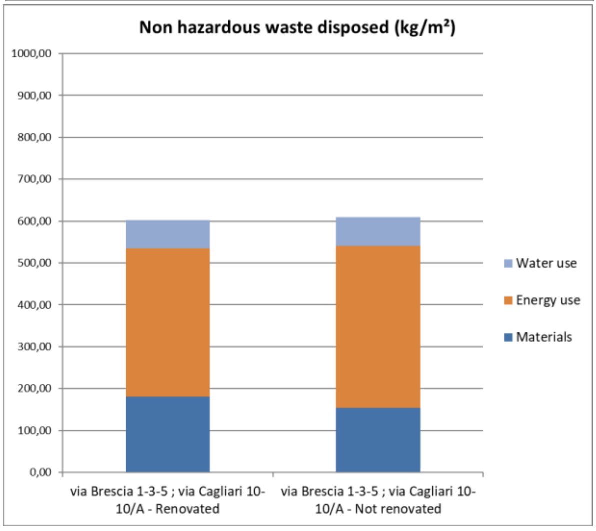

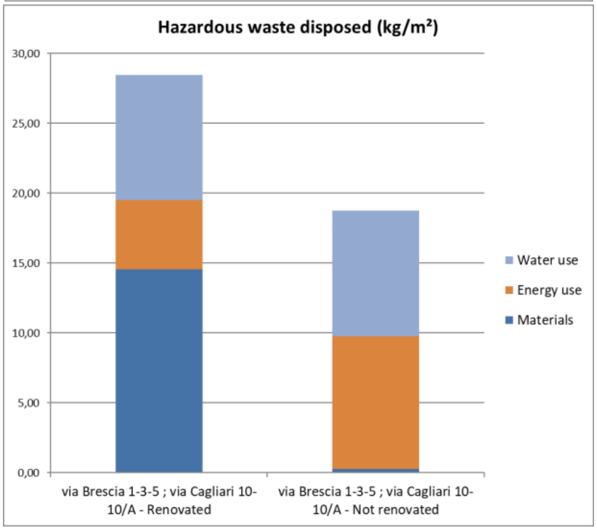

2.7.3 VIA PASSEGGIATA DEI CASTANI (A&B)

In the case of Passeggiata dei Castani, 2 buildings have been analysed. Since the results are very similar (see below the overall comparison – Building A at the top and Building B at the bottom), the detailed diagrams are then provided for building A only.

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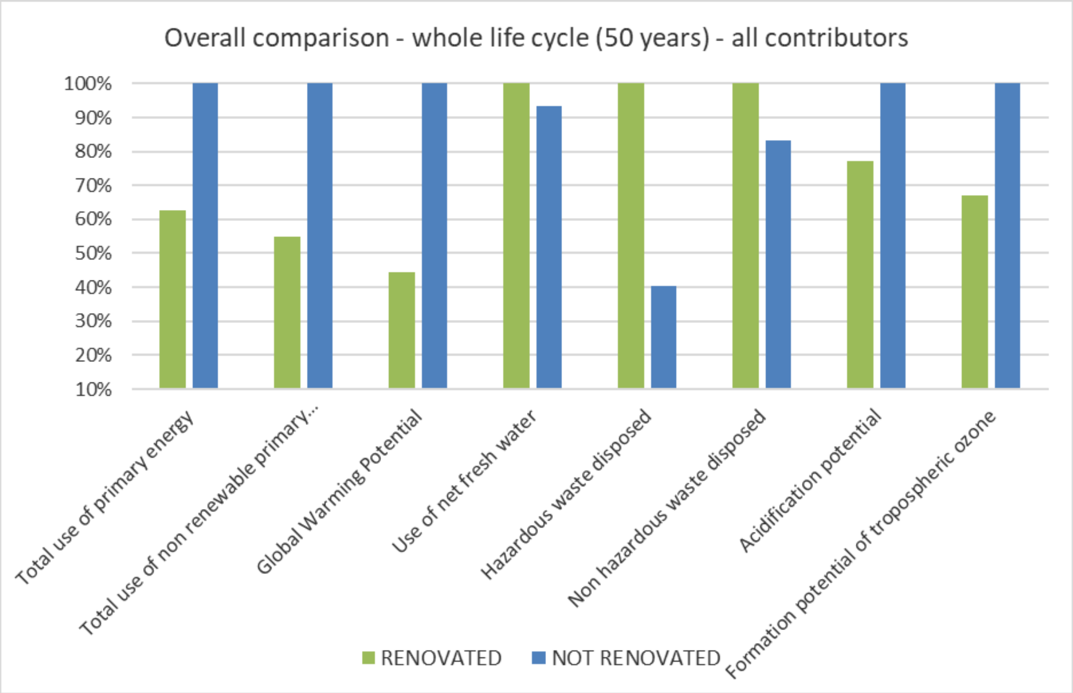

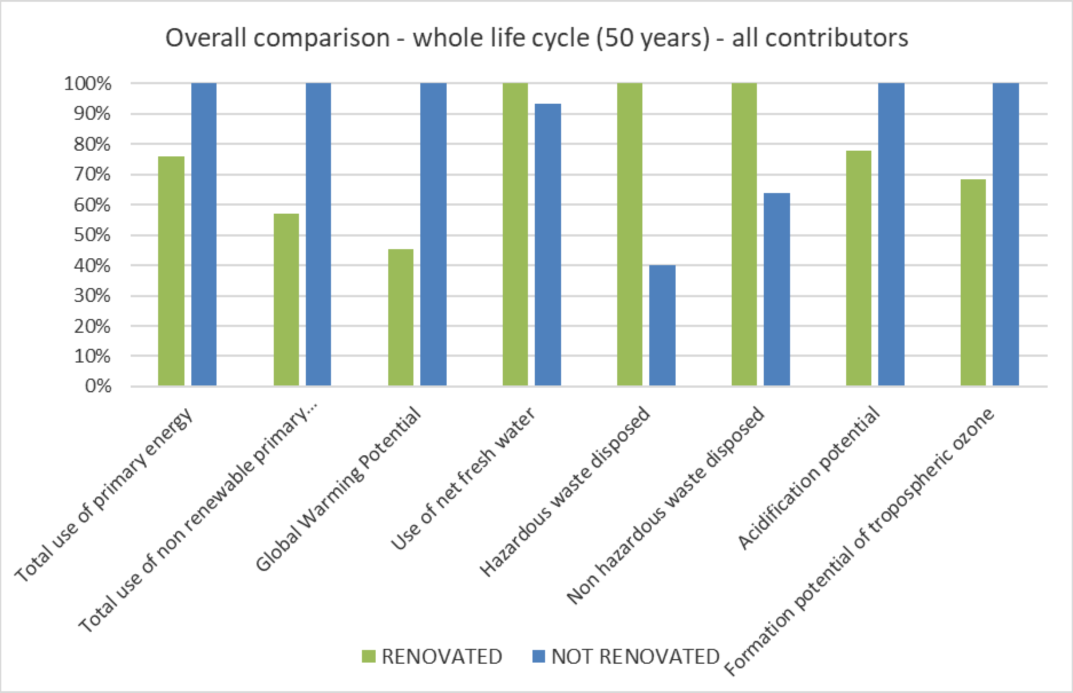

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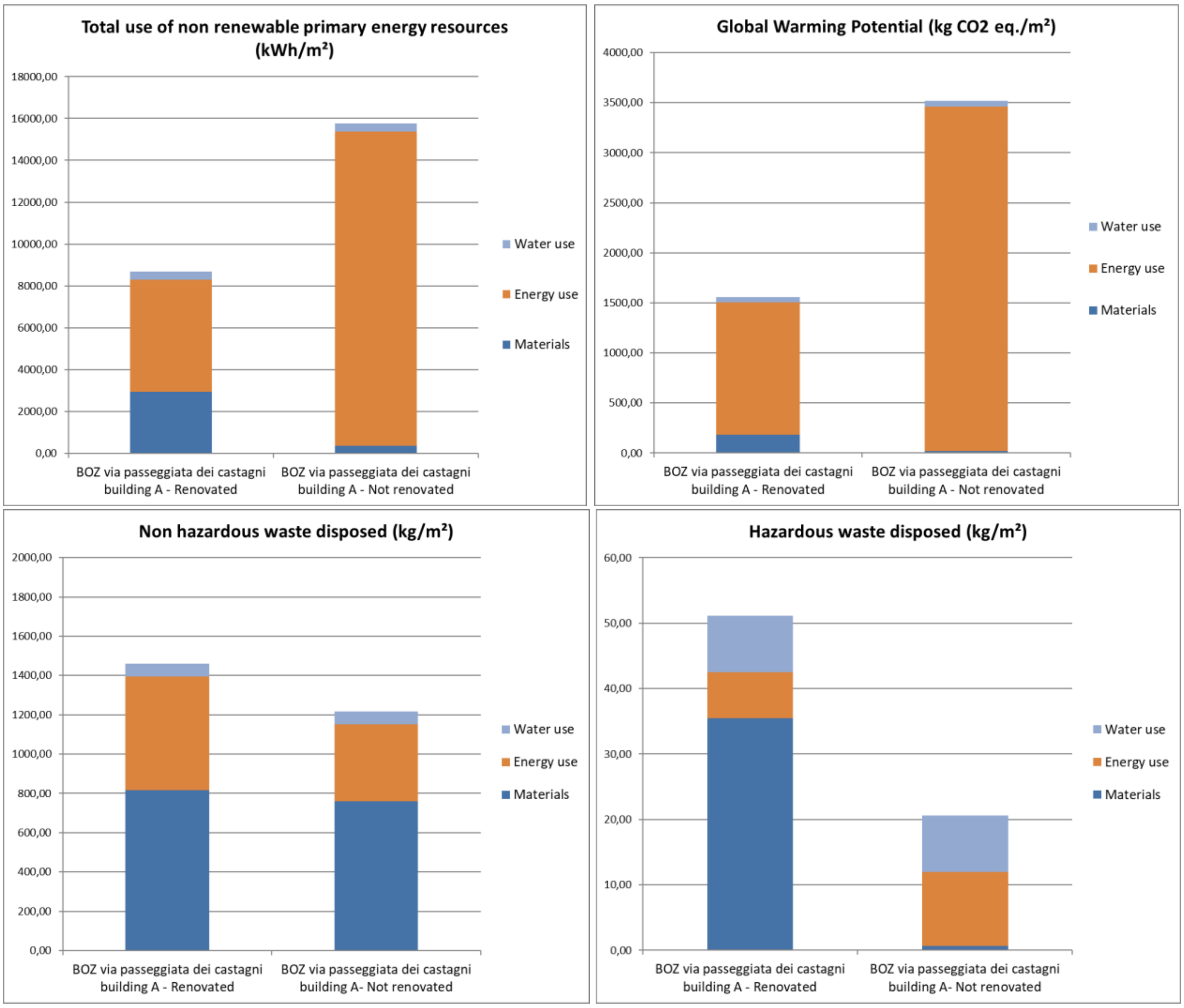

2.8 SYNTHESIS OF RESULTS FOR INNSBRUCK

The approach is the same as the one described for Bolzano.

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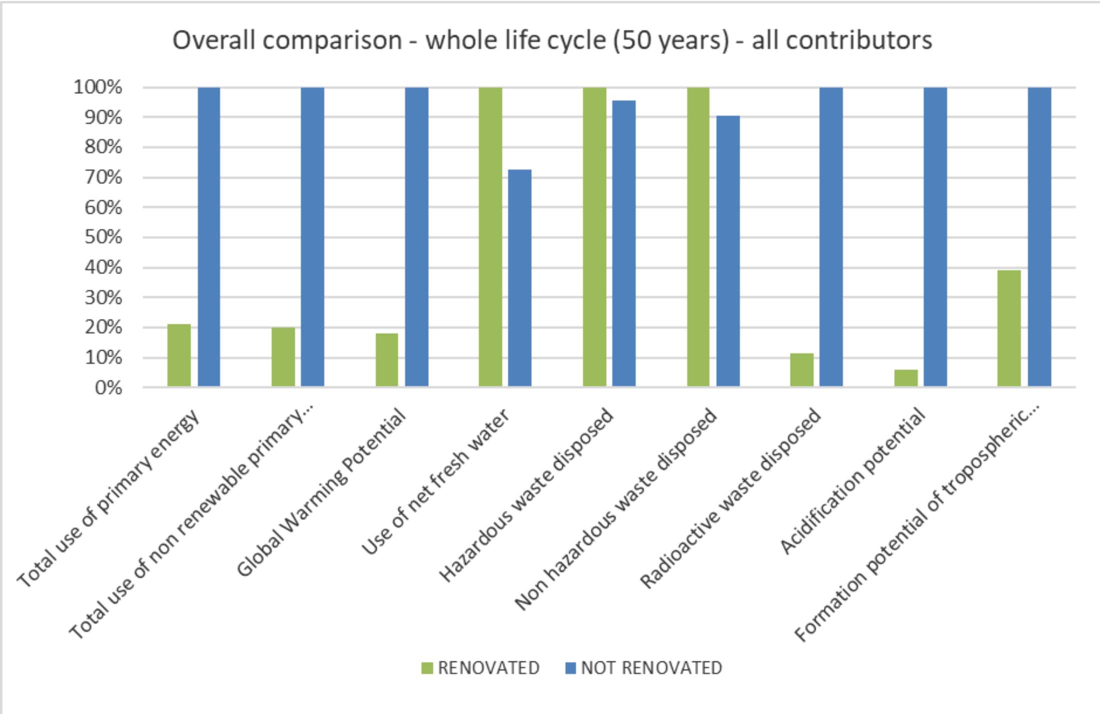
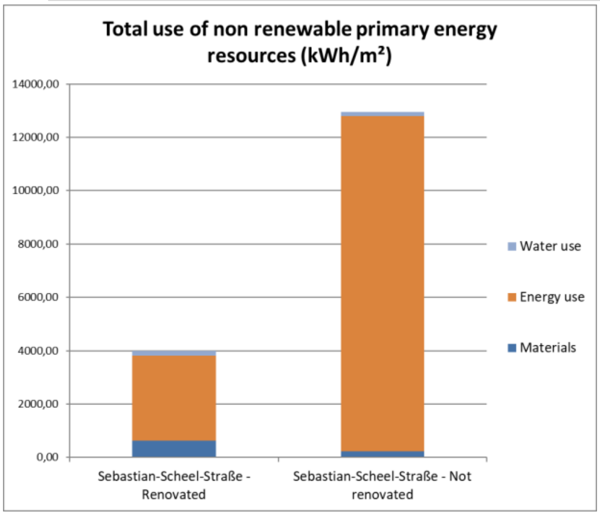
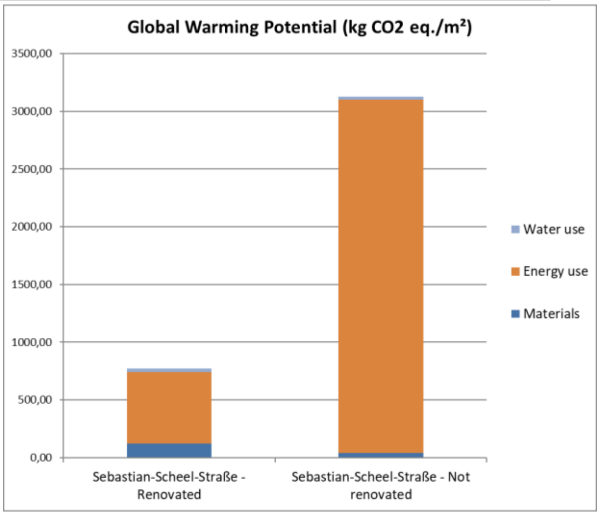
2.8.1 SEBASTIAN SCHEEL STRASSE







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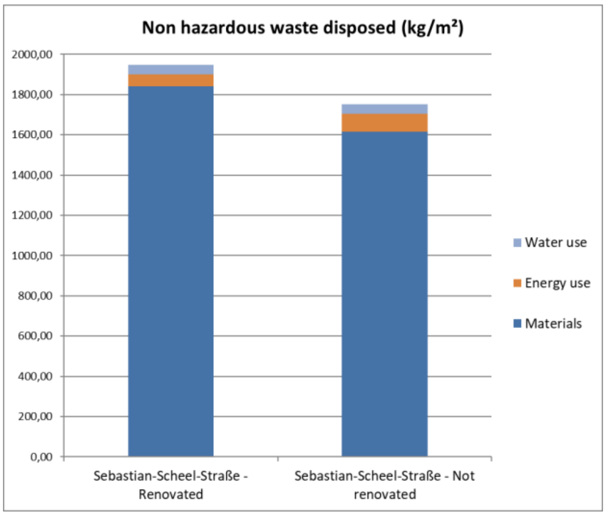
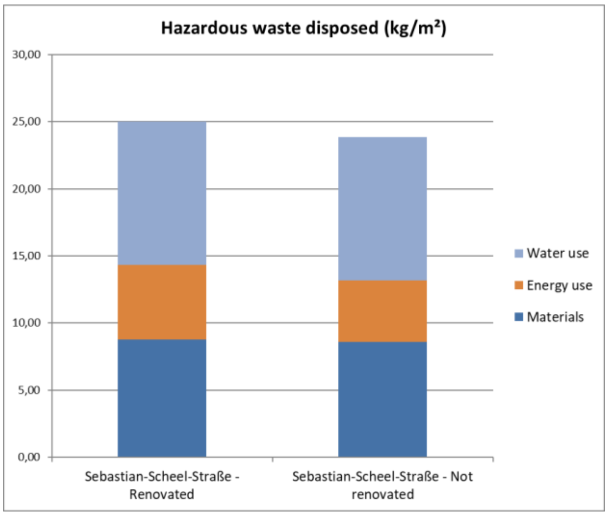
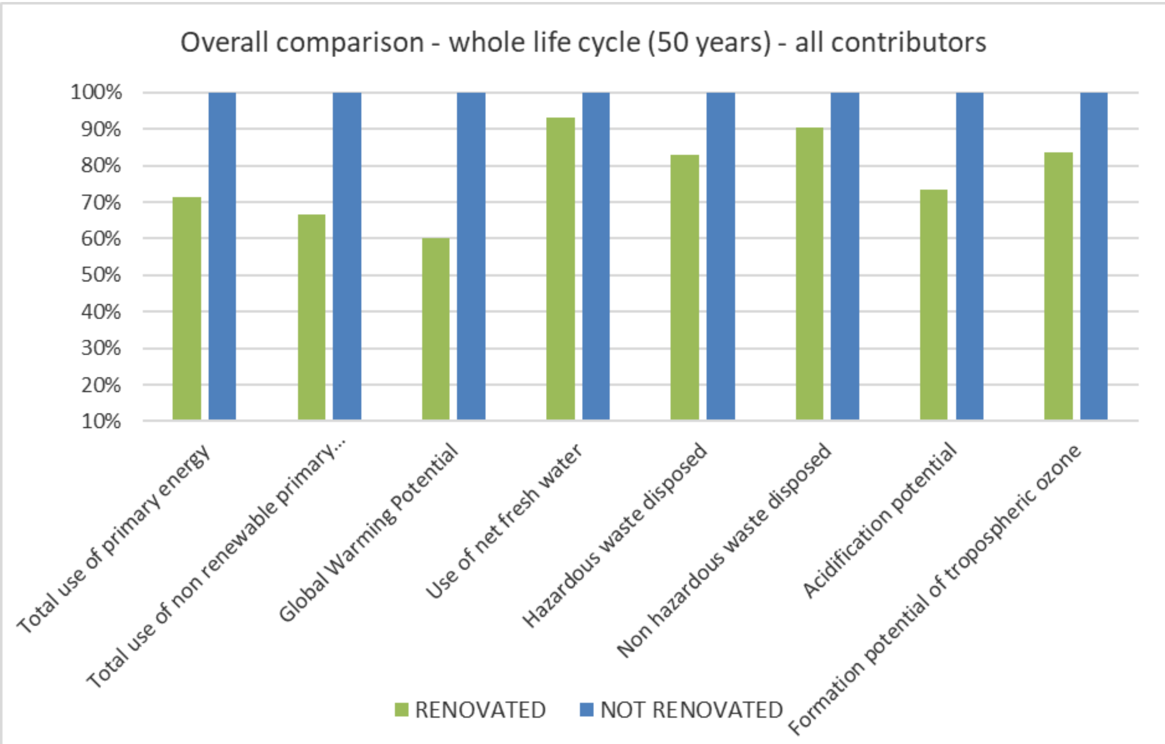




2.8.2 FENNERSTRASSE & OSWALD-REDLICH STRASSE

2 buildings have been analysed: Fennerstrasse and Oswald-Redlich Strasse. Since the results are very similar (see below the overall comparison – Fennerstrasse at the top and Oswald-Redlich Strasse at the bottom), the detailed diagrams are then provided for Fennerstrasse only.



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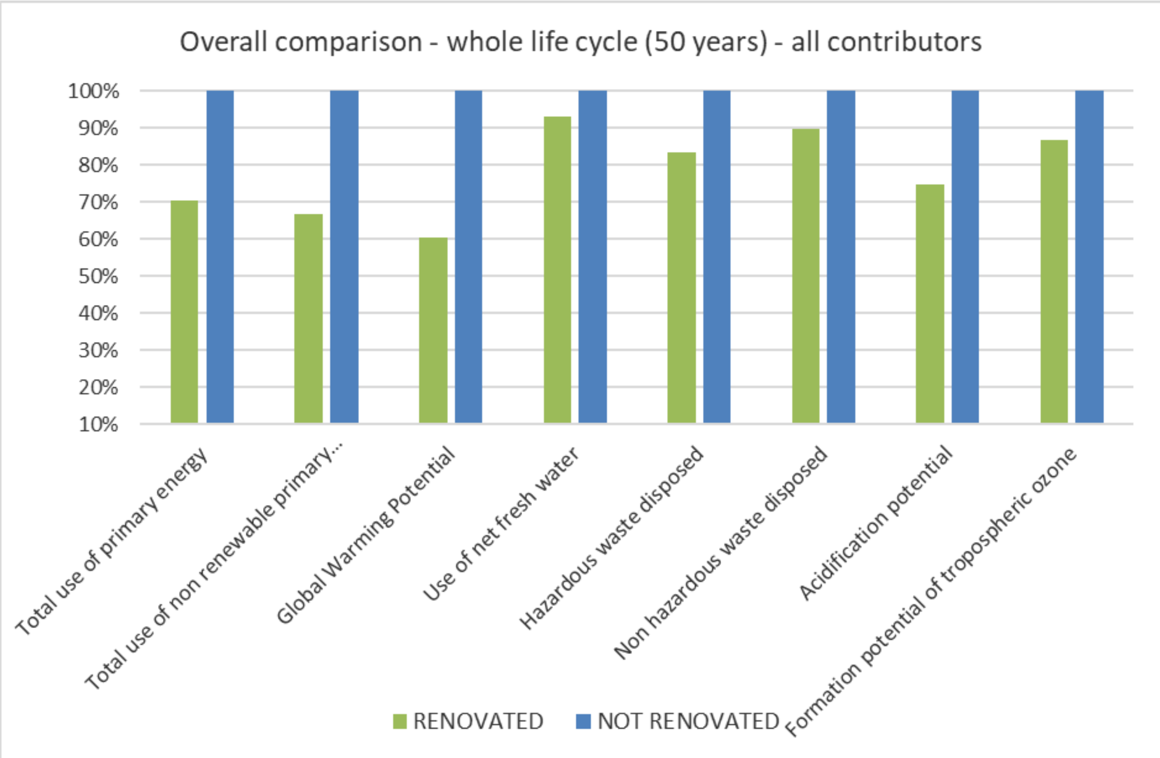

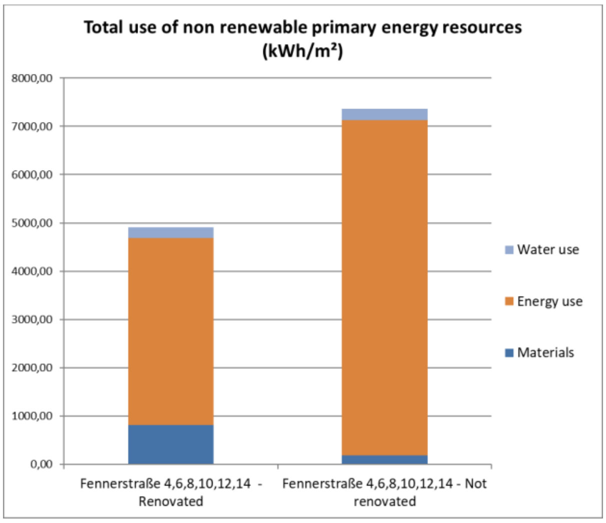

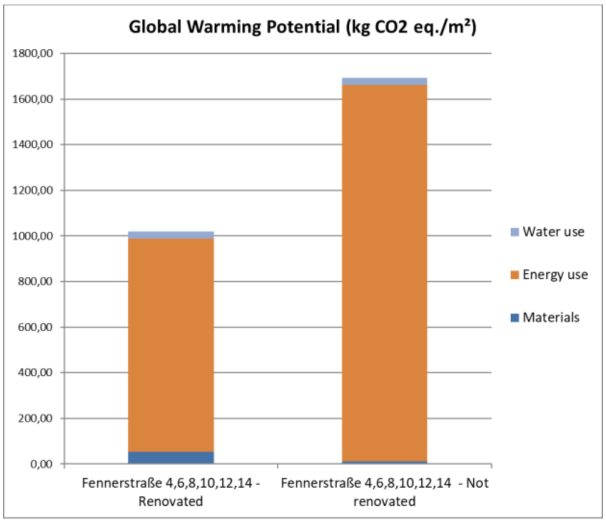

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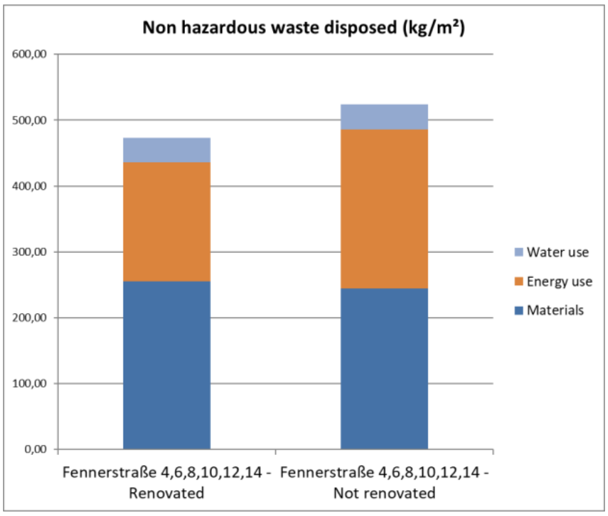

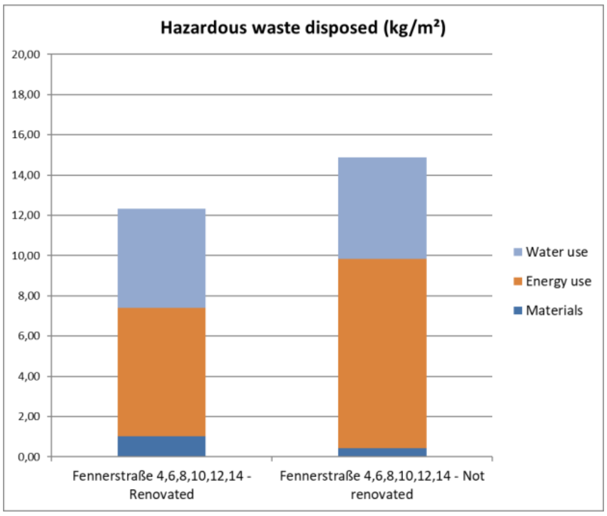

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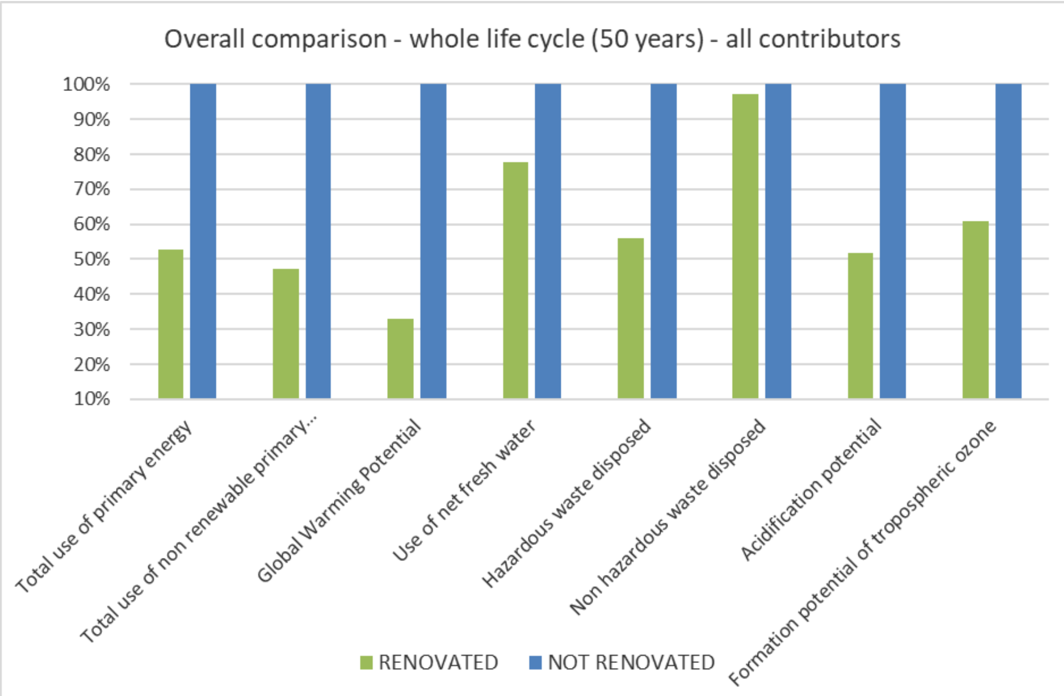
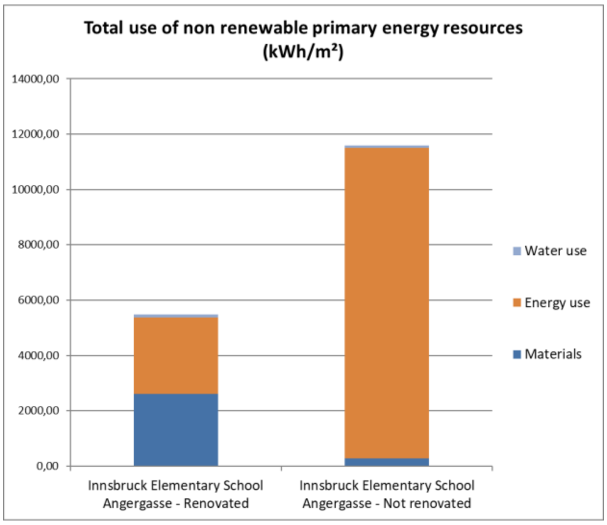
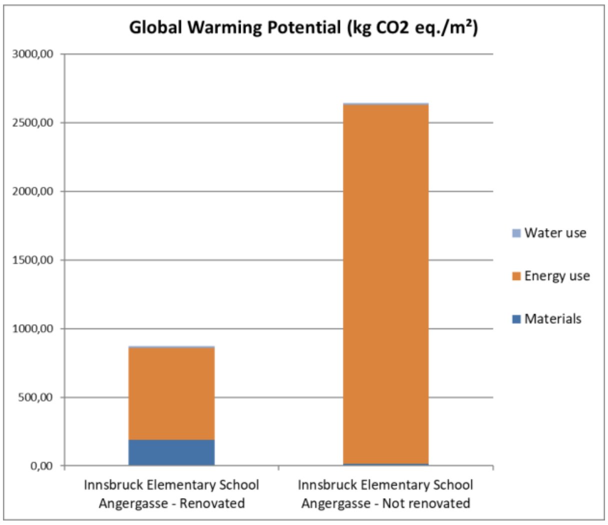
2.8.3 ANGERGASSE SCHOOL







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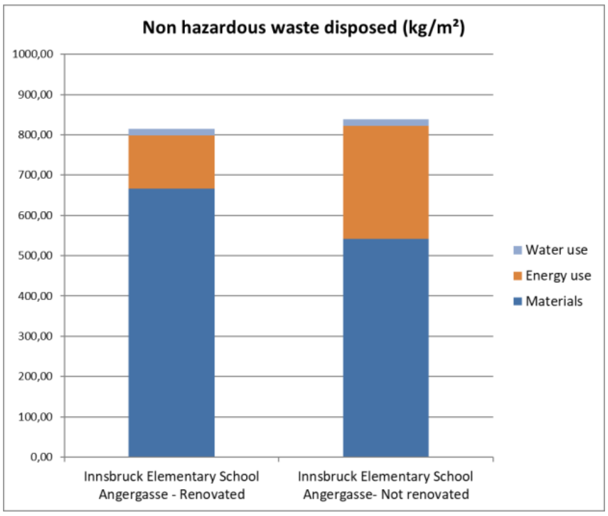

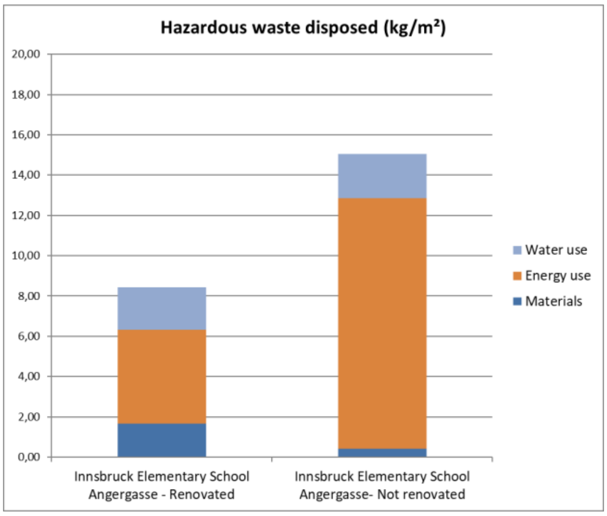

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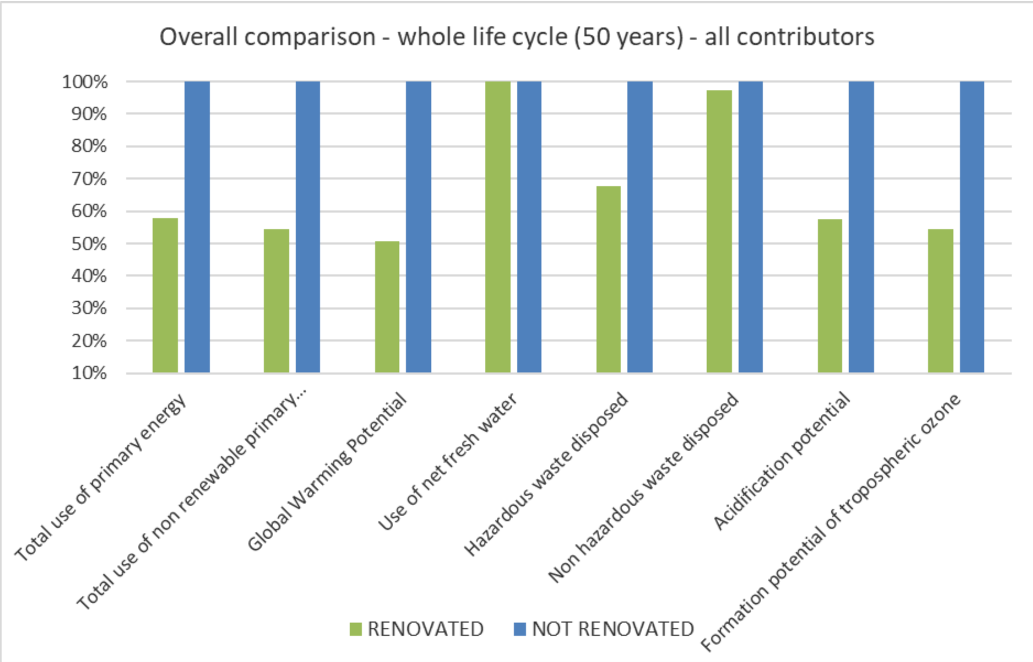
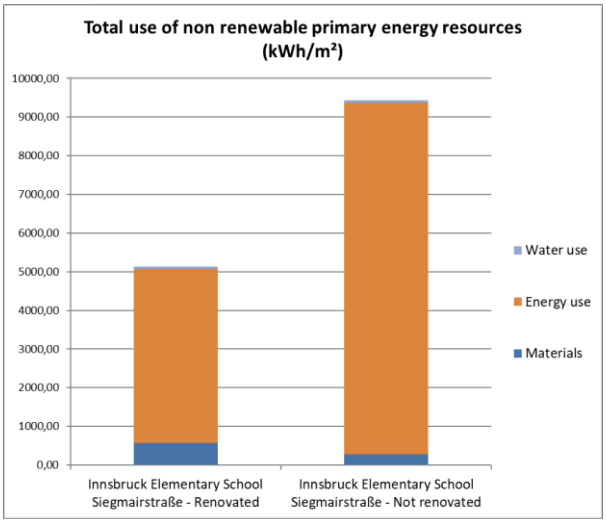
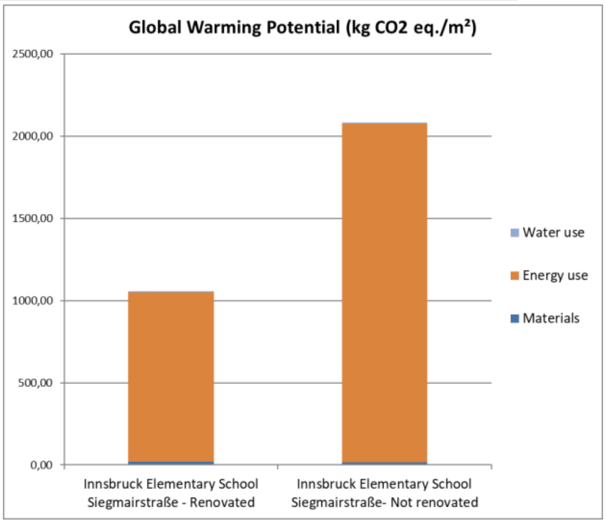
2.8.4 SIEGMAIR SCHOOL







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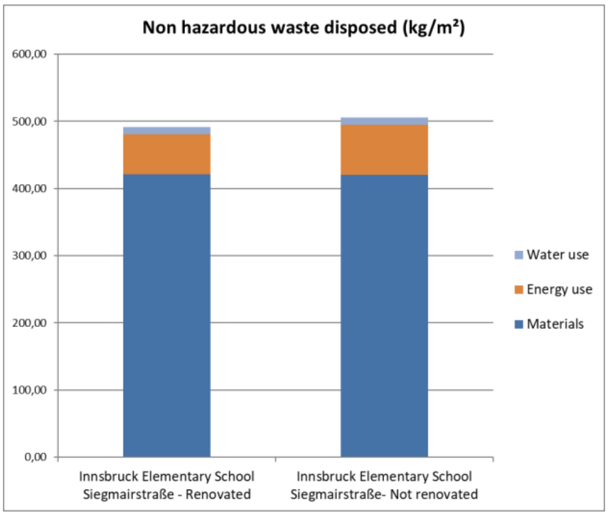

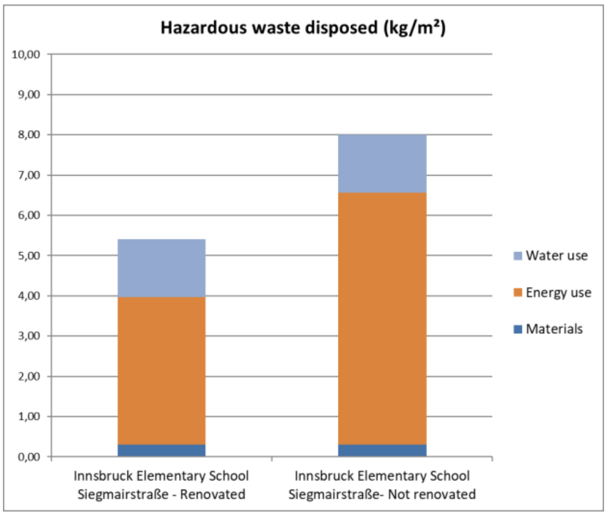

2.9 CONCLUSIONS

The comparison of the environmental impacts of the two scenarios for the whole life cycle and all contributors demonstrates that:

- For 5 of the 8 indicators shown, the environmental profile is substantially improved by the renovation for all buildings: Energy use indicators, Global warming potential (GWP), and acidification potential (AP), Formation potential of tropospheric ozone (POCP) are clearly lower in the case of the renovated building.
- The 3 remaining indicators (Use of net fresh water, Hazardous and Non-Hazardous Waste) show either a relatively similar profile in both scenarios or, for some buildings, are deteriorated by the renovation:
  - For via Cagliari and via Passeggiata dei Castani, the installation of solar thermal collectors and corresponding heating system negatively impacts the indicator “Hazardous waste disposed” (however the impact on the energy use indicators is positive)
  - For Sebastian Scheel Strasse, the need for a new foundation with a gravel layer has an impact on the indicator “Non-hazardous waste disposed”. For the other buildings, the amount of new materials is so small in comparison to the existing ones (structural materials in particular) that their negative impact is largely offset by the avoided non-hazardous waste from the energy use.

In conclusion, the Life Cycle Assessments performed on the studied buildings confirm that **the renovation substantially reduces the environmental impact of a building** and **decreases in particular its Global Warming Potential.** This conclusion is valid both for Innsbruck and Bolzano.

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3. LCA OF DISTRICT HEATING

3.1 APPROACH

The approach of the LCA of district heating differs from the one performed on building level. For the LCA of the district heating solutions, the same methodology is used as the one used for the LCC in T.9.2. The intention with this approach is to focus on the use stage in the lifecycle and make a comparative analysis of the emissions with the demonstrated solutions and the existing system.
The equation used in this analysis is presented as equation 1.

$$\frac{E_{difference}}{functional\ unit} = \sum_{i=1}^{\tau} \frac{E_{before}}{functional\ unit} - \frac{E_{after}}{functional\ unit} \quad \text{(Eq.1)}$$

where

$E_{difference}$ Difference in CO2 emission before and after the investment
E_{before} CO2 emissions before the investments are made
E_{after} CO2 emissions after the investments are made
$functional\ unit$ measure of the function of the studied system, e.g. 1 kWh of heat

3.1.1 ALLOCATION

In some of the demonstration sites, more than one product or energy carrier is generated e.g. both heat and electricity, which makes it necessary to divide the environmental impacts from the demonstration site between the energy carriers. In this analysis the allocation has been done based on size of the energy output. If electricity represents 80% of the output, in terms of energy, heat 20% of the output, 80% of the CO_2 emissions is allocated to the electricity and 20% to the heat.

3.2 RESULTS OF THE ANALYSIS FOR DISTRICT HEATING SOLUTIONS IMPLEMENTED IN BOLZANO

The demonstration projects in Bolzano included in this report are:

- Mix hydrogen with natural gas as fuel in CHP
- Optimisation of district heating network

3.2.1 GENERAL ASSUMPTIONS

The emission factors used in this analysis is based on the life-cycle emission perspective of the fuels and are gathered from GEMIS[7]. The electricity emission factor is the same used in the baseline calculations in T4.4, which is also based on GEMIS numbers. However, there were no emission factor for hydrogen included in GEMIS. Since the hydrogen used for this demonstration within the SINFONIA project is produced through electrolysis based on renewable electricity, it was in discussion with Alperia decided to use the emission factor of 0 for hydrogen.

TABLE 8. CO_2 EMISSION FACTORS USED IN BOLZANO EVALUATION.

	Hydrogen	Natural gas	Waste	Electricity	Diesel
g CO_2/kWh_{fuel}	0	198.5	359.7	452.4	267.9

[7] IINAS. *GEMIS - Global Emissions Model for integrated Systems*. 2014; Available from: http://iinas.org/gemis.html.

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The functional unit used in the analysis of the demonstration projects in Bolzano is 1 kWh_{heat}.

3.2.2 MIX HYDROGEN WITH NATURAL GAS AS FUEL IN CHP

As part of the SINFONIA project, one of the two gas fired combined heat and power engines in Bolzano has been retrofitted to be able to use hydrogen and natural gas mix as fuel. Different blends of natural gas and hydrogen have been evaluated and tested in the power plant for short time periods, by volume between 5 and 30% of hydrogen. In the present life cycle analysis, one of these blends is evaluated, 30% hydrogen and 70% of natural gas. The hydrogen has lower energy content per Nm^3 which implies that the fuel consumption in volume will be greater after the retrofit.
The CO_2 emissions is allocated between the electricity and heat generated according to the method described in section 3.1.1. The numbers used for the calculations can be seen in table.

TABLE 9. REPRESENTATION OF THE CONSUMPTION AND ENERGY GENERATION BEFORE AND AFTER IMPLEMENTATION OF HYDROGEN IN THE CHP.

	After implementation	Before implementation
Natural gas consumption [Nm^3/year]	1 659 931	1 885 800
Hydrogen consumption [Nm^3/year]	711 399	0
Generated heat [MWh/year]	7 047	7 047
Generated electricity [MWh/year]	6 906	6 906
Diesel consumption due to hydrogen transportation [l/year]	283.5	0
Emissions/Heat delivered [g/kWh_{heat}]	323	284

$$E_{difference} = 284 - 323 = -38.6$$

By blending 30% of hydrogen to the natural gas lower the emissions with 38.6 g/kWh_{heat}. This is calculated with a hydrogen emission factor of zero, which reflects “green hydrogen” that is produced by electrolysis powered by renewable energy sources. As discussed in the SWOT analysis made by (Laffont, o.a., 2014), this is one of the strengths as well as threats with this solution, the possibility to reduce CO_2 emissions if green hydrogen is used while at the same time the availability of green hydrogen is uncertain. If hydrogen produced from other sources is used instead, the emission reduction with this solution will be smaller. It can be seen in figure Figure 4 that mixing of hydrogen with natural gas at a rate of 30% will reduce the CO_2 emissions of the district heating system as long as the production of the hydrogen keeps the CO_2 emission factor for hydrogen below 215 kg CO_2/kWh_{H2}.

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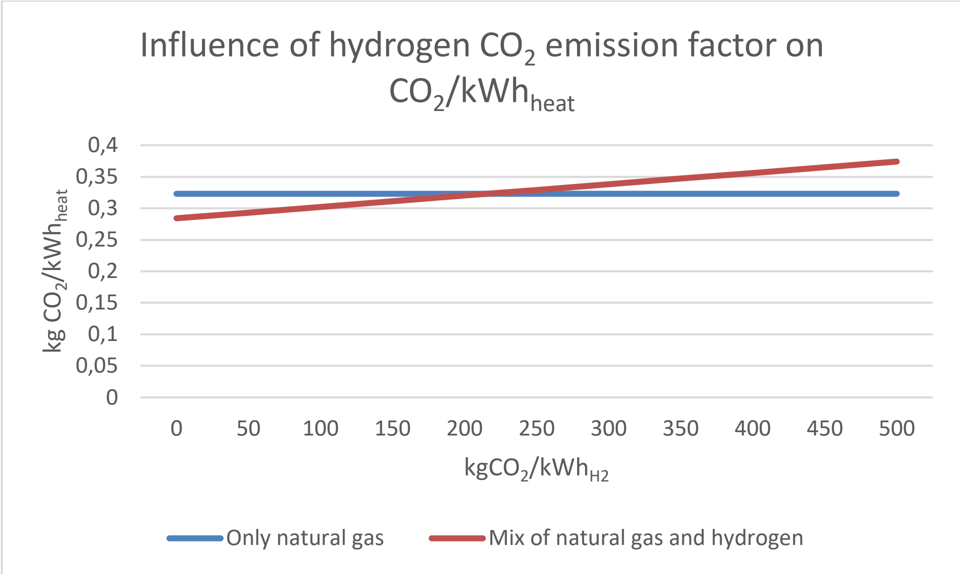

FIGURE 4. COMPARISON OF DIFFERENT CO_2 EMISSION FACTORS FOR HYDROGEN AND THE EFFECT ON THE CO2 CONTENT OF HEAT

3.2.3 OPTIMISATION DISTRICT HEATING NETWORK

The district heating optimization solution in Bolzano includes the creation of a new Termis model, its deployment and the creation of new routines for its usage at Alperia. The optimization is made at the distributional level where the temperature is optimized, which reduces heat losses in the district heating network that consequently reduces the required heat generation. The main difference with or without the optimization implemented is the usage, full load hours, of the various units included in the district heating system, which is reflected in the energy use.

This solution is evaluated with two different scenarios in line with the work provided in WP4, one with the district heating system expansion of 2018 and one with the district heating system expansion of 2024.

3.2.3.1 DISTRICT HEATING NETWORK 2018

With the district heating system in line with 2018 scenario, it is possible to provide all the heat through the waste incinerator connected to the district heating system. Therefore, there are no natural gas consumption within this scenario. The implementation of the optimization model makes it possible to reduce the waste consumption and keeping the heat delivered to customers at the same level.

TABLE 10. REPRESENTATION OF THE CONSUMPTION AND HEAT GENERATION BEFORE AND AFTER THE OPTIMISATION OF THE DISTRICT HEATING NETWORK AS OF THE 2018 SCENARIO.

	After implementation	Before implementation
Heat generation [MWh]	99 400	103 154
Heat delivered to customers [MWh]	91 266	91 266
Natural gas consumption [Nm^3/year]	0	0
Waste consumption [MWh/year]	122 716	127 350
Emissions/Heat delivered [g/kWh_{heat}]	483.7	501.9

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$$E_{difference} = 483.7 - 501.9 = -18.2$$

By optimising the district heating network with a system design of 2018, the emission intensity decreases with 18.2 g/kWh$_{heat}$.

3.2.3.2 DISTRICT HEATING NETWORK 2024

With the district heating system in line with 2024 scenario, more production units need to be used to supply the heat to the district heating network, since it is expanded. The waste incinerator is no longer enough, and CHPs and natural gas boilers also must be used. The CHP units generate both electricity and heat and the allocation method used is described in section 3.1.1.

TABLE 11. REPRESENTATION OF THE CONSUMPTION AND HEAT GENERATION BEFORE AND AFTER THE OPTIMISATION OF THE DISTRICT HEATING NETWORK AS OF THE 2024 SCENARIO.

	After implementation	Before implementation
Heat generation [MWh]	167 218	170 850
Electricity generation [MWh]	11 918	11 918
Natural gas consumption [Nm^3/year]	1 499 516	1 779 695
Waste consumption [MWh/year]	141 425	144 534
Emissions/Heat delivered [g/kWh$_{heat}$]	350.347	350.296

$$E_{difference} = 350.296 - 350.347 = 0.051$$

By optimising the district heating network with a system design of 2024, the emission intensity increases with 0.051 g/kWh$_{heat,}$ which is a very small increase in emission intensity for heat generation. The total emission of both the electricity and heat generation decreases when the demonstrated solution is implemented, but the emission per heat delivered has a slight increase. This depends on how the production units are operated. The share of the CHPs is according to the estimations by Alperia, increasing after 2024 since the absolute generation is kept constant for the CHPs while both the boilers and waste incinerator decrease their generation. With the higher emission intensity of the CHPs this makes the emission intensity per heat produced also increasing.

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3.3 RESULTS OF THE ANALYSIS FOR DISTRICT HEATING SOLUTIONS IMPLEMENTED IN INNSBRUCK

There are several demonstrations included in Innsbruck, with different connections to the energy system in the city, both to the electricity, space heating and district heating system. Not all demonstrated solutions that are generating heat is connected to the district heating network. For Innsbruck it is only the Powerhouse Rossau that is connected to the district heating network in Innsbruck. The demonstration projects in Innsbruck included in this report are:

- Heat recovery transformer station UW Mitte
- Power-to-heat Amras
- Powerhouse Rossau

3.3.1 GENERAL ASSUMPTIONS

The emission factors used in this analysis is based on the life-cycle emission perspective of energy generation and includes both the different fuels and generation technology and are gathered from GEMIS[8]. The electricity emission factor is the same used in the baseline calculations in T4.4, which is also based on GEMIS numbers. In the district heating network in Innsbruck there are waste heat from different sites. The emission for this heat is allocated to the production of the product and the emission factor is therefore assumed to be 0 for the waste heat. Some of the waste heat is made use of through absorption heat pumps at the industrial sites which also has a very low electricity demand, only electricity for pumps which could be neglected. In the different power plants, in e.g. the district heating network the allocation method used for the different fuels and production sites depends on the energy equivalents of the output, e.g. heat and electricity. In cases when there is a lack of data, relevant assumptions have been made to be able to make a comparison of the emission intensity of heat production before and after implementation of the different solutions.

TABLE 12. CO_2 EMISSION FACTORS FOR DIFFERENT FUELS, INCLUDING THE PROCESS OF ENERGY GENERATION (IINAS, 2014).

	Waste heat	Biomass, wood chips (ORC cogen)	Biogas, biowaste (cogen)	Biogas, sewage gas (cogen)	Natural gas (boiler)	Electricity Austria
g CO_2/kWh_{heat}	0	0.913	2.711	1.209	238.081	181.121

The functional unit used for the solutions in Innsbruck is 1 kWh_{heat}.

3.3.2 HEAT RECOVERY TRANSFORMER STATION UW MITTE

This project changes energy supply of the administrative building of IKB to heat pumps which uses waste heat from a transformer of the substation UW Mitte. Two natural gas boilers are also installed to cover peak load. Two heat storage tanks with 4000 litres are installed to be able to compensate for irregular operation of the transformer substation. The difference of the two systems, before and after the implementation is shown in Table 13. The emission factors used in this calculation are the ones for natural gas and electricity presented in Table 12.

[8] IINAS. *GEMIS - Global Emissions Model for integrated Systems*. 2014; Available from: http://iinas.org/gemis.html.

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TABLE 13. SUMMARY OF SITUATION BEFORE AND AFTER IMPLEMENTATION OF HEAT RECOVERY TRANSFORMER STATION UW MITTE.

	After implementation of heat recovery transformer station	Before implementation
Heat generation [MWh]	500	500
Natural gas consumption [MWh/year]	235	588
Electricity consumption [MWh/year]	100	0
Emissions/Heat output [g CO_2/kWh_{heat}]	131.5	238.1

$$E_{difference} = 131.5 - 238.1 = -106.6$$

The emission intensity decreases with 107 g CO_2/kWh_{heat} by changing the energy supply of the administrative building of IKB to heat pumps. This is because of the lower emission intensity of the electricity that is used after the implementation compared to the natural gas that is used before.

3.3.3 POWER TO HEAT AMRAS

THE POWER TO HEAT IN AMRAS IS IMPLEMENTED TO INCREASE THE FLEXIBILITY IN THE ELECTRICITY GRID BY GENERATING HEAT THROUGH ELECTRIC HEATING ELEMENT AND STORE IT IN THE 80 M^3 LARGE STORAGE TANK, WHEN THE ELECTRICITY PRICES IS LOW. IT IS ASSUMED THAT THE CONVERSION FROM ELECTRICITY TO HEAT IS ALMOST LOSSLESS WHICH MAKES THE THERMAL CAPACITY AS LARGE AS THE ELECTRICAL CAPACITY. THE HEAT GENERATED IN THE POWER TO HEAT SYSTEM REDUCE THE USE OF NATURAL GAS IN THE EXISTING HEATING SYSTEM. THE DIFFERENCE OF THE TWO SYSTEMS, BEFORE AND AFTER THE IMPLEMENTATION IS SHOWN IN

Table 14. The emission factors used in this calculation are the ones for natural gas and electricity presented in Table 12.

TABLE 14. SUMMARY OF SITUATION BEFORE AND AFTER IMPLEMENTATION OF HEAT RECOVERY TRANSFORMER STATION UW MITTE.

	After implementation of electrical heating element	Before implementation
Heat generation [MWh]	1 500	1 500
Natural gas consumption [MWh/year]	0	1 765
Electricity consumption [MWh/year]	1 500	0
Emissions/Heat output [g CO_2/kWh_{heat}]	181.1	238.1

$$E_{difference} = 181.1 - 238.1 = -57$$

The emission intensity decreases with 57 g CO_2/kWh_{heat} by implementing power to heat Amras. This might be a conservative number since it is calculated with the average emission factor for the

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electricity system of around 181 g CO_2/kWh_{heat}, while the aim of this solution is to use the electric heating elements when the electricity price is low. The electricity price tends to be low when the wind and solar PV's are producing, which also means that the CO_2 emissions at that time are lower than the average value.

3.3.4 POWERHOUSE ROSSAU

Powerhouse Rossau is the wastewater treatment plant in Innsbruck where several production units have been built and transformed it from an energy consumer to an energy supplier. The demonstration plant generate heat, electricity, activated carbon and dried sewage sludge.
This analysis of Powerhouse Rossau focus on the effects that the connection of Powerhouse Rossau has on the emissions related to the district heating production. It compares the emissions per produced kWh of district heat before Powerhouse Rossau was connected to the network, with the emissions per produced kWh of district heat after the implementation. The data available before the implementation is from 2016 and data after the implementation is from 2019. During that time also other changes have been made in the district heating system and it is therefore difficult to capture what effects that could be derived to the introduction of Powerhouse Rossau in the system. The difference of the two systems, before and after the implementation is shown in Table 15. The emission factors used in this calculation are the ones waste heat, natural gas, biogas (biowaste), biomass and biogas (sewage) presented in Table 12.

TABLE 15. SUMMARY OF SITUATION BEFORE AND AFTER IMPLEMENTATION OF POWERHOUSE ROSSAU, INCLUDING OTHER CHANGES IN THE DISTRICT HEATING NETWORK.

	District heating system after Powerhouse Rossau (2019)	District heating system before Powerhouse Rossau (2016)
Heat from waste heat [MWh/year]	45 800	37 104
Heat generated from natural gas [MWh/year]	0	12 106
Heat generated from biogas (biowaste) [MWh/year]	2 158	1 428
Heat generated from biomass (wood chips) [MWh/year]	25 041	9 070
Heat generated from biogas (sewage) [MWh/year]	4 264	0
Emissions/Heat output [g CO_2/kWh_{heat}]	0.44	48.18

$$E_{difference} = 0.44 - 48.18 = -47.74$$

The emission intensity decreases with 47.74 g CO_2/kWh_{heat} when powerhouse Rossau is connected to the district heating network. However, there are some larger changes as well, since there is no district heating generated through natural gas in 2019 compared to in 2016. To be able to evaluate the effects of connecting powerhouse Rossau to the district heating system, another comparison is made, where

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the district heating system is assumed to be constant except the implementation of powerhouse Rossau. This is presented in Table 16 and the same emission factors are used as in the previous calculation.

TABLE 16. SUMMARY OF SITUATION BEFORE AND AFTER IMPLEMENTATION OF POWERHOUSE ROSSAU, EXCLUDING OTHER CHANGES IN THE DISTRICT HEATING NETWORK.

	District heating system after Powerhouse Rossau	District heating system before Powerhouse Rossau (2016)
Heat from waste heat [MWh/year]	37 104	37 104
Heat generated from natural gas [MWh/year]	12 106	12 106
Heat generated from biogas (biowaste) [MWh/year]	1 428	1 428
Heat generated from biomass (wood chips) [MWh/year]	9 070	9 070
Heat generated from biogas (sewage) [MWh/year]	4 264	0
Emissions/Heat output [g CO_2/kWh_{heat}]	45.33	48.18

$$E_{difference} = 45.33 - 48.18 = -2.86$$

The emission intensity decreases with 2.86 g CO_2/kWh_{heat} when powerhouse Rossau is connected to the district heating network, as it was operated in 2016. With a comparison to the previous calculation it is then clear that some of the reduction in emission intensity of the district heating network in 2019 could be derived from powerhouse Rossau, while most of the reduction is related to the reduction in use of natural gas and increase in waste heat and biomass.

3.4 CONCLUSIONS

With the system boundaries and assumptions made for the analysis of the district heating system in Bolzano, it can be seen that the mixing of hydrogen into the CHP reduces the CO_2 emissions with 38.6 g CO_2/kWh_{heat}. The carbon intensity of the district heating system will be reduced with this solution as long as the production of hydrogen keep the emission factor below 215 g CO_2/kWh_{H2}.

The optimisation of the district heating network reduces the carbon intensity with 9 g CO_2/kWh_{heat} with the system of 2018. There is a small increase in carbon intensity with 0.1 g CO_2/kWh_{heat} with the district heating expansion in 2024 and the assumed operation of the different plants.

All three demonstrations in Innsbruck evaluated in this analysis reduces the carbon intensity of heat generation, although it is only powerhouse Rossau that is connected to the district heating network. Both the demonstration at UW Mitte and power to heat Amras does only affect the heat generated at those sites.

The carbon intensity decreases with 107 g CO_2/kWh_{heat} by implementing heat pumps at the transformer station of UW Mitte.

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The carbon intensity decreases with 57 g CO_2/kWh_{heat} by implementing power to heat Amras. This might be a conservative number since it is calculated with average emission factor of electricity generation, while the aim is to operate the electric heating element while the electricity prices are low, which indicate that the emission level is lower as well.
Powerhouse Rossau is the only measure out of the three studied in Innsbruck with affects the emission intensity of the district heating system. Between 2016 and 2019, the carbon intensity of the district heat decreased by 47.74 g $CO_2/kWh_{heat.}$ However, this reduction is not due to the implementation of powerhouse Rossau only and the comparison when the district heating system is kept constant except from the implementation of powerhouse Rossau shows a reduction of carbon intensity of the district heat with 2.86 g CO_2/kWh_{heat}.

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4. LCA AT DISTRICT SCALE: EXPLORATORY NOTE

4.1 INTRODUCTION

Could LCA type approaches support the decision making on planning issues towards sustainable cities?

Studies of environmental impacts at the level of a district or a city by urban planners could be carried out to identify impacts of options such as building types, urban density, morphology of urban fabrics, retrofit or new constructions. Such use remains limited for the time being (see Annex 2) but it could play a role of target setting, monitoring and assessing sustainable urban environment programs in the general context of the integration of climate strategies. Analytical tools over the whole life cycle may support such decisions.

While literature on LCA at the building level is very rich (review on tools, approaches, case studies), at the district level publications are not plethoric. An LCA case study at the district scale based on the use of Equer and other related modules was developed[9] for a district in Paris in 2011. Decision making ability of such tools was tested and validated. The application showed however the criticality of the phase related to the interpretation of results. The authors also recommend further exchange between different applications of LCA at the district scale through for instance a repository of good practice.

From 2016 to 2019, the CSTB team involved in SINFONIA also studied the LCA applicability at district scale[10,11] and demonstrated it throughout a case study to identify shortcomings and perspectives for future improvements. The methodology was developed for a new district, with the following approach:

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[9] Published in journal « Urban environment » journal, vol. 5, 2011, p. c-1 à c-21. « ACV à l'échelle du Quartier, un outil d'aide à la décision. Le cas de la ZAC Claude Bernard à Paris »

[10] A. Mailhac et al. (2016) LCA applicability at district scale demonstrated throughout a case study: shortcomings and perspectives for future improvements

[11] A. Mailhac et al. (2016) Articulation d'un logiciel de simulation énergétique et d'un logiciel d'ACV à l'échelle quartier, illustration à travers une étude de cas

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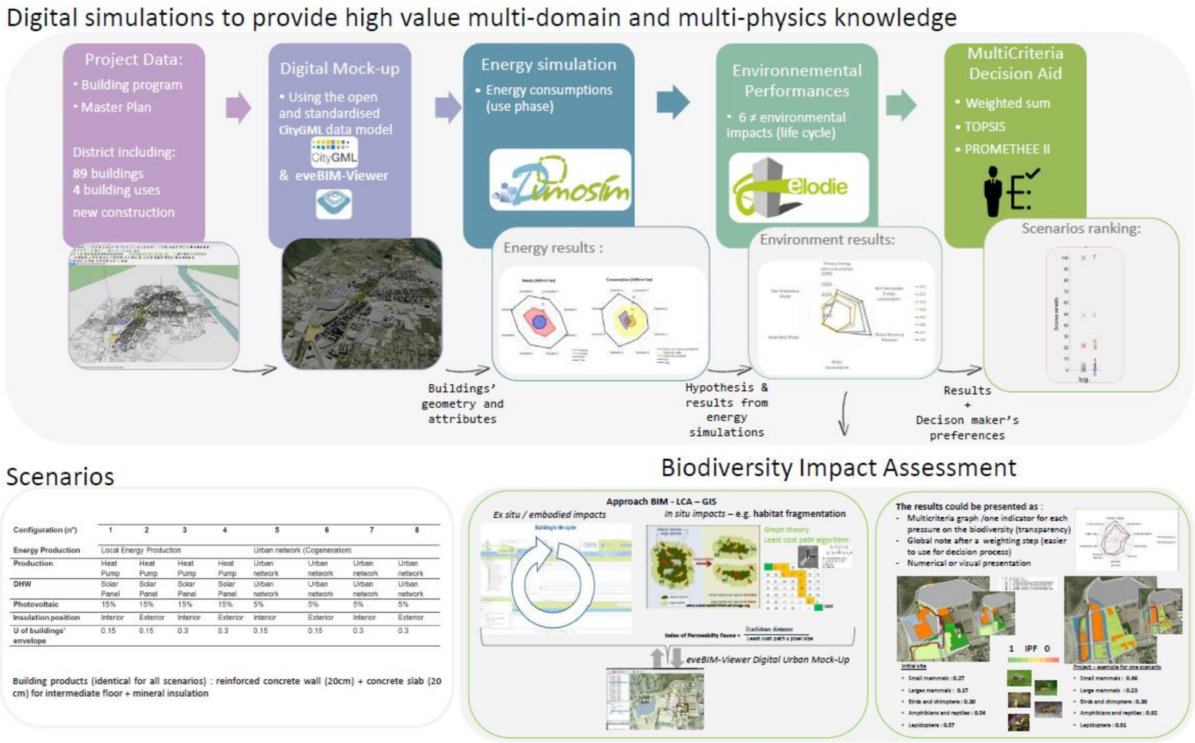

FIGURE 5: POTENTIAL OF COUPLING THE ENERGY AND LCA TOOLS WITH THE BIM AND GIS TOOLS FOR THE ENVIRONMENTAL ASSESSMENT OF NEIGHBOURHOODS[12].

The test case illustrated above contains 89 buildings in the same neighbourhood (new constructions).

4.2 APPLICATION TO SINFONIA

The different district tools and approaches presented in the State of the Art (Annex 2) and above focus on new constructions and small and dense districts (neighbourhoods). Their application to SINFONIA is therefore complex since SINFONIA is dealing with existing buildings, spread over very large districts.

It was therefore decided to focus on studying the synergistic impacts of renovation measures addressing both buildings and the district heating network.

The only building covered by our analysis which is connected to District Heating is the one located **via Cagliari**. Two scenarios have been assessed:

- Scenario 0: no renovation, no improvement of District Heating
- Scenario 1 as described in the Section 2: renovation of the building with District Heating network "as-is" (based on 2014 data initially used in the calculations)
- Scenario 2: renovation of the building + optimised District Heating Network (2018 data)

Scenario 0 & 1 – reminder

[12] N. Schiopu et al. (2017) Supporting LCA up scaling to neighbourhoods by using BIM and GIS tools

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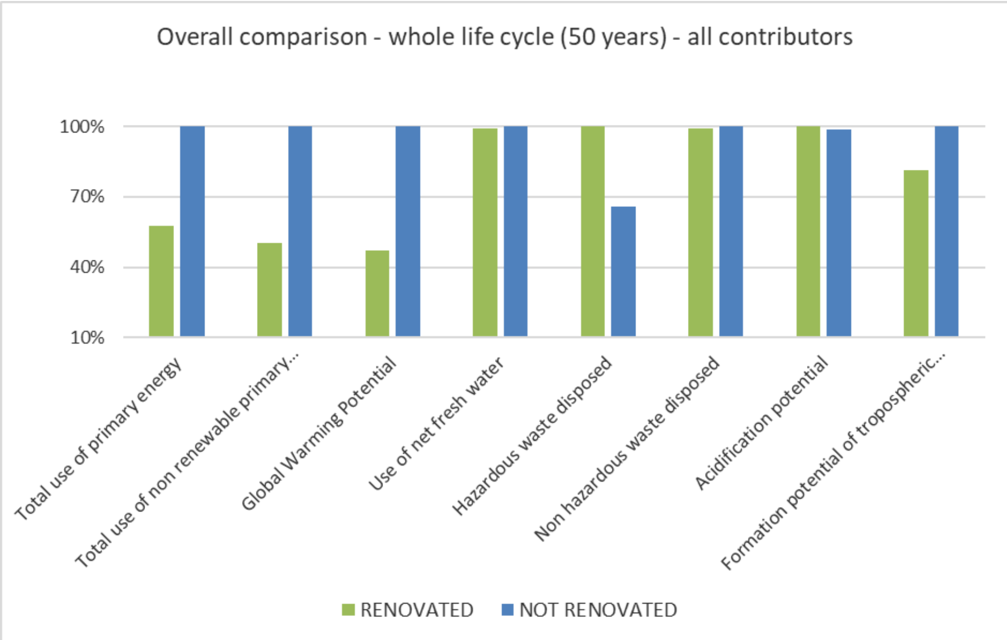

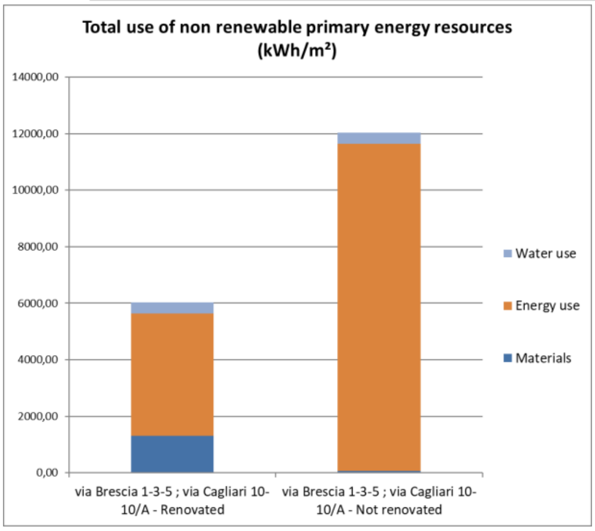

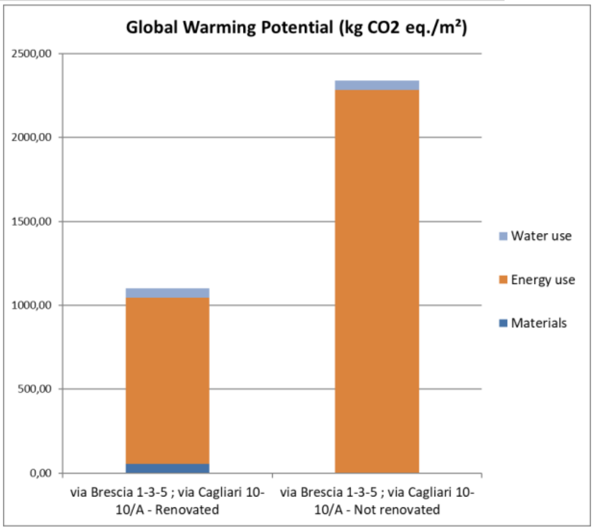

Scenario 2

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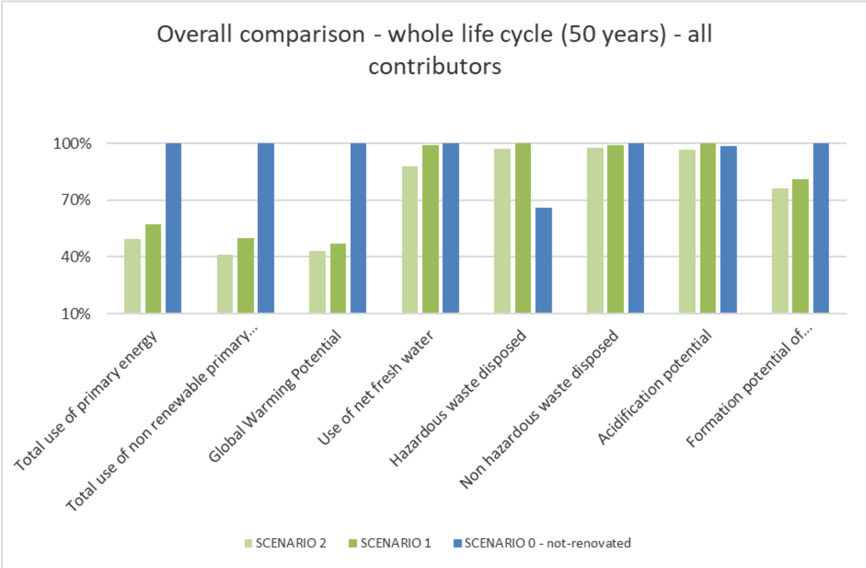

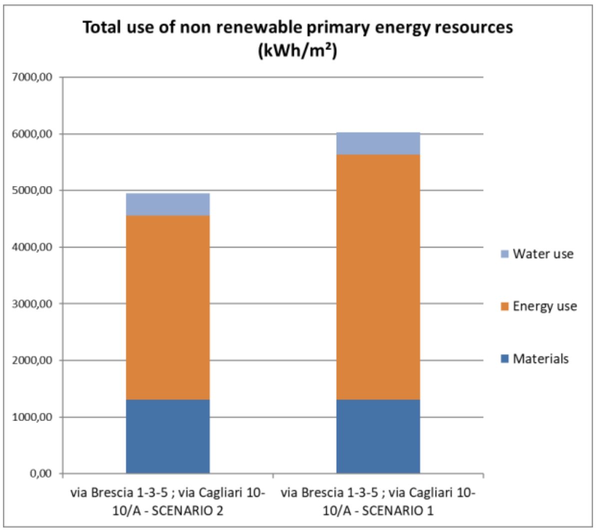

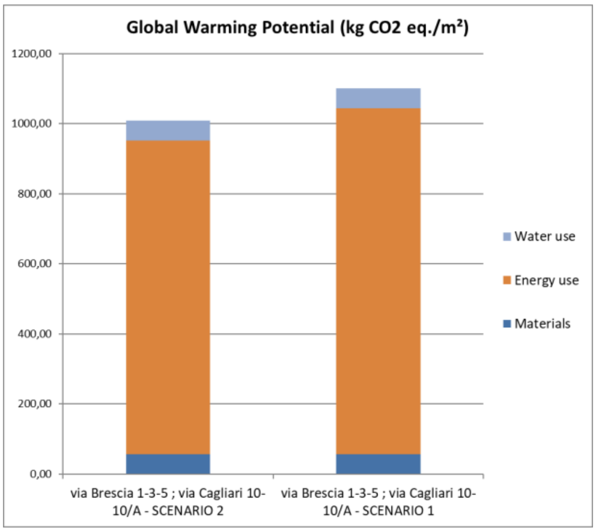

Analysis of results

All indicators (in particular “Total use of primary energy”, “Total use of non-renewable primary energy” and “Global warming potential”) are further improved by the optimisation of the district heating network (additional 8% for the GWP and 18% for the use of non-renewable primary energy).

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5. CONCLUSIONS AND RECOMMENDATIONS

At building scale:

The Life Cycle Assessments performed on the studied buildings confirm that the renovation substantially improves the environmental profile of a building and decreases in particular its Global Warming Potential. This conclusion is valid both for Innsbruck and Bolzano.

Energy use indicators, Global warming potential (GWP), and acidification potential (AP), Formation potential of tropospheric ozone (POCP) are clearly lower in the case of the renovated building. The 3 remaining indicators (Use of net fresh water, Hazardous and Non-Hazardous Waste) show either a relatively similar profile in both scenarios or, for some buildings, are deteriorated by the renovation (depending on new materials and the renewable energy solutions installed).

As a whole, **the Life Cycle Assessments demonstrate that the deep renovation of buildings brings multiple environmental co-benefits**, in addition to the CO_2 indicator which is the most commonly used. As already mentioned in Deliverable 9.2 (Economic analyses of the demonstrations), the non-financial benefits of energy renovation measures, such as improvement of comfort, health, well-being and accessibility, green property value, environmental benefits, tackling fuel poverty, should be taken into account when assessing the benefits of renovation, to go beyond the ‘kWh’ and ‘payback’ rationale. Those benefits are however difficult to monetise, and more research is needed to be able to internalise them into a financial analysis.

Green certificates (based on the Emission Trading Scheme) could here provide an interesting option as they would enable to integrate the CO_2 cost into the financial equation and thereby decrease the payback time by a few years (the payback time of deep renovation being often above 25 years).

For District Heating:

With the system boundaries and assumptions made for the analysis of the district heating system in Bolzano, it can be seen that the mixing of hydrogen into the CHP reduces the CO_2 emissions with 38.6 g CO_2/kWh_{heat}. The carbon intensity of the district heating system will be reduced with this solution as long as the production of hydrogen keep the emission factor below 215 g CO_2/kWh_{H2}.
The optimisation of the district heating network reduces the carbon intensity with 18.2 g CO_2/kWh_{heat} with the system of 2018. There is a small increase in carbon intensity with 0.051 g CO_2/kWh_{heat} with the district heating expansion in 2024 and the assumed operation of the different plants.

All three demonstrations in Innsbruck evaluated in this analysis reduces the carbon intensity of heat generation, although it is only powerhouse Rossau that is connected to the district heating network. Both the demonstration at UW Mitte and power to heat Amras does only affect the heat generated at those sites.
The carbon intensity decreases with 107 g CO_2/kWh_{heat} by implementing heat pumps at the transformer station of UW Mitte.

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The emission intensity decreases with 57 g CO_2/kWh_{heat} by implementing power to heat Amras. This might be a conservative number since it is calculated with average emission factor of electricity generation, while the aim is to operate the electric heating element while the electricity prices are low, which indicate that the emission level is lower as well.
Powerhouse Rossau is the only measure out of the three studied in Innsbruck with affects the emission intensity of the district heating system. Between 2016 and 2019, the carbon intensity of the district heat decreased by 47.74 g $CO_2/kWh_{heat.}$ However, this reduction is not due to the implementation of powerhouse Rossau only and the comparison when the district heating system is kept constant except from the implementation of powerhouse Rossau shows a reduction of carbon intensity of the district heat with 2.86 g CO_2/kWh_{heat}.

District scale

With regard to the Life Cycle Assessment at district scale, i.e. combining buildings with district heating, it demonstrates that improving both the performance of buildings and of the district heating network has a synergistic effect which enables reaching a substantial impact (e.g. for Via Cagliari in Bolzano: Use of primary energy over the whole life cycle reduced by 51%, and GWP reduced by 57%).

Recommendations

As a general conclusion, a Life Cycle Approach is instrumental when developing a long-term urban plan and can be used to make informed decisions when defining energy efficiency strategies. When it comes to energy efficient renovation (of buildings or district heating), the LCA usually provides positive results, and in that case **it is recommended to use it *ex ante* to compare different options, and *ex post* to confirm the impacts (once real measures are available).**

The availability and quality of data is essential: in the present report, simplified analyses have been carried out as some data were missing (for instance on the waste generated during the renovation works). Different hypotheses were also made on the structural materials, and on the consumption per energy carrier before renovation. So as to ensure the quality of the LCA done at building level, detailed datasets should therefore be made available on:

- The energy consumption before renovation (per energy carrier), based on real measurements or energy bills
- The energy consumption after renovation (per energy carrier), based on real measurements or energy bills
- The materials already in place before the renovation, and those removed during the renovation works
- The materials and equipment installed during the renovation (with information on their lifetime)
- Ideally, the water consumption

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Finally, **the use of LCA at district scale brings an interesting added value – although it seems to be better suited for new constructions** (or for very ambitious operations such as Positive Energy Districts/ Building Blocks) than for punctual renovations as in SINFONIA.

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6. ANNEX 1 – EXAMPLE OF DETAILED LCA AT BUILDING LEVEL

6.1 INNSBRUCK SEBASTIAN SCHEEL STRASSE / BEST SHEET N° 3

6.1.1 TECHNICAL DESCRIPTION OF THE BUILDING

Only energy uses related to heating (space heating and domestic hot water), cooling and lighting are included in the studies. Floor areas were also provided in the BEST sheet, and were corroborated with the data given in the ENERGIEAUSWEIS sent by IIG.

The following table describes the building into more detail:

Technical description of the building		
	Year of comissioning:	*1941*
	Year and type of refurbishment:	*2016 (energy systems and envelope)*
	Structural type:	*massive (brick)*
	Number of storeys:	*3*
	Net Floor Area [m²]:	*2115 m²*
	Gross Floor Area [m²]:	*2534 m²*
	Calculated electrical end energy demand - **Final Energy** [kWh/(m²*a)]:	*before retrofitting : 23.51 kWh/(m²*a) | After retrofitting : 41.37 kWh/(m²*a)*
	Calculated thermal end energy demand [kWh/(m²*a)] (energy wich is used to supply heating needs)	*before retrofitting : 213.4 kWh/(m²*a) | After retrofitting : 10.6 kWh/(m²*a)*
	Energy calculation methodology:	*Austrian regulations OIB-330.6-009/15*
	Considered energy uses	*Heating, ventilation, lighting, air-conditionning, domestic hot water.*
	Most important materials for supporting structure, insulation, windows:	*Brick, double & tripple glazing, XPS, PUR and rockwool insulation.*
	Type of facade:	-
	Energy supply system and energy transfer system (short description; name renewable components, if used):	*Individual gaz heating (11 units), Electrical heaters. PV system : PV 156m² 20,1kWp 19MWh/year*
	Number and description of underground levels	*No undergound level*
	Information about external features	*Not included within the boundaries of the study.*

Building materials, construction and transport processes are described regarding their ecological effects. ÖKOBAUDAT offers both generic datasets and specific environmental declaration datasets from diverse companies or associations.

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6.1.2 INFORMATION ABOUT THE SURROUNDING ENVIRONMENT

Most of the aspects related to the surrounding context of the buildings have been ignored.

6.1.3 SYSTEM BOUNDARIES

6.1.3.1 OVERVIEW OVER THE INCLUDED LIFE CYCLE STAGES AND CONTRIBUTORS

See section 2.4.as the approach is the same for all buildings.

6.1.3.2 OVERVIEW OF THE INCLUDED PRODUCTS AND SYSTEMS

The table below summarizes the considered products and equipment.

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			Considered in the study	Not existing in the building	Screening	Simplified	Complete
Included procucts and equipments	1. External works	On-plot network (water, gaz, sewers, heat…)	☐	☐	0	0	M
		Vats and tanks, water retention…	☐	☐	0	0	M
		Parkings and covered surface	☐	☐	0	0	M
	2. Foundations - infrastructure	Foundations -Load- bearing structure	☑ ☑	☐ ☐	M	M	M
		Wall basement			M	M	M
	3. Exterior walls -vertical structure	Exterior walls	☑	☐	M	M	M
		Structural vertical elements	☑	☐	M	M	M
		Stairs, pedestrian ramps	☑	☐	0	0	M
		External surface coating, facing, painting	☑	☐	M	M	M
	4. Floor - horizontal structure	Floor structure and slabs	☑	☐	M	M	M
	5. Roof	Covering and tightness elements	☑	☐	M	M	M
		Roof framework	☑	☐	M	M	M
	6. Interior walls	Paritionning walls and internal doors	☑	☐	0	0	M
		Suspended ceilling	☐	☐	0	0	M
	7. Windows and joinery work	Windows and joinery work	☑	☐	M	M	M
		Doors	☐	☐	0	0	M
	8. Interior finishes	Floor finishes and covering, screeds	☑	☐	M	M	M
		Paintings, wallpaper, decorative products	☐	☐	0	0	M
	9. HVAC	Heating - Ventilation - Cooling - Domestic hot water system	☑	☐	0	0	M
	10. Sanitary facilities	Toilet (bowl and sets hunting), Urinals, Shower trays, plumbing…	☐	☐	0	0	M
	11. Electricity and communication network	Electricity wiring and equipment (high and low voltage)	☑	☐	0	0	M
		Communication network and equipment	☐	☐	0	0	M
	12. Safety equipments	Fire safety system, intrusion detection system…	☐	☐	0	0	M
	13. Lighting	General interior lighting and control systems…	☐	☐	0	0	M
	14. Lifts	Elevator, escalator, dumbwaiters…	☐	☐	0	0	M
	15. Electricity generating units	Photovoltaic systems including inverters…	☑	☐	0	0	M

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6.1.3.3 OVERVIEW OF THE INCLUDED OPERATIONAL ENERGY AND WATER USES

Considered operational energy uses				Comments
	Building related uses	Heating	☑	Gaz and electric (individual)
		Air conditioning (Cooling and humidification/de-humidification)	☐	No air conditionning installed.
		Domestic hot water	☑	Gaz and electric (individual)
		Ventilation	☑	Electric (individual)
		Lighting	☑	Electric
		Auxiliary (pumps, control and automation)	☐	Not included
		Building integrated systems (eg. Lifts, shutters, automated gate, lighting for parkings…)	☐	Not included
	Non building related uses	To specify (e.g. plug-in appliances, dishwachers, TV…)	☐	Not included

Considered operational water uses				Comments
	Building-related water-consuming processes	Drinking water	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.
		Water for sanitation	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.
		Domestic hot water	☑	Based on average value, not correlated to energy consumption for DHW (energy use based on Austrian building code) .
		Irrigation of associated landscape areas	☑	Based on average value (French context : total water use = 48 m3/tenant.year,
		water for heating, cooling, ventilation and humidification	☑	Based on average value (French context : total water use = 48 m3/tenant.year,
		other specific water use of building-integrated systems e.g. fountains, swimming pools, saunas	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.
	Non building-related uses	To specify…	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.

Note: the information on 51 tenants (for 34 dwellings) was extracted from PHI database (WP4)

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6.1.4 LIFE CYCLE INVENTORY ANALYSIS

6.1.4.1 DATA COLLECTION AND CALCULATION PROCEDURES

Data collection follows the guidance provided in **ISO 14044** clause 4.3.2. The calculation procedures described in **ISO 14044** are applied consistently throughout the study.
According to the definition of the scope of the study, all relevant inputs and outputs related to the building are identified and quantified.

6.1.4.2 SELECTION OF DATA/ BACKGROUND DATA

For life cycle modelling of the building, ELODIE LCA software has been used. Some preliminary calculations involved the use of the SimaPro LCA software (v 7.3.3).

Life cycles of new products were considered using data from ÖKOBAUDAT (see table 17).

Additional data used during the studies were taken directly from the INIES Database and from the Ecoinvent Database (v2.2.).

Impacts related to electrical energy uses are representative of the Austrian electric mix (based on Ecoinvent 2.2 data).

6.1.4.3 PRODUCT AND MATERIAL CONTRIBUTOR

The product and material contributor includes:

- *The production, transport, implementation, use phase and end of life of building products and systems that are implemented during the retrofitting (new materials);*
- *The end of life of products that are kept during the retrofitting;*
- *When known, the replacements that are kept during the retrofitting during the reference study period;*

Table 17 summarizes the main hypotheses and data used for each material/component.

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Material/building component	New material/ system	Existing materials	LCA/LCI Data used for production (A1-A3) or whole life cycle	Additional data used for end of life	Service life
Render	X		ÖKOBAUDAT - 5.4.02 exterior paint silicate emulsion paint (A1-A3)	*End of life not included*	30 years
Adhesive mortar	X		ÖKOBAUDAT - 1.4.05 tile adhesive (A1-A3)	*End of life not included*	50 years
Insulation - PUR	X		ÖKOBAUDAT - 8.1.02 polyurethane rigid foam (pipe insulation) (A1-A3)	*End of life not included*	50 years
Insulation - PU fastening/pedestal	X		*No data avalable*	*No data avalable*	*No data avalable*
Insulation - rock wool	X		ÖKOBAUDAT - 3.2 rock wool medium raw density - ROCKWOOL (A1-A3), 94 kg / m3 density	*End of life not included*	50 years
Insulation - XPS	X		ÖKOBAUDAT - 2.3.01 XPS insulation material (A1-A3), 32 kg / m3	*End of life not included*	50 years
Particuleboard	X		ÖKOBAUDAT - 3.2.06 chipboard (average) (A1-A3), 681.5 kg / m3	*End of life not included*	50 years
Lath	X		ÖKOBAUDAT - 3.1.01 sawn timber (12% moisture/10.7% H2O) (A1-A3), 482 kg / m3 at 12% moisture content	*End of life not included*	50 years
Insulation - cellulose wadding	X		ÖKOBAUDAT - 2.11.02 cellulose fibre panels (A1-A3), 80 kg / m3	*End of life not included*	50 years
vapor barrier	X		ÖKOBAUDAT - 6.6.02 steam brake PE (A1-A3)	*End of life not included*	50 years
Plaster	X		ÖKOBAUDAT - 1.4.04 lime-gypsum Interior plaster (A1-A3), 1600 kg / m3	*End of life not included*	50 years
Plasterboard	X		ÖKOBAUDAT - 1.3.13 gypsum board (plate) (A1-A3), 8.5 kg / m2	*End of life not included*	50 years
PE film	X		ÖKOBAUDAT - 6.6.02 steam brake PE (A1-A3)	*End of life not included*	50 years
Gravel	X		ÖKOBAUDAT - 1.2.02 gravel 16/32 (A1-A3)	*End of life not included*	50 years
Screed	X		ÖKOBAUDAT - 1.4.01 ready-mixed concrete C20/25 (A1-A3), 2365 kg / m3	*End of life not included*	50 years
Windows	X		ELODIE – PVC windows -02-07-2015	End of life included (Elodie data)	30 years

Cement-bonded particleboards	X		ÖKOBAUDAT - 1.3.12 fibre cement corrugated panel - Eternit (A1-A3), >1550 to 1750 kg / m ^{3}; average weight per unit area 17, 55 kg / m2	*End of life not included*	50 years
PV	X		ELODIE – PV system – 22-09-2014	End of life included (Elodie data)	30 years
De-central ventilation unit	X		ÖKOBAUDAT - 8.2.01 ventilation decentralized with heat recovery (wall and ceiling) 60 m3/h (A1-A3), 1 piece	*End of life not included*	15 years
Electrical heater	X		A1-A3 Based on Ecoinvent and bill of materials from "ACCESSIO" PEP-Ecopasport EPD - 1 kW.	*End of life not included*	15 years
Gaz heater (heating and DHW) – Kept from previous life cycle		X	A1-A3 Based on Ecoinvent and bill of materials from " Chaudière gaz Condensinox " PEP-Ecopasport EPD - 25 kW.	*End of life not included*	Estimated residual service life = 10 years (hypothesis: total service life 15 years) Number of replacement for the rest of the reference study period : 40/15 = 2,67
Electrical heater for DHW	X		ÖKOBAUDAT - 8.1.01 of electric instantaneous water heater (21 kW) (A1-A3) 1 piece	*End of life not included*	15 years
Electrical heater for DHW – Kept from previous life cycle		X	ÖKOBAUDAT - 8.1.01 of electric instantaneous water heater (21 kW) (A1-A3) 1 piece	*End of life not included*	Number of replacement for the rest of the reference study period : 40/15 = 2,67 product service life adjustment to limit the total number of replacement to 2,67 over 50 years : ESL = 50/2.67=18.72
Structure - Concrete		X		Transport – treatment – recycling – End of life – Concrete (based on Ecoinvent 2.2)	Material component kept until building deconstruction.
Structure - Bricks		X		Transport – treatment – recycling – End of life – Brick (based on Ecoinvent 2.2)	Material component kept until building deconstruction.
Structure - plaster		X		Transport – treatment – recycling – End of life – Gypsum based materials (based on Ecoinvent 2.2)	Material component kept until building deconstruction.
Structure - Wood		X		Transport – treatment – recycling – End of life – Wood based materials (based on Ecoinvent 2.2)	Material component kept until building deconstruction.
Structure - Metals		X		Transport – treatment – recycling – End of life – metals (based on Ecoinvent 2.2)	Material component kept until building deconstruction.

Structure - Plastics		X		Transport – treatment – recycling – End of life – Plastics (based on Ecoinvent 2.2)	Material component kept until building deconstruction.
Structure - Built-up roofing		X		Transport – treatment – recycling – End of life – Unspecified non- dangerous materials (based on Ecoinvent 2.2)	Material component kept until building deconstruction.
Structure - Unspecified materials - non-dangerous waste (end of life only)		X		Transport – treatment – recycling – End of life – Unspecified non- dangerous materials (based on Ecoinvent 2.2)	Material component kept until building deconstruction.
Structure - Unspecified materials - dangerous waste (end of life only)		X		Transport – treatment – recycling – End of life – Unspecified dangerous materials (based on Ecoinvent 2.2)	Material component kept until building deconstruction.

TABLE 17 COMPONENTS AND MATERIALS AS IMPLEMENTED WITHIN THE ELODIE SOFTWARE

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6.1.4.4 OPERATIONAL ENERGY AND WATER USE

Use of electricity for the use phase (operational energy) has been taken into account using country specific energy mixes, based on Ecoinvent data (including imports from other countries).
Use of gas for heating has been modeled as “Natural gas, burned in boiler condensing modulating <100kW/RER U” for all the studies (median value for Europe).

Considered operational energy uses				Comments
	Building related uses	Heating	☑	Gaz and electric (individual)
		Air conditioning (Cooling and humidification/de-humidification)	☐	No air conditionning installed.
		Domestic hot water	☑	Gaz and electric (individual)
		Ventilation	☑	Electric (individual)
		Lighting	☑	Electric
		Auxiliary (pumps, control and automation)	☐	Not included
		Building integrated systems (eg. Lifts, shutters, automated gate, lighting for parkings...)	☑	Included (Electric)
	Non building related uses	To specify (e.g. plug-in appliances, dishwachers, TV...)	☑	Included (Electric)

TABLE 18: OPERATIONAL ENERGY USE

Energy demand values (final energy) gathered from the BEST sheet (not-renovated state) and the Energieausweis (renovated state) are ‘translated’ into delivered energy for each energy carrier using the hypotheses described below, and then implemented within Elodie. The environmental impacts related to energy use are calculated using data from the Ecoinvent Database.

Estimation of delivered energy for the LCA (kWh/m².year)				
	Heating - before	DHW - before	Heating - after retrofit	DHW - after retrofit
gas	55.23	4.45	3.43	7.11
elec	7.18	7.86	7.17	14.86
other (wood, oil)	154.48	5.09	0.00	0.00
TOT	**216.90**	**17.40**	**10.6**	**21.97**

The following hypotheses have been used:

Energy carrier used for heating (% of dwellings)	Space heating - before	Space heating - after	DHW - before	DHW - after
gas	32%	32%	32%	32%
elec	3%	68%	41%	68%
other (wood, heating oil)	65%		26%	
Total	**100%**	**100%**	**100%**	**100%**

(values estimated from the list of heating appliances sent by IIG on 24/01/17)

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Details of calculated energy consumption and production are presented Table 19.

TABLE 19 DETAILS OF ENERGY CONSUMPTION AND PRODUCTION (FINAL ENERGY)

FINAL ENERGY USES		BEFORE RETROFITTING	AFTER RETROFITTING
HEATING - GAS	kWh/m².year	55.23	3.43
HEATING - ELEC.	kWh/m².year	7.18	7.17
HEATING - OIL	kWh/m².year	154.48	0
DHW - GAS	kWh/m².year	4.45	7.11
DHW - ELEC.	kWh/m².year	7.86	14.86
DHW - OIL	kWh/m².year	5.09	0
VENTILATION	kWh/m².year	0	2.92
LIGHTING	kWh/m².year	6.28	3.66
OTHER (ELEC)	kWh/m².year	0	0.73
APPLIANCES (ELEC)	kWh/m².year	26.18	15.71
PV - PRODUCTION	kWh/m².year	0	6.23

After retrofitting, electric energy is produced on site using PV panels. It is estimated that 50% of the produced energy is exported to the public grid. Exported energy is not considered as avoided impacts during the assessment.

TABLE 20: ENERGY IMPORTED/ EXPORTED AFTER RENOVATION

Energy imported/ exported		
	Description of thermal and electrical energy:	*Electric energy is produced on site using PV panels. It is estimated that 50% of the produced energy is exported to the public grid.*
	Imported thermal energy [kWh/a]	*22292 kWh/year (natual gaz)*
	Imported electrical energy [kWh/a]	*88692 kWh/year*
	Exported thermal energy [kWh/a]	*0*
	Exported electrical energy [kWh/a]	*6588 kWh/year*

Operational water consumption for the use phase (operational water use) was calculated from the number of tenant on the basis of 48 m³ per person per year and on the basis of an average occupancy of 51 tenants.

TABLE 21: OPERATIONAL WATER USE

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				Comments
Considered operational water uses	Building-related water-consuming processes	Drinking water	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.
		Water for sanitation	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.
		Domestic hot water	☑	Based on average value, not correlated to energy consumption for DHW (energy use based on Austrian building code) .
		Irrigation of associated landscape areas	☑	Based on average value (French context : total water use = 48 m3/tenant.year,
		water for heating, cooling, ventilation and humidification	☑	Based on average value (French context : total water use = 48 m3/tenant.year,
		other specific water use of building-integrated systems e.g. fountains, swimming pools, saunas	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.
	Non building-related uses	To specify…	☑	Based on average value (French context : total water use = 48 m3/tenant.year, 51 tenants.

6.1.4.5 INDICATORS FOR THE LIFE CYCLE INVENTORY ANALYSIS

The indicators used for the analysis are presented in section 2.6.6.
LCA results are presented table 22.

TABLE 22 OVERALL LCA RESULTS (TOTAL LIFE CYCLE – ALL CONTRIBUTORS)

		Total life cycle		Products and materials		Energy use		Water use	
		BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Renovated	BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Not Renovated	BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Renovated	BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Not Renovated	BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Renovated	BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Not Renovated	BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Renovated	BEST SHEET NUM.3 - Sebastian-Scheel-Straße 18,18a,18b - Not Renovated
Total use of primary energy	(kWh/m²)	3,93E+03	1,85E+04	7,14E+02	2,31E+02	3,05E+03	1,81E+04	1,69E+02	1,74E+02
Total use of non renewable primary energy resourc	(kWh/m²)	3,64E+03	1,83E+04	6,35E+02	2,19E+02	2,85E+03	1,80E+04	1,54E+02	1,58E+02
Global Warming Potential	(kg eq. CO2/m²)	8,01E+02	4,48E+03	1,22E+02	3,82E+01	6,51E+02	4,42E+03	2,79E+01	2,81E+01
Use of net fresh water	(L/m²)	1,05E+05	7,59E+04	3,69E+04	1,73E+03	1,54E+03	4,89E+03	6,60E+04	6,93E+04
Hazardous waste disposed	(kg/m²)	2,50E+01	2,39E+01	8,76E+00	8,61E+00	5,56E+00	4,57E+00	1,07E+01	1,07E+01
Non hazardous waste disposed	(kg/m²)	1,92E+03	1,74E+03	1,84E+03	1,61E+03	3,24E+01	7,72E+01	4,66E+01	4,66E+01
Radioactive waste disposed	(kg/m²)	5,70E-02	4,92E-01	4,05E-02	5,25E-03	7,66E-03	4,78E-01	8,90E-03	9,26E-03
Acidification potential	(kg eq. SO2/m²)	2,38E+00	4,09E+01	1,48E+00	1,15E+00	6,91E-01	3,95E+01	2,07E-01	2,08E-01
Formation potential of tropospheric ozone	(kg eq. éthylène/m²)	2,65E-01	6,83E-01	8,63E-02	6,33E-02	1,71E-01	6,11E-01	8,40E-03	8,49E-03

6.1.5 INTERPRETATION OF THE RESULTS

A comparison of the environmental impacts of the two scenarios for the whole life cycle and all contributors is presented figure 6. For 6 of the 9 indicators shown here, the environmental profile is substantially improved by the renovation. Energy use indicators, Global worming potential (GWP), and acidification potential (AP), Formation potential of tropospheric ozone (POCP) and radioactive waste

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disposed are clearly lower in the case of the renovated building. The tree remaining indicators (Use of net fresh water, Hazardous and Non-Hazardous Waste) show a relatively similar profile in both cases[13]. A more detailed comparison is provided Figure 7.

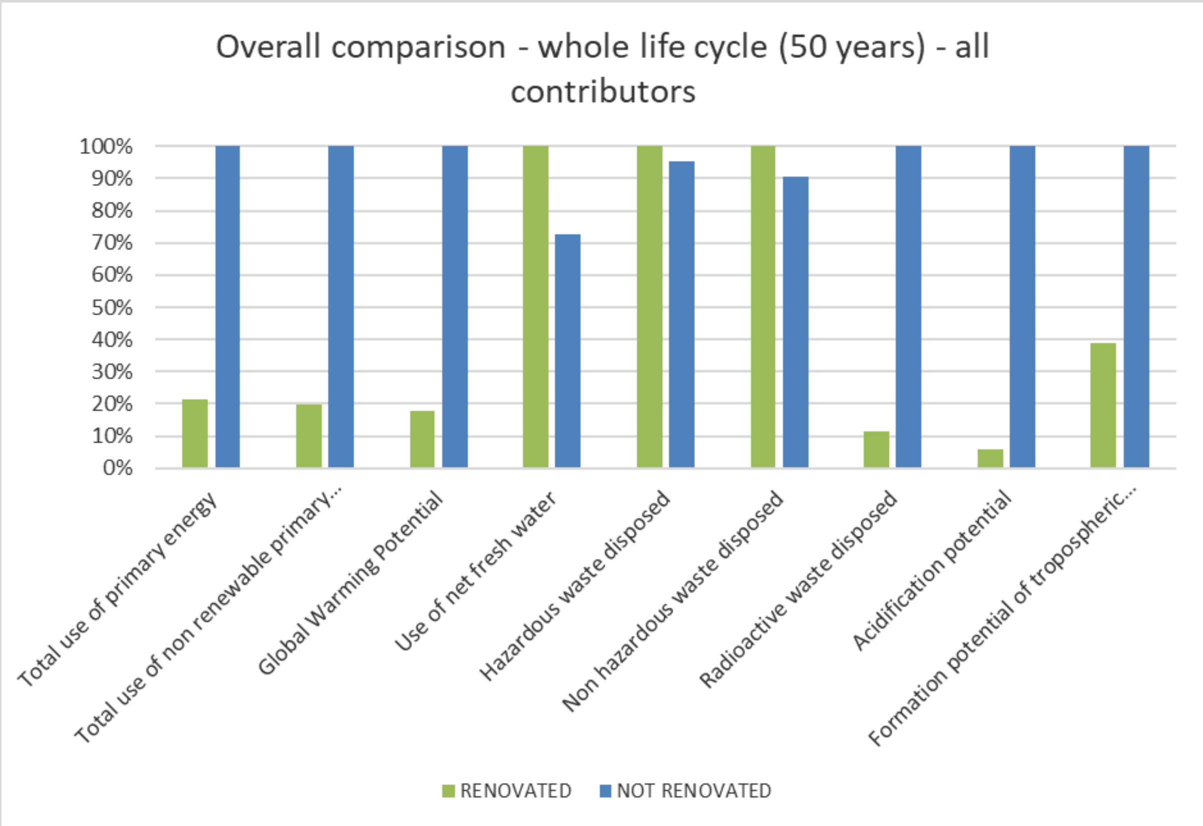

FIGURE 6 OVERALL COMPARISON OF IMPACTS BETWEEN THE TWO SCENARIOS

Energy used during the use phase (heating, lighting, etc.), as well as the type of energy used, explains most of the differences between the two scenarios for **Primary energy use** and **Global warming**. For those indicators, the important decrease in energy consumption after retrofitting is not compensated by a limited increase from building materials, leading to an overall better environmental profile. Similar conclusions could be drawn regarding indicators that are usually collinear with **Non Renewable energy use** (GWP, AP, POCP).

Use of net fresh water is mostly influenced by water used during the use phase of the buildings. As water used is calculated on a per-tenant basis it is similar in both cases and thus this result was expected.

Non-hazardous waste disposed is strongly influenced by the contribution from construction materials. In our case the main contributor is the building structure itself (which is similar in both scenarios).

[13] Keeping in mind the simplified nature of the studies and the hypothesis made, a 20 to 30% difference between two indicator values is not considered important enough to clearly rank scenarios.

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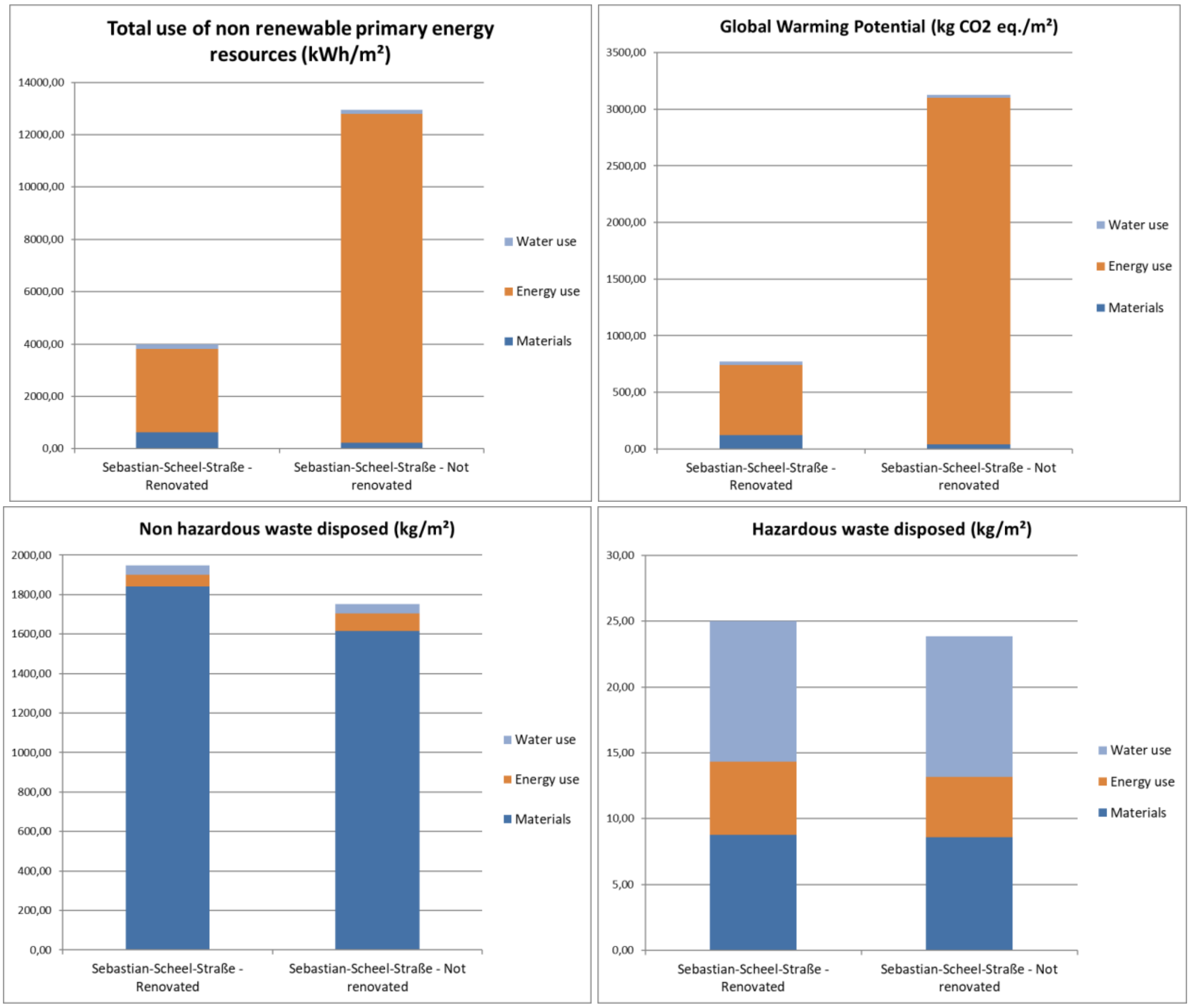

FIGURE 7 DETAILED COMPARISON BETWEEN THE TWO SCENARIOS

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7. ANNEX 2 - LCA TOOLS USED IN PRACTICE AT THE DISTRICT SCALE: STATE OF THE ART

7.1 ADDRESSING THE DISTRICT SCALE

The Lore-LCA project in the report "guidelines for LCA" identified two main applications for using LCA in the urban design context: (i) Target-setting and evaluation of environmental impact in governance strategies and (ii) Decision-making of development strategies, including decisions related to density, urban typologies, location of new settlements and evaluation of the environmental impact at city district level.

The first application relates to the way to define the target when the municipality delivers the land permits to developers. Tentative simplifications for LCA calculations could be designed according to the main goal of the study. For example one could consider only two life cycles stages, only building and more precisely only the production of construction materials for main building elements (roofs, slabs, external walls, etc.) and the sole operation and maintenance of buildings in terms of energy use over the whole life cycle. Critical parameters for such process include LCI-data for energy and materials, expected life time of building, performance of building components and system boundaries.

The second application on environmental assessment of a district or a city is more general and could be seen as analytical approach to provide metrics of sustainable at city level. A series of tools could be considered:

- A first series of tools (such as LEED 2009[14] for Neighbourhood Development, BREEAM Communities[15]) covers the city district level by calculating environmental impacts related to a certain density. They are rather indicators systems than actual LCA approaches[16].
- A second series includes tools aimed at monitoring and assessing the city's contribution to climate change. The guidelines developed by ICLEI aim to quantify the impacts of measures relevant in the local authority planning domain. Guidance is proposed to assess the GHG emissions and more precisely on the inventory data gathering. However it is not directly suitable for assessing various developments in a life time perspective. This second category includes also high level approaches focusing only on direct and indirect GHG emissions at the city scale[17].
- The Swedish Environmental load profile tool claims to use LCA for environmental assessment (applications to Hammarby Sjöstad district of Stockholm).

7.2 TOWARDS SIMPLIFICATION

A crucial question is the complexity and the simplification of life cycle stages in order to cope with a tractable amount of data to be collected. The nature of simplification should remain consistent with the type of options that have to be simulated (e.g. density alternative options should include the

[14] LEED® is a green building certification program for new constructions and renovation programs managed by the U.S. Green Building Council www.usgbc.org

[15] The world's leading design and assessment method for sustainable buildings. See www.breeam.org

[16] Source: LoRE-LCA project, deliverable D3.2 "Guidelines for LCA" pp 32-35

[17] A. Ramaswali, T. Hillman, B. Janson, M. Reiner, and G. Thomas, A demand-centered, Hybrid life- cycle methodology for city-scale GreenHouse Gas Inventories. Environmental Scence & Technology. Vol.42, N.17, 2008.

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location of services and personal transports while future energy systems variants should rather analyse various energy mix).

A practical simplification is proposed by EGFBPT[18], through an ecodesign type approach for carrying out LCA studies at the level of a city district[19]. It suggests modelling the project as a system with clear delimitations in space, time and functions. Then a four-step approach is implemented: setting the environmental goals, identifying the inputs/outputs of the defined system, calculating the environmental performance indicators, studying alternative options to improve the obtained performance levels. Due to the complexity to address the district level, it is recommended to carry out separate LCA studies for each of the main component, e.g. the buildings, the infrastructures and open spaces, the users' behaviours and to aggregate then the results at the level of the considered district.

However, the environmental performance of a district cannot be the direct sum of the various buildings (as for a building the performance is not the sum of its various components). Indeed buildings may interact (e.g., mutual shadow depending on the urban morphology), heating system such as district heating might be mutualized, road and transport systems are in direct interaction with urban density. A more systemic approach is needed with *ad hoc* tools.

7.3 THE CONTRIBUTION OF RESEARCH

On the academic side, recent research activity dedicated on quantitative approaches at the district levels permitted significant progress towards the development of LCA based tools (PhD on ADEQUA method, F; Cherqui 2005; "ACV quartier", B. Peuportier), on the assessment of sustainable neighborhoods (G. Yepez-Salomon, 2011; the NEST tool by Nobatek) and on the assessment of the environmental impact of urban settlements (G. Herfray, 2011)[20].

<u>The NEST tool</u> Neighborhood Evaluation for Sustainable Territories (resulting from an internal development in Nobatek) is a quantitative tool[21] to assess environmental impacts of an eco-district at the early-design phase though a set of 8 indices including primary energy, CO2 emissions, territory and biodiversity, wastes, quality of air, water consumption, economic impact, social impact.
The district is considered as composed of complex elements which are simplified in an early design project: The LCA of a district results from a weighted aggregation of four LCAs on Infrastructure + buildings + mobility + soil transportation[22]. Input data include data on site (map, location, altitude and initial soil), buildings (surface, status, typology, facilities, energy and water), nature of soils, public lighting, water consumption for maintenance, population and transports (distances and types).

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[18] Entreprises Générales de France · BTP (EGF · BTP), national syndicate, member of the FFB

[19] Des éco-quartiers à l'aménagement durable: Apports de l'éco-conception, flyer by Entreprises Générales de France BTP.

[20] PhD thesis, Grégory HERFRAY, Contribution to the evaluation of environmental impacts of urban settlements, Mines Paristech, October 2011

https://hal-sde.archives-ouvertes.fr/file/index/docid/877122/filename/EUE5_Colombert_et_al.pdf

[21] A technical description (in French): Outil NEST – NOBATEK – Description technique de l'outil. Avril 2013 in

http://www.nobatek-nest.com/file/NEST_Descriptif-technique_FR.pdf

[22] http://www.avnir.org/documentation/congres_avnir/diapos/atconstr/3bNobatek_LucieDuclos.pdf

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The PhD work carried out by Grace YEPEZ SALMON explores a systemic approach of a sustainable city through the development of an assessment tool for sustainable neighbourhoods[23] . In particular it claims that the district is the most relevant scale for experimentation and proposes a definition of the sustainable neighbourhoods as well as a typology in seven types. An overview of assessment tools of sustainable neighbourhood in early design phase is also made with a clear message that there is no ideal tool. The considered solutions include check lists, impact matrix, decision making approaches, simulation software, and various environmental assessment approaches (such as Carbon footprint, HQE2R Sustainable renovation of buildings for sustainable neighbourhoods or ADEQUA).

For instance one could mention several evaluation tools that are derived from the HQE2R project[24]:

- The INDI (INDicators Impact) model is an assessment model of projects or scenarios, which has been elaborated from the integrated sustainable development indicators system (ISDIS) identified in the HQE2Rproject. The model assesses the evolution of the neighbourhood
- The ENVI model (ENVironmental Impact) analyses the environmental impact of scenarios or projects. Its aim is to give local authorities a decision aid tool and an ex-ante evaluation, in their choice of projects and scenarios.
- The ASCOT (Assessment of Sustainable COnstruction and Technologies cost) tool is developed to assist the user in evaluating and thereby optimise the economic costs of a building project in relation to sustainable development issues.

With a clear focus on the district scale, the ADEQUA method (Methodology for assessing sustainable urban district project[25]) contributes to organize and structure the methodological work among the various methods dealing with the evaluation of environmental quality of a building project and the sustainability of a district project The assessment in ADEQUA is based on four groups of indicators (resources, ecosystems, risks & health, ambiances) which are assessed through indicators relating to the specific objectives of each sustainable alternatives. Radar type charts based on data, simulation results and expert view are produced[26].

The above-mentioned NEST tool is also based on the approach developed by B. Peuportier[27] within the project "ACV Quartiers".

ACV QUARTIERS, a project funded by French ANR, prepared the development of a tool that allows to analyse the lifecycle not of a single building but of an entire district, and is based on six indicators: primary energy consumption, greenhouse gas emissions, water consumption, waste production, the exhaustion of natural resources and the impacts on human health. By comparing the performance of a standard or regulatory arrangement and the performance of the eco-district project, ACV QUARTIERS improves the environmental performance of buildings and public spaces. ACV QUARTIERS led to the development and commercialization of the NovaEQUER tool.

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[23] Construction d'un Outil d'évaluation Environnementale des Ecoquartiers : vers une méthode systémique de mise en œuvre de la ville durable; Nobatek/GRECAU-Bordeaux 1: http://ori-oai.u-bordeaux1.fr/pdf/2011/YEPEZ_SALMON_GRACE_2011.pdf

[24] http://www.suden.org/fr/projets-europeens/hqe2r/#Les_outils_de_la_dmarche_HQE2R

[25] Frédéric Cherqui. Méthodologie d'Evaluation d'un projet d'aménagement durable d'un quartier - méthode ADEQUA. Engineering Sciences. Université de La Rochelle, 2005.

[26] https://hal.inria.fr/file/index/docid/64833/filename/These_FCherqui_20060301.pdf

[27] See ACV Quartiers: presentation to PREBAT, B. Peuportier 2010

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The NovaEQUER tool: application at the level of a district of the EQUER tool of Armines, commercialized by Izuba, it allows calculating the environmental footprint of a building based on 10 environmental indicators (energy use, materials, water use, waste, construction processes, etc.) over the entire life time of the considered project. Several buildings and public space (lighting, parks, etc.) of a district are considered in the analysis.

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Annex: DOCUMENT INFORMATION

SINFONIA DELIVERABLE FACT SHEET		
PROJECT START DATE	1 June 2014	
PROJECT DURATION	60 months	
PROJECT WEBSITE	http://www.sinfonia-smartcities.eu	
DOCUMENT		
DELIVERABLE NUMBER:	D9.3	
DELIVERABLE TITLE:	Life Cycle Assessment report of the demonstrations	
DUE DATE OF DELIVERABLE:	31/03/20	
ACTUAL SUBMISSION DATE:		
EDITORS:	Karine Laffont-Eloire (DOWEL)	
AUTHORS:	Karine Laffont-Eloire (DOWEL), Lovisa Axelsson (RISE), Adélaïde Mailhac (CSTB)	
REVIEWERS:		
PARTICIPATING BENEFICIARIES:	DOWEL, RISE, CSTB	
WORK PACKAGE NO.:	9	
WORK PACKAGE TITLE:		
WORK PACKAGE LEADER:	ZABALA	
WORK PACKAGE PARTICIPANTS:	All project partners	
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