Ref. Ares(2025)5205675 - 30/06/2025

REGEN

D 2.4 - Assessment Framework for Urban Regeneration (AFUR)

WP2, Task 2.5

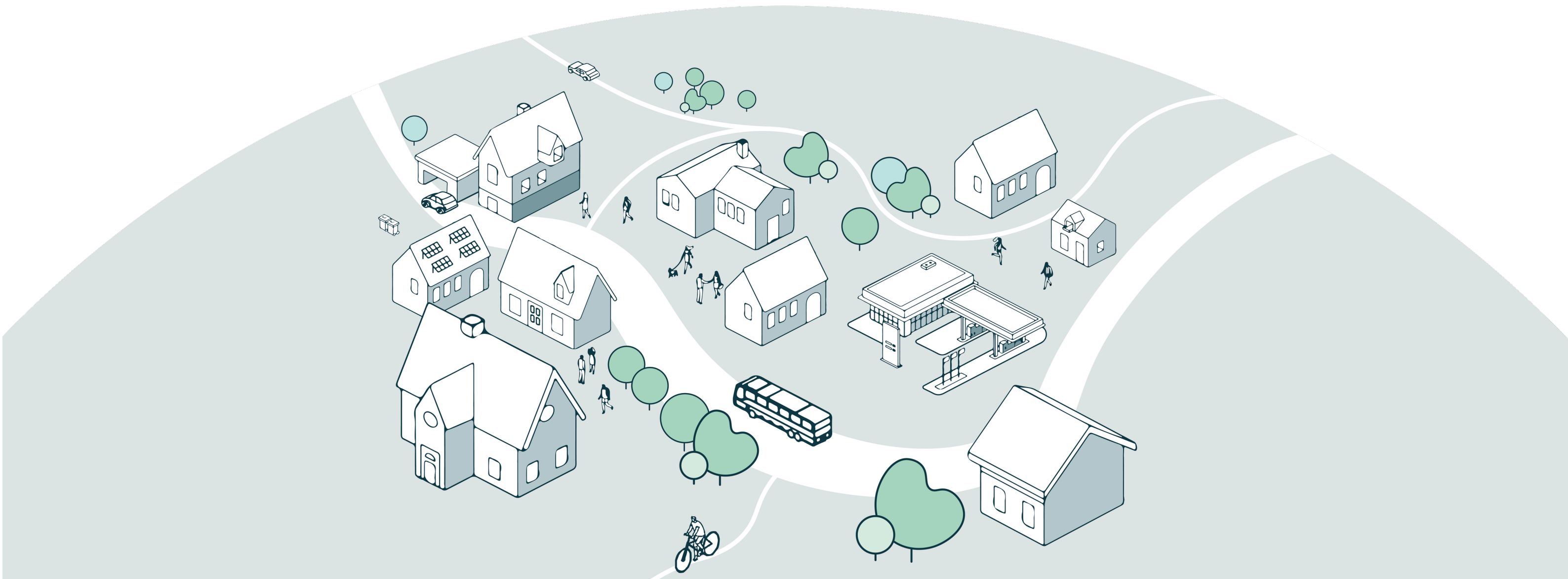
June 2025 [M18]

Author(s): Elorri Igos, Yoann Gorostiaga (NBK), Calin Boje, Marie-Sophie Roderich, Sylvain Kubicki, Annie Guerriero, Claudio Petucco (LIST), Elena Usobiaga Ferrer, Pablo De Agustin Camacho, Mauricia Benedito (TECNALIA), Niall Buckley (IES), Lorena Borges Dias, Samaneh Rezvani, Zhaoxing Wang (DEMO), Martin Dijst (LISER), Lidia Gryszkiewicz (TIL)

Disclaimer

Copyright notice

regenproject.eu | @REGEN EU Project | @REGENEuProject



Co-funded by the European Union

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Document Information

Grant agreement	101123325
Project title	REGENeration of neighbourhoods towards a low-carbon, inclusive and affordable built environment
Project acronym	REGEN
Project coordinator	Sylvain Kubicki (sylvain.kubicki@list.lu)- Luxembourg Institute of Science and Technology
Project duration	1st January 2024 – 31st December 2027 (48 Months)
Related work package	WP 2 - Development of socio-ecological regeneration innovations and sociotechnical components
Related task(s)	Task 2.5 - Development and validation of the REGEN Assessment Framework for Urban Regeneration (AFUR)
Lead organisation	LIST
Contributing partner (s)	NOBATEK, TECNALIA, IES, DEMO, LISER, TIL
Due date	30 June 2025
Submission date	X
Dissemination level	Public

History

Date	Version	Submitted by	Reviewed by	Comments
2025/05/19	0.1	Nobatek		DRAFT
2025/06/16	0.2	Nobatek	All authors	RELEASED for review
2025/06/26	0.3	Nobatek	iUE	
2025/06/27	1.0	Nobatek	LIST	DELIVERED - Submission to EC

Table of Contents

Executive Summary 8
Keywords 8
1 Introduction 9
1.1 Purpose and target group 9
1.2 Relation to other activities in the project 9
2 AFUR in a nutshell 10
2.1 Intervention domains 10
2.2 Multi-phase decision support process 11
2.3 Evaluation domains 12
2.4 Evaluation system boundaries 15
2.5 Evaluation indicators and thresholds 15
3 Consumption patterns indicators 17
3.1 Energy indicators 17
3.1.1 Assessment principles and calculation tools 18
3.1.2 Required input data 18
3.1.3 Identified thresholds 20
3.2 Material circularity indicators 21
3.2.1 Assessment principles and calculation tools 21
3.2.2 Required input data 22
3.2.3 Identified thresholds 22
3.3 Modal split indicators 22
3.3.1 Assessment principles and calculation tools 23
3.3.2 Required input data 23
3.3.3 Identified thresholds 23
4 Services to society indicators 23
4.1 Accessibility to services and public transports indicators 24
4.1.1 Assessment principles and calculation tools 24
4.1.2 Required input data 28
4.1.3 Identified thresholds 29
4.2 Outdoor thermal comfort indicators 29
4.2.1 Assessment principles and calculation tools 30
4.2.2 Required input data 30
4.2.3 Threshold definition for sustainable urban regeneration 30
5 Environmental impact indicators 30
5.1 Land use indicators 30
5.1.1 Assessment principles and calculation tools 31
5.1.2 Required input data 33
5.1.3 Identified thresholds 33
5.2 Life cycle assessment (LCA) indicators 34
5.2.1 Assessment principles and calculation tools 35
5.2.2 Required input data 37
5.2.3 Threshold definition for sustainable urban regeneration 39

Co-funded by
the European Union

6 Economic impact indicators ... 41
6.1 Socio-economic indicators ... 41
6.1.1 Assessment principles and calculation tools ... 41
6.1.2 Required input data ... 42
6.1.3 Identified thresholds ... 42
6.2 Life cycle costing (LCC) indicators ... 43
6.2.1 Calculation principles and tools ... 43
6.2.2 Required input data ... 45
6.2.3 Threshold definition for sustainable urban regeneration ... 47
7 Summary ... 48
Conclusions ... 51
Bibliography ... 52
Annex ... 54
Annex I – Example tools for urban modelling ... 54
Annex II – Accessibility - Service Categories ... 57

List of figures

Figure 1: AFUR in a nutshell ... 10
Figure 2: AFUR methodology multi-phase decision support process ... 11
Figure 3: Classification of AFUR indicators' domains ... 13
Figure 4: Relationships between intervention, consumption indicators, services indicators, economic indicators, and environmental indicators ... 14
Figure 5: Example of buffer zone application for rural area for Beckerich demo site (urban area in dark blue; buffer zone to restrain calculation to 100 m distance from urban area in light blue; and original demo site perimeter with dotted line) ... 33
Figure 6: Overall framework to apply life cycle methods for AESA (inspired by Bjørn et al., 2020) ... 39

List of tables

Table 1: Overview of AFUR indicators and related thresholds ... 15
Table 2: AFUR energy indicators ... 17
Table 3: AFUR thresholds for energy indicators ... 20
Table 4: EU Taxonomy criteria related to building energy performance ... 20
Table 5. AFUR material circularity indicators ... 21

Table 6: AFUR thresholds for circularity indicators ... 22
Table 7. AFUR modal split indicators ... 22
Table 8. AFUR accessibility indicators ... 24
Table 9: Values of parameters applied in REGEN to calculate the walkability to services ... 26
Table 10: Values of parameters applied in REGEN to calculate the walkability to public transport ... 27
Table 11: Correspondence between safety score and the value of parameter ... 28
Table 12: AFUR thresholds for accessibility indicators ... 29
Table 13. AFUR outdoor comfort indicators ... 29
Table 14: AFUR thresholds for outdoor thermal comfort indicators ... 30
Table 15. AFUR land use indicators ... 31
Table 16: List of permeability coefficients (PCi in Eq. 5) ... 31
Table 17: List of biodiversity coefficients (BCi in Eq. 5) ... 32
Table 18: AFUR thresholds for land use indicators ... 33
Table 19: LCA indicators (from EF 3.1 method) ... 34
Table 20: Examples of functional unit depending on intervention type ... 35
Table 21. AFUR socio-economic indicators ... 41
Table 22: AFUR thresholds for socio-economic indicators ... 43
Table 23. AFUR life cycle costing indicators ... 43
Table 24: AFUR thresholds for LCC indicators ... 47
Table 25: Summary of AFUR indicators and their calculation principles ... 49

Abbreviations and acronyms

Acronym	Description
AESA	Absolute environmental sustainability assessment
AFOLU	Agriculture, forestry and other land use
AFUR	Assessment Framework for Urban Regeneration
API	Application programme interface
CBSh	“Coefficient Biotope Surfacique harmonisé”, i.e. harmonized area-based biotope coefficient
CF	Characterization factor
EF	Environmental Footprint
EPC	Energy performance certificate
EPD	Environmental product declaration
EU	European Union
FCE	Final consumption expenditure
GDP	Gross domestic product
GHG	Greenhouse gas
GIS	Geographic information system
LCA	Life cycle assessment
LCC	Life cycle costing
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NBS	Nature-based solution
NPV	Net present value
NZEB	Net-zero energy building
P2W	Powered-two-wheeler
pkm	Passenger.kilometre
PM	Particulate matter
PV	Photovoltaic
UTCI	Universal thermal comfort index

Executive Summary

Urban level regeneration interventions are complex and require advanced tools and model to allow decision-makers to understand their benefits and potential trade-offs. This primary objective of the Assessment Framework for Urban Regeneration (AFUR) developed within REGEN is to provide the means to estimate and understand these complexities. AFUR provides a science-based holistic assessment of environmental, social and economic impacts (the three sustainability pillars) of interventions. This deliverable describes the AFUR methodology and its requirements so that other actors (e.g., urban planners, sustainability experts, etc.) can replicate the approach.

AFUR was developed considering the scope of REGEN demo sites, in particular to assess interventions related to building energy efficiency, energy system improvement, building components reuse, soft mobility fostering and nature-based solutions. AFUR indicators thus cover as much as possible the potential effects of these actions: energy, material circularity, modal split, urban accessibility, outdoor thermal comfort, land use, life cycle assessment, economic accessibility and life cycle costing indicators.

To be aligned with regeneration objectives, AFUR results interpretation is not only relative (e.g. between studied scenarios) but also based on ambitious thresholds coming from EU instruments (e.g. EU Taxonomy, EU policy targets, European certification schemes) or from state-of-the-art literature (e.g. planetary boundaries, review of energy poverty definitions).

The calculation of AFUR indicators requires varying levels of efforts, with sometimes the need of software tools. Within REGEN, tools specific to the project are applied, but AFUR evaluation could also rely on equivalent tools. In order to make the assessment framework replicable, two levels of data requirements are defined: the higher level, which requires specific and high-quality data, and the minimum level relying mostly on easily accessible data. The latter will be in particular applied for the evaluation of virtual cases within the project (D4.3).

While AFUR provides a guidance to support urban regeneration with a science-based quantitative evaluation, we are aware that the methodology described in this report is not fully comprehensive but can be used as first approach. The concept can be enriched depending on the specific issues of the studied area, available data and expertise.

Keywords

Sustainability assessment, diagnosis, indicators, modelling, decision-support, environmental impacts, socio-economic impacts

1 Introduction

1.1 Purpose and target group

REGEN supports the development of neighborhoods through so-called “regenerative” concepts which promote resilient social and ecological systems that can sustain and prosper. To do so, the project is developing a catalogue of interventions, i.e. actionable solutions at urban scale that have an impact on the built environment, energy systems, mobility, circular economy and land management. These interventions can provide multiple benefits but may also involve trade-offs. To support sustainable decisions, a holistic evaluation framework is therefore required. Hence the development of the Assessment Framework for Urban Regeneration (AFUR) within REGEN.

The objective of AFUR is to provide a scientific assessment of environmental, social and economic impacts and benefits associated with regeneration interventions, considering the life cycle of products and services holistically, covering the three dimensions of sustainability. An alignment with regenerative economy criteria from the Doughnut Economics approach from Raworth (2017) is also investigated within AFUR. The assessment framework thus provides a large range of quantitative indicators, to support decision makers towards regenerative urban planning.

This document describes the assessment framework, its scope, the related indicators, evaluation and interpretation methods. AFUR covers several intervention domains (documented in the REGEN Catalogue of Interventions), which are evaluated along a multi-phase process, covering several evaluation domains. The chapters describe the indicators for each major AFUR evaluation domain: consumption patterns, services, environmental impact and economic impact.

The documentation disseminated here is intended to be used by other actors (e.g., urban planners, sustainability experts, etc.) to identify the relevant evaluation criteria and replicate the developed AFUR methodology to other urban areas, using similar tools and data sources.

1.2 Relation to other activities in the project

Part of the AFUR methodology was already applied for the initial diagnosis of demo sites (D3.1). The consolidated framework described in this report will further be used to evaluate the impacts and benefits of regeneration scenarios demonstrated in WP3, as well as virtual scenarios in WP4. Results will be detailed in D4.1 and D4.3, respectively, and will feed the catalogue of interventions. In addition, AFUR methodology relies on various tools. The integration of these software tools is investigated in D2.1. AFUR methodology will be further developed in D4.2 to be able to upscale the evaluation at city level.

2 AFUR in a nutshell

There are several key components within our AFUR framework:

1) **Intervention domains** – urban level domains where stakeholders aim to act, aligned with the REGEN catalogue of interventions
2) **Multi-phased process** – incremental steps to support decision-making process with a comprehensive assessment
3) **Evaluation domains** – relevant environmental and socio-economic effects to be considered to assess interventions, using several methods and tools
4) **Evaluation indicators & thresholds** – quantitative results of the evaluation and their interpretation grid to support decision makers.

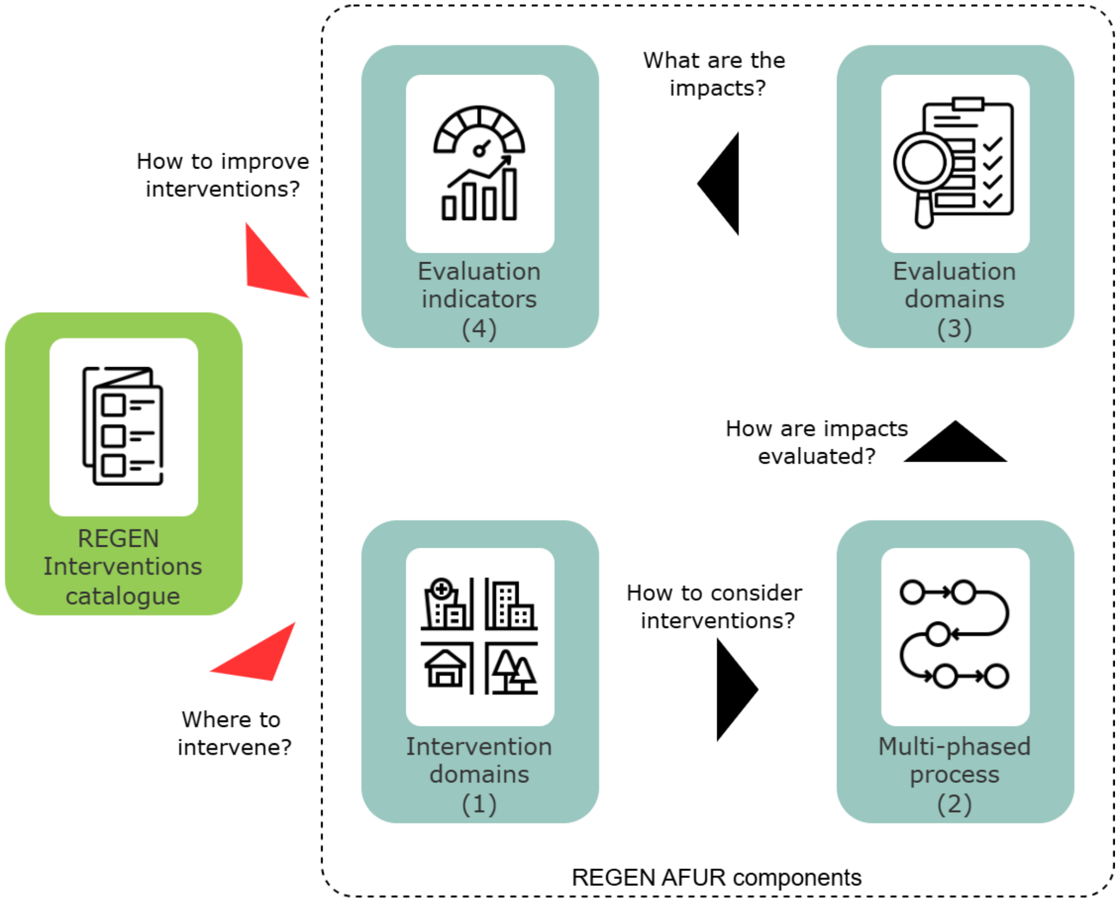


Figure 1: AFUR in a nutshell

2.1 Intervention domains

The AFUR scope of application has been tailored to evaluate the effects of interventions in different domains, in particular:

- **Built Environment –** focuses on built assets from buildings to infrastructure, their construction or retrofit (e.g. renovate buildings, deconstruct buildings, construct new infrastructures, etc.);
- **Energy systems –** focuses on urban level energy infrastructure and renewable energy sources (e.g. extending existing system networks, installing new energy harvesting technologies, etc.);

- **Mobility and transport –** with a focus on urban level mobility aspects and transportation infrastructure (e.g. promote public transport and active mobility, change transportation routes and schedules, etc.);
- **Circular economy –** with a scope on waste management and resource recovery from existing built environment infrastructure (e.g. foster building material and component reuse during a deconstruction project)
- **AFOLU - Agriculture, forestry and other land use –** focuses on enhancing green urban infrastructure, landscaping and land management (e.g. implement green areas, carbon sequestration, nature-based solutions, etc.)

2.2 Multi-phase decision support process

Employing the AFUR methodology involves a multi-phase process (Figure 2) to understand urban site characteristics and potential interventions effects towards urban regeneration. An initial diagnosis (P1) is used to identify improvement potential, followed by a monitoring phase (P2) via digital tools which provide data to evaluate interventions impacts (P3). The latter are analysed (P4) to finally support decision makers towards regeneration solutions implementation (P5).

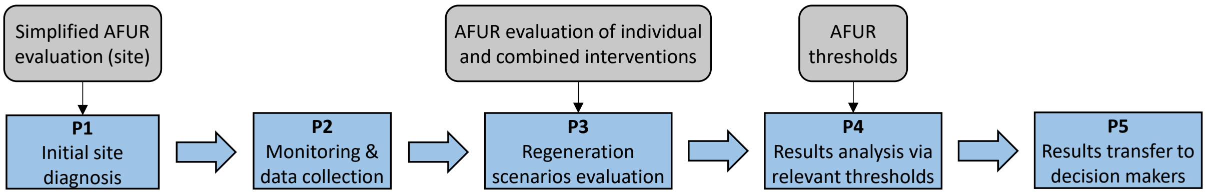


Figure 2: AFUR methodology multi-phase decision support process

The purpose and output of each AFUR phase are:

P1. Initial site diagnosis

Purpose: Conducting an initial diagnostic of the urban site of interest. Based on easily accessible data (e.g. open-source data, cadastral data, etc.), a simplified AFUR evaluation is carried out. Potential areas of improvement are identified based on the comparison with benchmark values.

Output: Screening baseline scenario results and identification of relevant regeneration interventions.

P2. Monitoring and data collection

Purpose: Identification of relevant data sources & digital tools to feed and refine the AFUR evaluation (for the baseline scenario and future regeneration scenarios) depending on the previously identified areas of interest.

Output: Refined baseline scenario results and data collected for further scenarios evaluation.

P3. Regeneration scenarios evaluation

Purpose: Definition of regeneration scenarios with decision-makers based on relevant and applicable interventions. A detailed evaluation of their benefits and impacts, based on specific tools, methods and collected data from the previous step (P2) is carried out.

Output: Intervention scenarios results.

P4. Results analysis via relevant thresholds

Purpose: Comparison of scenario results with relevant thresholds for each domain of indicators (e.g. minimum accessibility to services, targeted energy class, environmental impacts aligned with planetary boundaries, etc.) in order to understand if they are aligned with regeneration objectives, following a Doughnut Economics approach.

Output: Analysed scenarios results and alignment with regeneration objectives

P5. Results transfer to decision makers

Purpose: AFUR analysis can be transferred to decision makers via conventional tools (i.e. reporting documents) but also as interoperable data for interactive digital tools. This is particularly important to involve citizens or other stakeholder groups, potentially affected by the regeneration process. Within REGEN project, this participative process will be supported by the MUST visualization tool.

Output: AFUR indicators reporting & transfer based on intervention scenarios data for further decision making.

2.3 Evaluation domains

AFUR covers the three pillars of sustainability, i.e., environmental, economic, and social dimensions, to reveal the multiple effects of interventions. Within AFUR, the indicators are classified into 4 domains, corresponding to different stages of the cause-effect chain (see Figure 3):

1) **Consumption patterns** - refer to the use and disposal patterns of goods and services within the studied area. These patterns can be useful to understand the behaviour of citizens or the efficiency of various processes. The mapping of material and energy flows can further feed the evaluation of environmental and socio-economic impacts.
2) **Services to society** - refers to the benefits and functions that urban infrastructure, public spaces, and interventions provide to the community. These services can be both tangible and intangible, and they contribute to the well-being, resilience, and sustainability of urban life.
3) **Environmental impacts** – covers the effects of interventions on the environment, affecting ecosystems, human health or natural resources.
4) **Economic impacts** – covers the effects of interventions on the wealth of involved stakeholders.

As shown in Figure 3, an intervention can change the consumption patterns, e.g. building energy consumption, resident transport or waste disposal, but can also bring services to society, e.g., via improved accessibility, or thermal comfort. These changes further impact the environment or economy (e.g. energy supply changes due to improved building energy efficiency). Environmental impacts can be measured by on-site indicators such as soil permeability or biodiversity, but also with value-chain indicators thanks to life cycle assessment (LCA) methodology (including off-site impacts). Similarly, economic impacts can include on-site effects via energy poverty reduction or gentrification risk, and other value-chain costs which can be evaluated via life cycle costing (LCC) methodology.

Impacts on social indicators or quality of life are difficult to model but indicators related to the provisions of services and economic impacts could still represent proxy indicators on these aspects.

Consumption patterns	Services to society	Environmental impacts	Economic impacts
Energy consumption Energy sources Residents transport by means Waste disposal ...	Walkability to services Public transport access Access to green areas Thermal comfort ...	LCA indicators: climate change, particulate matter, resource depletion... Soil permeability Biodiversity index ...	LCC indicators: net present value, ROI... Energy poverty Unemployment Housing affordability ...

Proxy indicators for social impacts / quality of life

Figure 3: Classification of AFUR indicators' domains

The list of indicators can be adapted depending on the relevance according to the type of interventions. LCA and LCC evaluation can be applied regardless of the type of intervention.

In this report, the indicators that are mainly relevant to the interventions related to **building energy efficiency improvement** (e.g., insulation installation, window replacement), **energy system changes** (e.g., heat pump installation, district heating network extension), **building components reuse** (e.g., during demolition or change of building usage), **pedestrian and cycling path improvement** (e.g., new lane, urban furniture to improve usage and safety) and **nature-based solutions** (e.g., green roofs, trees, green park) are described. The relationship between these interventions and AFUR indicators are highlighted in Figure 4: Relationships between intervention, consumption indicators, services indicators, economic indicators, and environmental indicators.

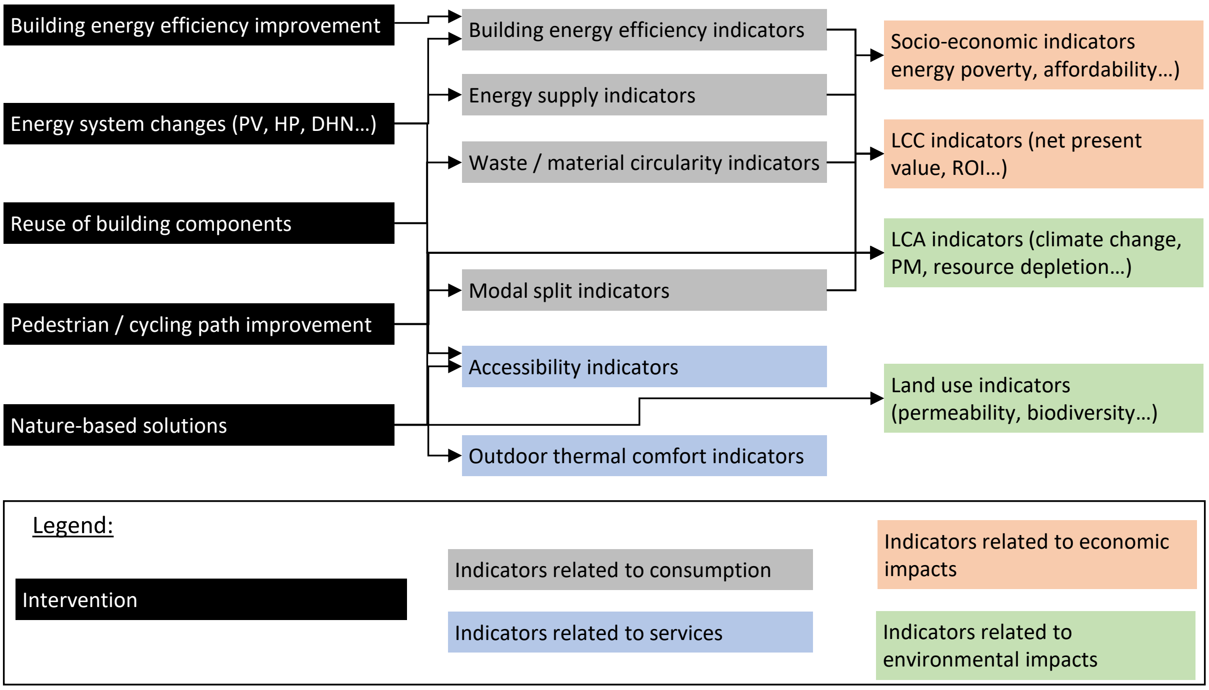


Figure 4: Relationships between intervention, consumption indicators, services indicators, economic indicators, and environmental indicators.

Inspired by the Doughnut Economics approach, the AFUR framework intends to define thresholds for the so-called social foundations (mainly linked to services to society and economic indicators) and ecological ceilings (related to environmental impacts) so that people can satisfy basic needs with a certain comfort without causing an unacceptable level of environmental damage.

Within AFUR indicators, the social ceilings can be represented by indicators related to energy (high-quality homes, renewable energy), accessibility (local economy, community and network), outdoor thermal comfort (healthy spaces) and socio-economic aspects (affordable energy and homes, fair contract, just acquisition).

Ecological ceilings are translated through environmental impact indicators, although energy, circularity, accessibility aspects also contribute to the respect of these ceilings. The global ecological ceilings can be represented by the planetary boundaries, for which Rockström et al. (2009) defined nine key Earth processes with associated metrics for humanity to act within a “safe operating space”. Other authors refer to the carrying capacity of the Earth, i.e. the maximum environmental pressure without irreversible negative changes (Bjørn and Hauschild, 2015). These concepts have been used to understand the environmental pressure of human activities at global scale, but also at national scale or even at smaller scales. In particular, life cycle assessment (LCA) practitioners used these thresholds to understand the absolute environmental sustainability of products or processes. This approach is applied in AFUR (see section 5.2).

2.4 Evaluation system boundaries

AFUR can be applied at different observation levels to support decision-makers:

- **Singular intervention level** to understand the specific benefits and impacts of one action when considered independently and thus support the choice for its implementation or not. If implemented, each singular intervention needs to be integrated and aggregated into a whole site observation level, below.
- **Urban site level** to understand the initial status of the studied area (diagnosis P1) and the combined effects of chosen evaluated interventions considered together. Thus, decision makers will be able to assess more pragmatically the achievement of regeneration objectives.

For each intervention, AFUR evaluation intends to evaluate the effects of:

- Elements required to implement and operate the intervention (e.g., supply of materials, construction works, maintenance)
- Elements already present before that can be affected by the intervention (e.g., building energy consumption, resident transport)

Compared to the baseline scenario, the first type of elements can mainly represent burdens (costs, emissions, new resources used, etc.), while the second type could represent benefits (e.g. energy savings for insulation intervention, avoided cars transport for bike network intervention). However, some of the latter might depend on variable factors such as users' behaviours or energy price. This creates uncertainty due to these behaviours or market effects, and because they generally happen in the future. Thus, employing additional digital tools, social studies or monitoring of the site progress are encouraged to limit such uncertainties.

2.5 Evaluation indicators and thresholds

The list of AFUR indicators (see overview in Table 1), their calculation principles and requirements, and the methods to interpret them via relevant thresholds values are detailed in the next chapters.

Table 1: Overview of AFUR indicators and related thresholds

Category	Indicator	Unit	Thresholds
Energy	Annual thermal energy demand per m^2	kWh/m^2/yr	Class C / Class A
	Annual thermal energy demand per inhabitant	kWh/inh/yr	-
	Renewable energy share	%	T45%
Material Circularity	Share of construction waste recycled	%	70% / 90%
	Share of reused building elements	%	1.5% / 20%
Modal split	Share of daily transport by car	%	

Co-funded by
the European Union

	Share of daily transport by public transport	%	No threshold, to be checked with local regulation / policies
	Share of daily -transport by P2W	%	
	Share of daily transport by soft / active mobility	%	
Accessibility	Walkability within 15 min. to services	%	75% total number of maximum services are accessible (15)
	Walkability within 15 min. to public transport	%	
	Bikeability within 15 min. to services	%	
	Average number of public transport nodes depending on their type and their frequencies within 15 minutes) [3 categories]	#	3 public transports accessible with av. frequency ≤ 10’ OR 5 with av. frequency ≤ 15’
	Safe Pedestrian Streets	%	Average street score of 75%
Outdoor thermal comfort	UTCI (Universal thermal comfort index)	°	
Land use	Soil permeability index	-	0.5
	Soil biodiversity index	-	0.5
Life cycle assessment (LCA)	Climate change	kg CO_2 eq	Application of AESA methodology to allocate planetary boundaries to the studied system
	Ozone depletion	kg CFC-11 eq	
	Human toxicity, cancer	CTUh	
	Human toxicity, non-cancer	CTUh	
	Particulate matter	Disease incidences	
	Ionising radiation, human health	kBq U^{235}	
	Photochemical ozone formation	kg NMVOC eq	
	Acidification	mol H^+ eq	
	Eutrophication, terrestrial	mol N eq	
	Eutrophication, freshwater	kg P eq	
	Eutrophication, marine	kg N eq	
	Ecotoxicity, freshwater	CTUe	
	Land use	-	
	Water use	m^3 world eq deprived water	
	Resource use, minerals and metals	kg Sb eq	
	Resource use, fossil	MJ	
Socio-economic	Energy effort rate	%	< 10%
	Share of housing cost over income	%	< 40%
	Gentrification Risk	-	-
LCC	Net present value	€	< baseline

	Payback period	Year	< baseline
	Net savings	€	>0

3 Consumption patterns indicators

3.1 Energy indicators

Energy used in buildings for heating and cooling is a major source of carbon emissions. Therefore, energy-efficient buildings are highly relevant to saving and achieving sustainability goals, while keeping comfortable indoor environments. In addition to benefiting building occupants, every unit of energy saved contributes at scale, as it reduces the need for generation and distribution. Furthermore, energy-efficient buildings can enhance resilience by meeting a larger share of their needs through on-site renewable sources.

In building certification schemes, the main indicator is annual **primary energy consumption** for typical local climatic conditions, which reflects both the building's thermal performance (i.e., heating and cooling loads) and the efficiency of its energy systems, but also on the type of energy sources used (e.g., gas, electricity, biomass, or on-site renewables). National regulations assign primary energy factors and CO_2 coefficients to each source, which influence the final rating. To be able to compare buildings of similar use, this consumption is normalized per unit of floor area, which is known as **energy intensity (kWh/m²/year)**. This is the key metric used in Energy Performance Certificates (EPCs) across the EU. Depending on national regulations, it may include heating, cooling, domestic hot water, and other uses. On-site energy generation, such as from photovoltaic systems, can be deducted from primary energy as a credit or evaluated separately.

Aligned with these European initiatives, the AFUR framework adopts and employs the **annual primary energy intensity** as the main indicator to evaluate the energy performance of buildings. Depending on the country of application, this indicator can be calculated differently, i.e., integrating different energy demands, as well as energy sources and associated local coefficients. Furthermore, this indicator can be normalized per inhabitant to facilitate individual benchmarking, depending on the availability and quality of data. Finally, the share of renewable energy indicator is useful to represent the effects of potential energy system changes.

Table 2: AFUR energy indicators

Category	Indicator Unit	Unit
Energy	Annual thermal energy demand per m²	kWh/m²/yr
	Annual thermal energy demand per inhabitant	kWh/inh/yr
	Renewable energy share	%

3.1.1 Assessment principles and calculation tools

The building energy performance can be evaluated via several approaches, such as statistics of historical measured data, simulated using physics-based models or more recently relying on novel data-driven approaches via surrogate models. High-quality, long-term, disaggregated data is often scarce, limiting the use of purely statistical or data-driven approaches. Physics-based models also enable the evaluation of virtual scenarios that represent potential future changes, and the possibility of optimizing scenarios without implementing them in reality.

The AFUR framework adopts and employs the physic-based modelling approach, but specifically at the urban scale, which is known as urban building energy modelling (UBEM). Within the REGEN project context, this approach is implemented through two main simulation tools: IES's Intelligent Community Lifecycle (ICL) tools (in particular, intelligent community design – iCD – and intelligent virtual network – iVN), as well as Tecnalia's RENOSTOCK tool.

Physics-based tools simulate energy consumption based on buildings' geometry, uses, characteristics, systems, and local climatic conditions. To facilitate the creation of representative large-scale models at the district and city levels, including several buildings, the UBEM approach employs building archetypes. Thus, these archetypes characterise and represent local or regional common groups of buildings of similar use, age, envelope thermal properties, enabling a scalable setting of the model for large number of buildings. These building archetypes can be defined based on different data sources, such as Tabula building typology webtool[1], ASHRAE building archetypes[2] or national reference databases. In UBEM, heat and mass flows through buildings, as well as other environmental factors, are simulated during a calendar year for typical climate conditions (i.e. typical meteorological years[3]), resulting in estimated energy loads influenced by the building's local environment, physical properties, and user profiles. As a result, detailed information about indoor environmental conditions and building energy needs can be obtained at different timescales (hourly, monthly or annually).

In AFUR, the archetype-based modelling approach for UBEM will be further refined when possible, using 1) local EPC data and 2) measured energy from dwellings. This allows respectively 1) for improvement of the thermal characterisation of the buildings stock and 2) calibration of the model in the second.

3.1.2 Required input data

To develop an UBEM, run energy simulations, and calculate the relevant energy performance indicators, a range of spatial, physical, and environmental data is required. This input data can be grouped into the following categories:

Geometry data

[1] https://webtool.building-typology.eu/#bm
[2] https://www.energycodes.gov/prototype-building-models
[3] https://climate.onebuilding.org/

Defines the physical shape, volume, and spatial arrangement of buildings and is fundamental for constructing the UBEM. Required information includes:

- Building footprints and height, and/or number of floors.
- Roof and façade orientation.
- Building location and context (e.g., density, surrounding shading elements).

This data is typically extracted from cadastral building layers in GIS vector formats (e.g., Shapefile, GeoJSON, GeoPackage), which often include attributes such as number of floors, number of dwellings, and year of construction. While such datasets are often publicly available, they may require preprocessing to ensure completeness and consistency of these attributes.

Thermophysical data

Describes the thermal performance characteristics of the building envelope. These properties are critical for calculating energy transfer and include:

- U-values of external walls, roofs, windows, and floors.
- Glazing ratios and window properties.

In the absence of building-specific data, these values can be inferred from building archetypes based on age, use, and construction type, using national databases or typologies such as TABULA or ASHRAE. In some cases, additional calibration using Energy Performance Certificates (EPCs) can improve accuracy.

Building typologies and use

The function or usage type of a building helps define typical occupancy schedules and internal heat gains. This information may be derived from census records, local surveys, or archetype libraries.

Climate data

Provides the boundary conditions for energy simulations. Required data typically include hourly data for outdoor temperature, humidity, solar radiation, and wind speed, among others. which are characterized in Typical Meteorological Year (TMY) datasets for the location under study. These datasets are commonly sourced from national meteorological agencies or international repositories and are essential for defining heating and cooling loads throughout the year.

Energy Matrix and System Characteristics

Determine how energy is produced, consumed, and converted within buildings. Relevant data include:

- HVAC system types and configurations.
- System efficiencies (e.g., coefficients of performance COP)
- Fuel types (e.g., electricity, gas, biomass).
- On-site renewable energy systems (e.g., photovoltaics).
- Regional or national energy mix, including primary energy factors and CO_2 emission coefficients (e.g., from Eurostat or national energy agencies).

Other Supporting Data

Additional inputs that can enhance model calibration and validation include:
- Energy Performance Certificates (EPCs) with geolocation.
- Measured energy consumption data from utility records, sensors, or bills.

3.1.3 Identified thresholds

The proposed thresholds for the energy indicators are described in Table 3. These first thresholds have been taken from the EU Taxonomy criteria for new buildings, retrofitting as well as acquiring new buildings (Table 4). No threshold is defined for the energy demand per inhabitant since it can be largely influence by the environmental context. This indicator can be useful for benchmarking and for the further environmental impact evaluation aligned with planetary boundaries (see section 5.2).

Table 3: AFUR thresholds for energy indicators

Indicator	Minimum Objective	Regeneration objective
Annual thermal energy demand per m^2	EPC Class C of the country	EPC Class A of the country
Annual thermal energy demand per inhabitant	-	-
Renewable energy share	45%	45%

Table 4: EU Taxonomy criteria related to building energy performance

Type of Activity	Minimum criteria – Do No Significant harm (DNSH)	Advanced criteria – Substantial Contribution (SC)
Construction of new buildings	Net Zero Energy Building (NZEB)	NZEB – 10%
Renovation of existing buildings	-	Reduction in primary energy demand by 30% after renovation
Acquisition and ownership of buildings	EPC Class: C OR Building within 30% of national or regional building stock, expressed in Primary Energy demand	EPC Class: A OR Building within 15% of national or regional building stock, expressed in Primary Energy demand

Given that not all European countries have defined what a Net Zero Energy Buildings means according to their regulation (in our case, only Spain and Ireland have) the Energy Performance Certificate has been chosen as an absolute objective for the baseline. The reduction of 30% in energy demand compared to the existing building will help assess the impact of the interventions.

Concerning the renewable energy share, there is no specific threshold for the EU Taxonomy. EU countries can have different renewable energy plans. The latter should all comply with the EU target for 2030 of minimum 42.5% renewable energy, with the aspiration to reach 45%. This ideal value is thus considered in AFUR to steer urban regeneration towards ambitious sustainability targets.

3.2 Material circularity indicators

Buildings are a major contributor, using vast amounts of concrete, steel, glass, and plastics. A circular economy approach aims to reduce the extraction of new materials and waste generated through production and demolition of built environment infrastructure. Circularity and waste indicators can be particularly relevant for interventions related to the transition towards circular economy.

Within REGEN demo sites, the main circular economy interventions focus on the reuse or valorization of building components when constructing, renovating, deconstructing or changing the functionality of a building or urban infrastructure. There are several methodologies for the calculation of various types of indicators which support circular-economy implementation across various domains. Within the built environment and urban domains, these methods are applied at building scale. Said methodologies and calculator tools investigate the material makeup, their reusability and disassembly potential of building products. The most widely used circularity indicator is the Material Circularity Indicator (MCI) developed under the Ellen MacArthur Foundation (MacArthur, 2015), which has since been adapted by several other tools and research works. MCI scores can be aggregated from a product level to an entire building, scaling linearly. The MCI needs detailed data about the material compositions, ratios of their recycling and generated waste at several stages across the life cycle, for effective calculation. Other support methodologies exist at building level, such as the Reusability Potential (Durmisevic et al. 2021) or design for disassembly indicators, which are more specific to building element levels and in connection with BIM model data.

While the methods and indicators mentioned above can be used to aid decision-making, the key AFUR indicators for material circularity (Table 5) are identified to understand material flows efficiency at site scale.

Table 5. AFUR material circularity indicators

Category	Indicator Unit	Unit
Material circularity	Share of construction waste recycled	%
	Share of reused building elements	%

3.2.1 Assessment principles and calculation tools

Monitoring on site, together with contractor material take-offs reported during construction activities can be used to evaluate material circularity indicators. No specific modelling tools are strictly necessary, but quantity take off tools should be employed to ensure accurate sizing of building elements and waste generated.

3.2.2 Required input data

Quantities of materials by type per construction asset, expressed in mass units (kg or t). The list of material types considered is aligned with the Level(s) framework (Dodd et al., 2021a) description of circularity and waste categories (Dodd et al., 2021a)., not restricted to major ones such as stone, concrete, steel, PVC plastics, etc. The tonnage of material flows on site is then aggregated and reported as a percentage.

3.2.3 Identified thresholds

The proposed thresholds for the waste indicators are listed in Table 6.

Table 6: AFUR thresholds for circularity indicators

Indicator	Minimum Objective	Regeneration objective
Share of construction waste recycled	70%	90%
Share of reused building elements	1,5%	20%

The first indicator is directly taken from the EU Taxonomy. The second one is inspired by the EU project Interreg FCRBE, which had an objective of reusing 1,5% of buildings' elements.

3.3 Modal split indicators

Interventions related to road infrastructure changes, or the implementation of new services can affect the way residents or other users (e.g. workers, tourists) move in the urban area. Urban freight for last-mile logistics can also be affected and represent a challenge for cities. However, this issue is not further investigated within REGEN project.

The modal split of passenger transport, i.e. the share of people's transport according to various transport modes, is thus an important indicator to measure these potential effects. In addition, during diagnosis, it can highlight the dependency on private cars, which is a sustainability issue, from an environmental (associated pollution and resource use) and socio-economic perspective (traffic jam causing stress, space constraint, fuel costs, etc.).

Table 7. AFUR modal split indicators

Category	Indicator Unit	Unit
Modal split	Share of daily transport by car	%
	Share of daily transport by public transport	%
	Share of daily transport by P2W	%

Co-funded by
the European Union

	Share of daily transport by soft / active mobility	%

3.3.1 Assessment principles and calculation tools

The modal split is calculated as the percentage of each mode of transport in the total transport measured in passenger-kilometres (pkm).

At urban scale, the focus is on the transport of people within the area for daily activities (work, school, shopping, leisure…), thus ignoring long-distance transport for holidays. For these daily transport, one can distinguish passenger transport by cars (the latter can be further refined by car types), public transports (train, bus, coaches, metro, tramway), powered-two-wheelers (mopeds, motorcycles) and soft or active mobility (walking, biking, skateboarding…).

Some tools can be used to compile such data, e.g. traffic model (used by AMAT for Milan demo site) or sensors to understand people movements (e.g. Dynicon used in Laredo demo site).

3.3.2 Required input data

Mobility behaviour surveys or traffic data can be used to determine the modal split.

If no specific data are available for the studied zone, Eurostat data[4] can be used as proxy but concern the overall passenger transport by countries (not only daily transport).

3.3.3 Identified thresholds

No threshold has been defined for modal split indicators, but they can be useful to understand the behaviours of residents and the car dependency. Local policies might define objectives related to these indicators and could thus be applied.

4 Services to society indicators

The interventions can bring functionalities related to the quality of life in the neighbourhood. Within the AFUR methodology, two aspects are mainly evaluated: the access to various services (depending on road / mobility infrastructures and on the presence of services in the area) and the outdoor thermal comfort (depending on building geometry, trees and surface typology). Building renovation interventions could also affect the indoor thermal comfort, but the latter is not included here for simplification purpose.

4 https://ec.europa.eu/eurostat/databrowser/view/tran_hv_ms_psmod/default/table?lang=en&category=tran.tran_hv_ms

4.1 Accessibility to services and public transports indicators

These indicators help evaluate the site's provision of local life services and its accessibility to public transport, aiming to minimize the environmental, economic, and social burdens caused by frequent or long trips made by users, especially those relying on private vehicles. Different indicators are included in AFUR for accessibility:

- Walkability to services within 15 minutes
- Walkability to public transport within 15 minutes
- Bikeability to services within 15 minutes
- Quality of walkability within the studied area

The different services categories considered are as follows (cf. Annex II for details):

- Health
- Education
- Culture
- Shops
- Sport
- Leisure
- Local Services
- Green spaces and nature

The different public transport categories considered are the following:

- Bus
- Tramway
- Metro
- Railway

Table 8. AFUR accessibility indicators

Category	Indicator Unit	Unit
Accessibility	Walkability within 15 min. to services	%
	Walkability within 15 min. to public transport	%
	Bikeability within 15 min. to services	%
	Average number of public transport nodes depending on their type and their frequencies within 15 minutes) [3 categories]	#
	Safe Pedestrian Streets	%

4.1.1 Assessment principles and calculation tools

➢ ***Walkability to services and public transport within 15 minutes***

The concept of the 15 minutes city has been promoted in Europe and by the C40 cities worldwide, so that citizens can reach basic services within 15 min walk, reducing the dependency on private cars. If relevant, this time of 15 minutes can be adapted according to the feedback of stakeholders (including citizens), such as 5 or 10 minutes.

At urban scale, this 15-min walkability indicator can be evaluated as follow:

- **Identification of all relevant services and public transport nodes:** Considering a maximum perimeter outside the studied area corresponding to 15-min distance from the area borders, all the services and public transport nodes are identified. This is done via a router based on Open Trip Planner (OTP), Openrouteservice or equivalent. The results obtained are stored as shapefiles, .csv or .geojson formats, to be further treated via GIS tools.
- **Filtering based on the walk time with each address of the area:** For each address in the area, the previously identified services and public transport nodes are filtered to obtain the ones accessible within 15-walk. Typical walking speed can be considered: 1.33 m/s for standard pedestrians; 0.875 m/s for vulnerable pedestrians. Regarding public transport nodes, to avoid considering multiple stops from the same transport line, we can identify the transport lines available at each stop and only compute the walking time to the nearest stop.
- **Average number of accessible services and public transport of the area:** The average of accessible services or public transport is calculated for each category for the addresses located in the studied area. When available, this score can be further weighted by the number or surface of dwellings, or by the number of residents at each address (see Eq. 1).

Eq. 1
$$n\_services_{average,catj} = \frac{\sum_i n\_services_{i,catj} \times w_i}{\sum_i w_i}$$

With:
- $n\_services_{average,catj}$: average number of accessible services for the category *j* [unit]
- $n\_services_{i,catj}$: number of accessible services for the category *j* for the address *i* [unit]
- w_i: weighting factor for the address *i*, which can be the number of dwellings, their surface, or the number of residents in address *i* [m^2 or unit]. If such more specific data is not available, $w_i = 1$.

The same equations are valid to calculate the number of accessible public transport nodes for each public transport category k $n\_pt_{average,catk}$.

- **Aggregation of all categories scores:** A unique score can be obtained to aggregate all the categories of services and public transport. To avoid considering the over-representativeness of some services, a maximum number of accounted services or public transport nodes is defined for each category ($n\_services_{max,catj}$ *or* $n\_pt_{max,catk}$). If the average number $n\_services_{average,catj}$ or $n\_pt_{average,catk}$ overpasses this threshold, the threshold ($n\_services_{max,catj}$ or $n\_pt_{max,catk}$) is considered instead. In addition, a further weighting factor can be applied on each category depending on the estimated importance by stakeholders. For public transport, a minimum frequency of 10 min is considered to be sufficient for a service of quality. The ratio between this ideal frequency and the minimal one within the category of transport for the accessible stops is applied to refine the calculation.

Eq. 2
$$Walkability\ (services) = \frac{\sum_j \min\left(n_{services_{average,catj}}; n_{services_{max,catj}}\right) \times w_j}{\sum_j n_{catj} \times w_j}$$

Eq. 3
$$Walkability\ (transport) = \frac{\sum_k \min\left(n\_pt_{average,catk}; n\_pt_{max,catk}\right) \times \frac{f_{ideal,catk}}{f_{min,catk}} \times w_k}{\sum_k n_{catk} \times w_k}$$

With:

- w_j: weighting factor for the category of services *j* (see Table 9) [-]
- w_k: weighting factor for the category of public transport *k* (see Table 10) [-]
- n_{catj}: number of categories of services considered (= 8 in REGEN)
- n_{catj}: number of categories of public transport considered (= 3 in REGEN)
- $f_{ideal,catk}$: ideal frequency for the public transport category k [= 10 min in REGEN]
- $f_{min,catk}$: minimum frequency for the accessible stops for the public transport category k [min]

The parameters used in REGEN to apply the equations 1, 2 and 3 are described in the Table 9 and Table 10. The latter can be adapted according to the context and stakeholders' feedback. For instance, a neighborhood focusing on welcoming young families, could increase the impact factor/accounted services for education and leisure. On the other hand, a neighborhood with vulnerable people might want to increase the importance given to health services.

Table 9: Values of parameters applied in REGEN to calculate the walkability to services

Categories of services *j*	**Number of maximum accounted services *n_services*$_{max,catj}$**	**Weighting factor w_j**
Health	1	1
Education	1	1
Culture	1	1
Shops	4	1
Sport	2	1
Leisure	2	1
Local Services	2	1
Green spaces and nature	2	1

Co-funded by
the European Union

Table 10: Values of parameters applied in REGEN to calculate the walkability to public transport

Categories of public transport *k*	**Number of maximum accounted stops $n\_pt_{max,catk}$**	**Weighting factor w_k**	**Ideal frequency $f_{ideal,catk}$**
Bus lanes	5	1	10'
Tramways	5	1	10'
Metro lines	5	1	10'

➢ ***Bikeability to services within 15 minutes***

For bikeability, the same approach than for walkability is applied. The only difference is that the considered speed is different, which differs depending on the street type (going from 6 km/h for a pedestrian route to 18 km/h for a cycle path or a motorway).

➢ ***Quality of walkability within the studied area***

To foster pedestrian mobility, it is crucial to ensure that walking paths are safe and comfortable. The parameters to characterize the safety of a street have been chosen from a review of literature and certification schemes. Rhoads et al. (2023) proposes 3 parameters to define a street's safety: the sidewalk's width, the slope, as well as the possible hazard. The latest has been excluded because it requires image processing from public security cameras. Bartzokas-Tsiompras et al. (2023) and Basu et al. (2023) considered other factors such as pedestrian crossings, the sidewalk or streetscape environment, the sidewalk continuity or speed limits. Comfort parameters such as shading or outdoor thermal comfort index could also be included. Considering data availability and processing feasibility, the following parameters are considered in AFUR:

- Street slope
- Width of the sidewalk
- Speed limit
- Distance to closest crosswalk

These parameters could evolve depending on data accessibility, resident's or municipality's feedback. This would nevertheless imply to add a scoring system for each added parameter (see below).

The calculation steps for the quality of walkability are:

- **Determination of the safety parameters for each street segment (50 m length):** This includes the calculation of the average slope between the starting and ending point of the segment ($p_{slope,i}$), of the minimum width of the segment's sidewalk ($p_{width,i}$), of the maximum segment's speed limit ($p_{speed,i}$) and of the closest crosswalk ($p_{cross,i}$).
- **Attribution of a safety score depending on the parameters value:** A score S_i between 0% and 100% is attributed according to the value of each category of parameter (see Table 11).

Table 11: Correspondence between safety score and the value of parameter

Safety score S_i	**0%**	**50%**	**75%**	**100%**
Distance between crosswalks [1]	≥ 200 m	[100; 200] m	-	<100 m
Slope [2; 3]	≥ 4.5° (7.87%)	[3.5; 4.5] ° [6; 7.87] %	[1.0 ; 3.5] ° [1,75: 6] %	< 1° (1,75%)
Street Speed Limits [4]	≥ 50 km/h	[30;50] km/h	-	< 30 km/h
Sidewalk's width [2]	< 1.8 m	[1.8; 2.5] m	-	≥ 2.5 m

[1] (City of New Yor, 2010) and (Officials NA of CT et al., 2016)/ [2] (Ministerio de Transportes, Movilidad y Agenda Urbana, 2021)/ / [3] (Rhoads, 2023) / [4] (Basu, 2023)

- **Average of safety scores for each segment:** The average between all safety scores for each segment is calculated (Eq. 4) and can be visualized to support urban regeneration process.

Eq. 4
$$Safe\ walkability_i = \frac{S_{slope,i} + S_{width,i} + S_{speed,i} + S_{cross,i}}{4}$$

4.1.2 Required input data

The calculation of accessibility indicators requires the following GIS files:

All indicators:

- Open Street Map navigable networks file for each site as well as other necessary information (speed limits)
- For projects that have a heterogeneous topography with important differences in altitude: Digital Surface Model file, through national databases

Walkability and bikeability indicators:

- GIS file with household postal addresses (GeoJSON file). These files can be obtained from different sources, such as national databases (cadastre).
- Open Street Map service categories, retrieved as points in a shapefile or a GeoJSON using a tool like the QGIS plugin QuickOSM. The categories and subcategories taken into account in the calculation can be found on Annex II
- General Transit Feed Specification (GTFS) datasets provided by national agencies or specific transport networks providers within each project[5] to determine public transport stops and routes.

Quality of walkability indicator:

[5] Demosite's data
- Dublin's GTFS: https://www.transportforireland.ie/transitData/PT_Data.html
- Milan's GTFS: https://www.transportforireland.ie/transitData/PT_Data.html
- Spain's GTFS: https://nap.transportes.gob.es/

- GIS files characterizing the speed limits, sidewalk's width (either from field observations or satellite observations) as well as the crosswalks

4.1.3 Identified thresholds

Although no national or European thresholds exist, a minimum level of accessibility is suggested for each indicator based on the framework review (Table 12).

Table 12: AFUR thresholds for accessibility indicators

Indicator	Threshold
Walkability to services in 15 minutes [8 categories]	On average, at least 75% of the total number of maximum services are accessible (15)
Bikeability to services in 15 minutes [8 categories]	
Walkability to public transport in 15 minutes [3 categories]	At least 3 public transports with an average frequency ≤ 10' OR 5 public transports with an average frequency ≤ 15'
Safe Pedestrian Streets	On average, street segments have a score of 75%

4.2 Outdoor thermal comfort indicators

Interventions modifying the shape / surface materials of urban infrastructures and the ones related to the implementation of nature-based-solutions can affect the outdoor thermal comfort. AFUR thus includes this aspect which is related to the well-being in urban areas.

The universal thermal comfort index (UTCI), expressed in degrees, intends to quantify the thermal stress perceived by people based on various parameters (temperature, humidity, wind speed, reference conditions…) and is supposed to be applicable for any conditions. UTCI can be interpreted via ranges of thermal stress categories. This indicator is applied in AFUR since it can be quite easily applied and replicated.

Table 13. AFUR outdoor comfort indicators

Category	Indicator	Unit
Outdoor thermal comfort	UTCI	°C

4.2.1 Assessment principles and calculation tools

UTCI provides the apparent temperature perceived by people based on a human thermoregulation model, a clothing insulation model and the environmental conditions (air temperature, wind, humidity and radiation).

Within REGEN, UTCI is simulated via ICL tool developed by IES. Within ICL, the 3D and 2D digital model objects (buildings, trees, ground surfaces) are geolocated to simulate the influence of radiance on their surfaces, based on surface albedo. The mean radiant temperature (MRT) for a single point 1.5 meters off the ground is then estimated for each square meter of the studied area. These data are processed to calculate the probable UTCI score for each square meter for the desired time of the year (i.e. 21st of June at 12:00, 2025).

4.2.2 Required input data

The UTCI calculation requires data regarding the urban object shapes and surface types, as well as local weather files (epw, TMY). The surface types can be gathered from OSM and other sources (site's model). The parameters considered for the calculation of the UTCI via ICL are as follows:

- From the exterior surfaces: albedo and mean radiant temperature (MRT)
- Sky view factors
- Local wind speed

4.2.3 Threshold definition for sustainable urban regeneration

Table 14: AFUR thresholds for outdoor thermal comfort indicators

Indicator	Minimum objective	Regeneration objective
UTCI	-	<26°C

The UTCI stress categories highlight that above 26°C, there is a moderate heat stress (becoming strong above 32°C). On the contrary, a moderate cold stress appears below 0° (becoming strong below -13°C).

5 Environmental impact indicators

5.1 Land use indicators

Several land use indicators can be used understand the site ecological resilience and reflect the effects of some interventions (in particular nature-based solutions): soil permeability index, biodiversity coefficient, type of soil, conserved buildings during regeneration, etc. With useability considerations and effort requirements in mind, AFUR focuses on soil permeability index and biodiversity as they require low calculation efforts.

Table 15. AFUR land use indicators

Category	Indicator	Unit
Land use	Soil permeability index	-
	Soil biodiversity index	-

5.1.1 Assessment principles and calculation tools

The soil permeability index or the biodiversity index of a site is the ratio between the sum of weighted surface types and the total site area (see Eq. 5). The type of soil surface is classified according to their capacity to infiltrate water (for the permeability index) or to host biodiversity (for the biodiversity index).

Eq. 5
$$\begin{cases} SPI = \dfrac{\sum_i PC_i \times A_i}{A_{total}} \\ SBI = \dfrac{\sum_i BC_i \times A_i}{A_{total}} \end{cases}$$

With:
- *SPI*: soil permeability index of the site [-]
- *SBI*: soil biodiversity index of the site [-]
- PC_i: permeability coefficient for soil surface type *i* [-]
- BC_i: biodiversity coefficient for soil surface type *i* [-]
- A_i: area of soil surface type *i* [m^2]
- A_{total}: total area of the site [m^2]

To determine the value of permeability and biodiversity coefficients, a review of European certification schemes was performed. These coefficients were found in the German framework DGNB[6] and the French framework (HQE[7] and the recently published CBSh – "coefficient de biotope surfacique harmonisé" i.e. harmonized area-based biotope coefficient – via CAP2030 working group on biodiversity[8]) frameworks provide tables.

For permeability coefficients, the DGNB list was taken as reference thanks to its easiness to use, but the HQE coefficients for roof types were added in order to consider potential different roof typologies (Table 16).

Table 16: List of permeability coefficients (PCi in Eq. 5)

Soil type	Permeability coefficient
Full sealed land (e.g. tarmac, concrete)	0.0

[6] https://static.dgnb.de/fileadmin/dgnb-system/en/buildings/new-construction/criteria/02_ENV2.3_Land-use.pdf for permeability; https://static.dgnb.de/fileadmin/dgnb-system/en/districts/criteria/DGNB-Criteria-Districts-ENV2_4_Biodiversity.pdf for biodiversity
[7] https://www.hqegbc.org/wp-content/uploads/2022/02/HQE-Amenagement-Part2-17-HD.pdf
[8] https://www.planbatimentdurable.developpement-durable.gouv.fr/les-livrables-de-la-1ere-phase-des-groupes-de-a1694.html

Water-bound cover (paths and roads, squares and other large, open plots, entrances and driveways, etc.)	0.2
Spaced paving with grass jointing and similar ground coverings, drain paving	0.3
Grass pavers	0.5
Gravel/stone chippings	0.6
Lawn on gravel	0.7
Impermeable roof	0
Extensive green roof (substrate depth below 15 cm)	0.3
Semi-intensive green roof (substrate depth between 15 and 30 cm)	0.4
Intensive green roof (substrate depth above 30 cm)	0.6

For biodiversity coefficients, both the list of DGNB and of the new harmonised French calculation via CBSh are very detailed, contrarily to the HQE framework. To simplify the calculation, HQE coefficients are chosen, but adapted for some soil type to be more aligned with CBSh values (Table 17).

Table 17: List of biodiversity coefficients (BCi in Eq. 5)

Soil type	**Biodiversity coefficient**
Impermeable surface (concrete, bitumen...)	0.0
Semi-impermeable surface without vegetation (clinker, sand, gravel...)	0.1
Semi-open surface including vegetation (wooden slab, lattice stone...)	0.2
Green space on slabs with soil depth below 80 cm	0.5
Green space on slabs with soil depth above 80 cm	0.65
Green space on natural soil	0.7
Conventional roof leading to rainwater runoff to planted soil	0.2
Green façade (at least 12 cm of substrate)	0.2
Green roof (at least 12 cm of substrate)	0.5

While these coefficients are applied in REGEN to harmonize calculation across demo sites, these values could vary depending on the local context and applicable frameworks.

The calculation is made thanks to GIS treatment of the exterior surface characterization: classification based on the categories of Table 16 and Table 17; and attribution of the corresponding coefficients. When a surface type does not correspond exactly to a pre-defined category, a conservative approach is applied (lowest applicable coefficient).

For rural area (as for Beckerich demo site), a buffer zone is suggested to avoid considering the whole village area with many green areas such as agricultural fields in the calculation. A distance of 100 m with the constructed areas is considered for this buffer zone, and the calculation is applied on this restrained area (see example in Figure 5).

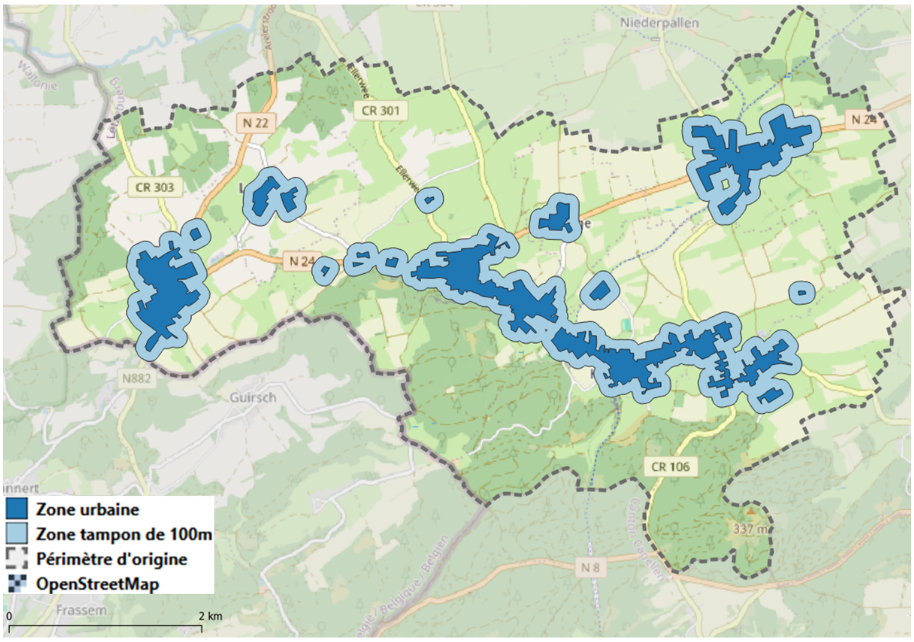


Figure 5: Example of buffer zone application for rural area for Beckerich demo site (urban area in dark blue; buffer zone to restrain calculation to 100 m distance from urban area in light blue; and original demo site perimeter with dotted line).

5.1.2 Required input data

The calculation of land use indicators requires GIS files of the studied site characterizing the exterior surfaces, such as Land Use and Land Cover maps. For instance, the pan-European CORINE Land Cover dataset developed by Copernicus Land Monitoring Service[9].

5.1.3 Identified thresholds

The interpretation of these land-use indicators is based on the points systems of DGNB and HQE. Both frameworks attribute a maximal score if the permeability is equal or above 0.5. This threshold is also used by HQE for biodiversity index while the DGNB framework applies a lower value of 0.35.

Following an ambitious regeneration approach, the threshold value of 0.5 is taken in REGEN for both permeability and biodiversity index to be considered as sustainable urban regeneration.

Table 18: AFUR thresholds for land use indicators

Indicator	Minimum objective	Regeneration objective
Soil permeability index	0.35	0.5
Soil biodiversity index	0.35	0.5

[9] https://land.copernicus.eu/en/products/corine-land-cover

5.2 Life cycle assessment (LCA) indicators

LCA methodology can be applied to any kind of interventions to assess their environmental impacts, following a comprehensive life cycle perspective. LCA is nevertheless less relevant for non-tangible interventions such as awareness campaign, even if the environmental impacts related to the supply of dissemination materials could still be evaluated. At European level, the Environmental Footprint (EF) method[10], which can be applied to products (PEF) or organisations (OEF) is the harmonized approach, applied in various certification or recognized assessment frameworks such as Level(s) (Dodd et al., 2021b). The related indicators from version 3.1 (Table 19) are applied in AFUR method. Their application and unit of reference (e.g. kg CO_2 eq/m^2, kg CO_2 eq/pkm or kg CO_2 eq/kg) depends on the studied intervention. At urban scale, results can be aggregated to represent the whole impacts of inhabitants (e.g. kg CO_2 eq/inh).

Table 19: LCA indicators (from EF 3.1 method)

Impact category	**Indicator**	**Unit**
Climate change	Radiative forcing as global warming potential	kg CO_2 eq
Ozone depletion	Ozone depletion potential	kg CFC-11 eq
Human toxicity, cancer	Comparative toxic unit for humans	CTUh
Human toxicity, non-cancer	Comparative toxic unit for humans	CTUh
Particulate matter	Human health effects associated with exposure to PM2.5	Disease incidences
Ionising radiation, human health	Human exposure efficiency relative to U^{235}	kBq U^{235}
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq
Acidification	Accumulated exceedance	mol H^+ eq
Eutrophication, terrestrial	Accumulated exceedance	mol N eq
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment	kg P eq
Eutrophication, marine	Fraction of nutrients reaching marine end compartment	kg N eq

[10] https://green-forum.ec.europa.eu/environmental-footprint-methods/life-cycle-assessment-ef-methods_en

Ecotoxicity, freshwater	Comparative toxic unit for ecosystems	CTUe
Land use	Soil quality index	-
Water use	User deprivation potential	m^3 world eq deprived water
Resource use, minerals and metals	Abiotic resource depletion	kg Sb eq
Resource use, fossil	Abiotic resource depletion – fossil fuels	MJ

5.2.1 Assessment principles and calculation tools

The ISO standards 14040/44 define four main LCA steps: i) goal and scope definition, ii) life cycle inventory (LCI), iii) life cycle impact assessment (LCIA), and iv) results interpretation.

The first step includes key elements of the evaluation which are the definition of the functional unit, the system boundaries and the main modelling principles.

The **functional unit**, i.e. quantified reference function which reflects the main performance of the system, allows comparing equivalent systems. The modelling of input and output flows, as well as the results, are normalized according to the reference flow used to satisfy the functional unit. When referring to a specific equipment, material or process, a functional unit commonly refers to the unitary output flow (e.g., 1 m^2, 1 km, 1 kWh), with the relevant performance characteristics (e.g., lifetime, thermal resistance). At urban scale, the comparison of scenarios usually involves several functions (e.g. provision of housing, energy, food, logistics). Expressing the function according to the services provided to citizens on an annual basis (see examples in Table 20), when possible, is interesting to compare results with other sites or with national targets or planetary boundaries. For example, the functional unit for building renovation intervention can be “the annual use of residential buildings occupied by 320 residents with minimal thermal comfort”. Different building typologies can be thus compared, even with different energy performances or residents’ behaviours (e.g. overheating due to lower energy bills).

Table 20: Examples of functional unit depending on intervention type

Intervention type	Examples of functional unit
Building energy efficiency improvement	- Annual use of buildings occupied by 100 residents with minimal thermal comfort - Building annual impacts normalized to 1 m^2 of useable space
Energy system changes	- Annual supply for the electricity demand of 100 residents - Supply of 1 kWh of electricity (low voltage)
Reuse of building components	- Annual management of construction materials of 1000 m^2 of buildings

	- Disposal of 1 tonne of construction / demolition waste
Pedestrian / cycling path improvement	- Annual transport of 100 residents to basic services - Transport of 1 passenger-kilometre (pkm)
Nature-based solution	- Annual management of 500 m^2 of land, exposed to specific environmental conditions

The **system boundaries** are defined for each intervention and demo site, following a holistic approach, i.e. including all flows and processes that could be affected by the intervention. Some exclusions could be done when justified (e.g., negligible impacts, mass flow lower than 1%). When applied to buildings or its components, one can refer to the module terminology defined in EN 15978 (LCA of buildings) and EN 15804+A2.

Regarding **other key modelling principles**, the treatment of multi-functional systems follows ISO 14044 hierarchy (subdivision in priority, followed by allocation based on physical causality or on other characteristics if not feasible). The "polluter pays" approach is considered, i.e. allocating the impacts of waste treatment to the waste producer, until it is not considered waste anymore (e.g. metal scrap, sold as raw material).

The **life cycle inventory (LCI)** step consists in collecting data to quantify the input and output flows for the specific processes included in the defined system boundaries. These so-called foreground data are complemented with generic data from LCA database (e.g. ecoinvent), also called background data, to represent the supply chain of inputs (e.g. electricity supply) or waste disposal of outputs (e.g. landfill of construction waste). The sources of data used depends on the assessed interventions (see section 5.2.2).

The **life cycle impact assessment (LCIA)** step consists of translating the emissions of pollutants and use of natural resources into environmental impacts (e.g. climate change, toxicity), via so-called characterization factors (CF, e.g. the CF of methane for climate change impact indicator is equal to 29.8 kg CO_2 eq/kg methane emitted). As stated above, for AFUR evaluation, the CFs from the Environmental Footprint (EF) method – recommended by the European Commission and covering 16 impact categories – are used.

The **results interpretation** depends on the objectives of the study. For AFUR evaluation, a comparison with the allocated planetary boundaries is performed in order to understand the "absolute" environmental sustainability of the interventions and thus better support decision makers towards sustainable regeneration (see section 5.2.3).

To perform LCA calculation, the open-source software package Brightway2[11] will be mainly applied, in combination with the ecoinvent database. Inventory datasets will be created to describe the interventions in each domain (built environment, energy systems, mobility and material circularity). These LCI data will be integrated and

[11] Introduction to Brightway2 — Learn Brightway

results aggregated according to the regeneration scenarios evaluated. This unified LCA evaluation will ensure correct consideration of background data and flows.

For the evaluation of trees as nature-based solution intervention, NBenefit$ tool will be applied (Babí Almenar et al., 2022). The latter follows the modelling principles mentioned above (e.g. "polluter pays" approach). The tool follows a methodological framework that was specifically developed to account for both the positive (ecosystem services) and negative (emissions and resource used) impacts of nature-based solution implementation (Babí Almenar et al., 2023). Following this methodological framework, NBenefit$ simulates the life cycle of urban tree archetypes from the implementation phase (tree nursery, site preparation, planting), the operational phase (irrigation, pruning, litter removal, replanting) and end of life (tree removal, transport to end of life location as landfill, biogas plant, compost producer). The archetype is a specific combination of site conditions, tree species, management, and end of life scenario (e.g., one archetype could be a holm oak tree in Milan, planted on paved ground, with sandy soil, irrigation, low intensity pruning, medium intensity litter removal and landfilling). The simulation of the archetype is done based on a dynamic system model considering the interactions between local climate (temperature, precipitation, wind, air pollution), soil characteristics (texture), and management over a period of 50 years. The archetypes are then combined via a user interface to define the nature-based solution implementation project. The LCA calculations are done by tracking all human activities related to the implementation and management of the nature-based solutions, which are then coupled with an ad-hoc life cycle inventory. NBenefit$ computes then the environmental impacts in biophysical units as well as the social costs related to these impacts.

Other LCA tools (e.g. SimaPro, LCA for Experts, OpenLCA, OneClickLCA, see Annex I) could also be used. In REGEN, the use of Brightway2 software package allows a flexible integration of various data, including the coupling with e.g. energy simulation tool, while NBenefit$ is specific for the evaluation of trees.

5.2.2 Required input data

As mentioned in the previous section, the required input data depends on the evaluated intervention.

- Building energy efficiency improvement
    - Building characteristics to be able to normalize data to the defined functional unit (e.g. m^2 of floor area, number of residents)
    - Amount and performances of the new or changed components, e.g. area of wall insulation with associated R-value or area of replaced window with associated U-value. The life cycle impacts of these building components can be further modelled via Environmental Product Declaration (EPD) if available.
    - Thermal energy consumption (heating and cooling), before and after the intervention. Such data could come from the energy simulation model (see section 3.1).

  - Thermal energy supply mix (share of energy supply by source) to model the impacts of this supply. Such data could come from the energy simulation model (see section 3.1).
- Energy system change
  - Amount and characteristics of the new or changed components, e.g. area of PV panel installed with associated power or number of heat pump installed with associated power. The life cycle impacts of these energy systems can be further modelled via Environmental Product Declaration (EPD) if available.
  - Thermal energy supply mix (share of energy supply by source), before and after the intervention. Such data could come from the energy simulation model (see section 3.1).
- Reuse of building components
  - Amount and disposal shares of building components, conventionally and for the new intervention scenario, e.g. 500 kg of carpet waste with a conventional scenario of 80% landfill and 20% incineration, and a new scenario of 50% reuse, 40% landfill and 10% incineration.
  - Characteristics of the reuse scenario, in terms of reconditioning processes (e.g. energy consumption for polishing), transport (on-site or off-site reuse with associated distance and transport mode) and application (avoided virgin materials / components).
- Pedestrian / cycling path improvement
  - Area characteristics to be able to normalize data to the defined functional unit (e.g. m^2 of studied area, number of residents/users)
  - Amount and characteristics of the new or changed road infrastructures, e.g. dimensions (length, area) of the cycling path and dimensions of the removed road.
  - Daily distance travelled by residents, before and after the intervention (e.g. in pkm/year).
  - Modal split for daily transport, expressed in share of pkm for each transport mode, before and after the intervention
- Nature-based solutions (trees)
  - Characteristics of the environment (site characteristics, area, soil texture, temperature and precipitation data, air pollution data).
  - Number and characteristics of trees (species, initial age, initial size).
  - Trees management characteristics (plantation, pruning, irrigation, waste management).

The level of details and representativeness (geographically, temporally and technically) for these data can vary. The more specific and detailed the obtained data is, the better the quality of evaluation will be. The above listed data represent the minimum ones to gather, even if they are based on assumptions. Additional data could be collected to refine the evaluation, such as the location of materials suppliers, the specific energy consumption for the construction works or the specific mass of fertilizers used for NBS management.

Some input data can be quite uncertain, in particular the ones that depend on users' behaviours (e.g. building energy saving depending on the indoor temperature setting choices). Alternative scenarios can be explored to reflect this uncertainty (e.g. optimistic vs. pessimistic scenarios) and can also be fed with surveys on residents' preferences. In REGEN, the surveys developed by LISER partner could be used to explore alternative scenarios depending on users' behaviour. The parametrization of the LCI model facilitates the update and analysis of results, e.g. for scenarios exploration or to calculate break-even points (threshold value for key parameter to start generating environmental benefits).

5.2.3 Threshold definition for sustainable urban regeneration

For LCA methodology, absolute ecological thresholds, e.g. related to planetary boundaries or other guidance (e.g. WHO recommendations for PM exposure), can be applied within an emerging approach called absolute environmental sustainability assessment (AESA).

AESA intends to calibrate environmental impacts results with absolute reference value in order to understand the risk level to cause deleterious or catastrophic environmental change. This risk aspect is usually not considered in LCA where the results can be interpreted to understand if a system is better than another but not if it is good enough to maintain sustainable conditions on Earth.

The steps to implement life-cycle methods for AESA were formalized by Bjørn et al. (2020): i) evaluation of the environmental impacts of the studied system; ii) quantification of the carrying capacity for the assessed impacts (also called budget or safe operating space); iii) allocation of the latter to the studied system; and iv) comparison of the environmental impacts of the studied system with the allocated carrying capacity to interpret the results (Figure 6).

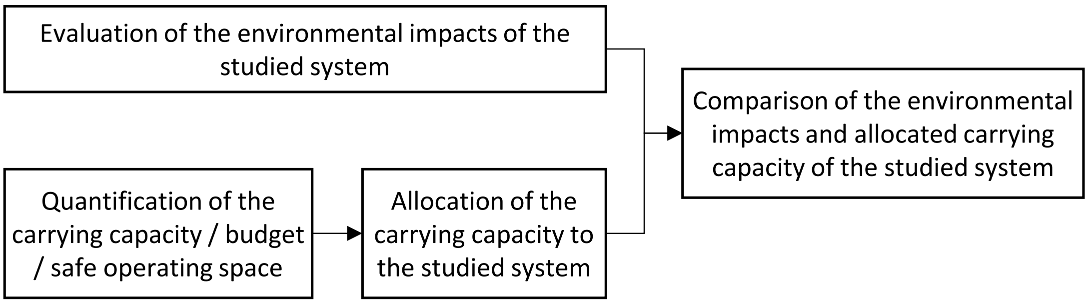


Figure 6: Overall framework to apply life cycle methods for AESA (inspired by Bjørn et al., 2020)

For AFUR approach, the following principles are applied for each of these steps.

- **Evaluation of interventions impacts**

While some AESA studies considered the impact assessment method developed by Ryberg et al. (2018) based on the planetary boundaries' units defined by Rockström et al. (2009), the conventional LCA units implemented via EF method (see section 5.2) are applied in AFUR to facilitate the understanding of involved stakeholder (e.g. kg CO_2 eq unit is more known than W/m^2 of energy imbalance for climate change impacts). This step is carried out following the modelling principles defined in section 5.2.1, taking care of considering an annual basis for the functional unit definition and if possible, the service provided to people (see examples in Table 20Table 20) to follow Ryberg et al. (2020) recommendations.

Co-funded by the European Union

- **Definition of carrying capacity**

Sala et al. (2020) defined the global carrying capacity of each indicator included in the EF v2.0 method. These values were updated by Lund et al. (2025) to be compatible with EF v3.1 method. The uncertainty ranges defined by Sala et al. (2020) can also be used to analyse the potential results variability.

- **Allocation of carrying capacity**

The assignment of the carrying capacity of the studied system can be done via one or several allocation methods, which follow sharing principles according to ethical values, thus involving subjective choices, such as:

- Egalitarian principle mainly applied via equal per capita approach
- "Acquired rights" or "grandfathering" principle based on historical impacts of the studied system (e.g. energy or GHG emissions share of the sector)
- Ability to pay based on GDP shares (usually applied for country allocation)
- Utilitarian approach commonly applied via the share of final consumption expenditures (FCE) for a specific sector within a country
- Sufficientarianism based on a "reasonable" share to satisfy human needs, which can be based on impact shares for a scenario which respect planetary boundaries while respecting decent living standards (Kromand et al. 2025).

Several approaches can be combined depending on the allocation scale. Following the recommendations of Ryberg et al. (2020), the first sub-step for AFUR is to downscale the global carrying capacity at national scale based on the equal per capita approach. This approach can also be applied to focus on the studied area, e.g. number of inhabitants of the studied site.

Due to the subjectivity of the sub-steps to allocate to the specific studied system (e.g. energy supply, building operation, daily transport), different approaches will be tested to understand the range of AESA results. Utilitarian and sufficientarianism approaches could be preferred to reflect the provided services and/or basic human needs. The latter could also be compared to the commonly used approach based on acquired rights. Data required for these allocation steps (GHG emission share, FCE share) are usually available at sectoral level. The further allocation to the specific function of the intervention could require additional data or assumptions, e.g. share of heating energy consumption within residential energy consumption, the share of passengers transport dedicated to local services access. Data used for these allocation steps will be consistently selected (as much as possible), e.g. based on the same reference year, in accordance with the scope of the evaluation.

- **Comparison of impacts and allocated carrying capacity**

In order to analyse the obtained results, sensitivity and uncertainty analyses will be performed (as recommended by Andersen et al., 2024) to understand the robustness of conclusions, despite the various assumptions and AESA subjectivity.

Aligned with the recommendations of Bai et al. (2024), Goodwin et al. (2021) and Bjørn et al. (2020), the evaluation will be made in a transparent manner to facilitate the further communication of the results, highlighting the potential limitations of the conclusions, and eventually the replicability of the results.

6 Economic impact indicators

6.1 Socio-economic indicators

The regeneration interventions can have various socio-economic impacts. Indeed, the changes of buildings components, energy system or urban infrastructures (e.g. mobility solutions, NBS) can affect the expenses of the population, but also their social characteristics (e.g. if a greater attractiveness of a neighbourhood leads to higher housing prices and thus gentrification effect). Within AFUR method, three aspects are considered for socio-economic indicators, listed in the table below.

Table 21. AFUR socio-economic indicators

Category	Indicator	Unit
Socio-economic	Energy poverty	%
	Housing affordability	%
	Risk of gentrification	-

6.1.1 Assessment principles and calculation tools

➢ ***Energy poverty***

Energy poverty is usually measured via the energy effort ratio (EER), i.e. the share of household's annual energy bill compared to its annual income. This indicator is considered in AFUR methodology.

The energy consumption computed via simulation tools (see section 3.1), alternatively complemented by statistical data (e.g. to cover consumption related to lighting or other electric / electronic devices), are combined with energy price to calculate the household's annual energy bill.

The calculation of the energy effort ratio can be performed at different granularity levels depending on data availability, e.g. using geo-spatialized income data or average ones for the area.

➢ ***Housing affordability***

Similarly to the energy poverty indicator, the share of housing cost in total disposable income is considered in AFUR to understand the overburden rate related to this category of costs.

No tool is required for this calculation and the representativeness of the indicator depends on the quality of collected data.

➢ ***Risk of gentrification***

Gentrification is the process of displacement of low-income households outside a neighborhood and replacement by households with higher revenues, due to the increased attractiveness / value of a neighborhood. The regeneration of urban areas can lead to such effects, as it often correlates with increased better quality of life in regenerated the area (energy-efficient buildings, green areas, accessible services...).

The gentrification process can be measured via several parameters (e.g. residents' characteristics, housing market, economic activities, safety). Since it is a process occurring over time, it is important to measure the evolution of these parameters in time to understand the level of gentrification risk.

Within AFUR, to simplify this assessment, the temporal evolution of three key parameters is considered:

- Households' income (via specific income data or via the applied social classes in the country)
- Residents' education attainment
- Real estate pricing

Other parameters, such as the residents' age, ethnicity, vacant buildings, capital investments, economic businesses or crime rate, could be considered when relevant and available.

To understand the risk level, it is important to identify the evolution trend over a sufficiently long period, e.g. during the last 5 to 10 years. Increase of households' income, education attainment and/or real estate pricing would represent the beginning (or continuation) of the gentrification process.

6.1.2 Required input data

To calculate the previously described socio-economic indicators, the required data are:

- Household energy consumption and associated costs (which can be derived from energy simulation tools)
- Housing costs (rent or loan) and real estate price
- Socio-economic characteristics of the population including at least their annual income and education attainment, if possible, over at least the last 5 to 10 years (to evaluate gentrification risk),

Apart from the energy consumption, the other required data can be obtained from municipal, regional or national statistics. The quality and level of detail obtained for these data will influence the representativeness of results and thus the quality of the conclusions.

6.1.3 Identified thresholds

For gentrification risk, the interpretation of the indicators depends on the obtained temporal trends and on the knowledge of local experts. No threshold definition is feasible.

For energy poverty, different thresholds exist for the reasonable share of energy expenses[12], often around 10 %. This threshold of 10 % is thus chosen for AFUR methodology.

For housing affordability, Eurostat considers an overburden if the share of housing costs is higher than 40%[13]. This value is thus applied for AFUR.

[12] https://www.odyssee-mure.eu/publications/policy-brief/measuring-energy-poverty.pdf
[13] https://ec.europa.eu/eurostat/cache/digpub/housing/bloc-2b.html?lang=en

Co-funded by the European Union

Table 22: AFUR thresholds for socio-economic indicators

Indicator	Threshold
Energy effort rate (share of household's annual energy bill compared to its annual income)	< 10 %
Share of annual housing costs over annual income	< 40 %

6.2 Life cycle costing (LCC) indicators

Similarly to LCA, the LCC methodology assesses economic impacts over the life cycle of a system. LCC can be applied to any type of intervention. LCC covers different types of money flows along the life time of a product or service (e.g. research services, investment, operational, maintenance or disposal costs, revenues) but can also include externalities (indirect market affects), i.e. costs caused by an activity due to environmental or societal impacts (e.g. pollution affecting human health and thus medical costs) but that are not yet included in product / service price. In REGEN, externalities are not quantified within LCC since the related environmental impacts are already considered in the LCA evaluation and to avoid additional uncertainty to translate these impacts into monetary values.

LCC methodology allows the calculation of the net present value (NPV) (€), which considers all life-cycle costs even in the future, which are discounted to the present. Depending on the interests of stakeholders, other indicators can be calculated, such as the payback period (in years), net savings (€) or savings-to-investment ratio. LCC is also included in the sustainability performance assessment framework of buildings Level(s) (Dodd et al., 2021c).

Table 23. AFUR life cycle costing indicators

Category	Indicator	Unit
LCC	Net present value	€
	Payback period	Year
	Net savings	€

6.2.1 Calculation principles and tools

The same steps than LCA methodology can be applied, i.e. goal and scope definition, life cycle inventory, impact assessment and results interpretation. For LCC, the steps of life cycle inventory and impact assessment can be performed simultaneously, i.e. collecting directly the costs of material purchase or annual maintenance (and not collecting first physical flows e.g. kg/year and associating unit price for impact assessment e.g. €/kg). To provide consistent results with AFUR application, the scope for LCA and LCC will be similar for a specific intervention. However, there can be some differences. For example, the LCC scope includes the method of accounting for the time value of money, the period of analysis and the identification of stakeholders (e.g. the ones investing capital, the ones paying the operation costs). Similarly, some flows can be relevant for LCC while they are excluded in LCA, such as human labor.

According to the NEN-ISO 15686-5:2017, the net present value (NPV) may be described as the sum of the discounted benefits of an alternative less the sum of the discounted costs. A stream of future costs and benefits should be converted to a net present value. Where costs only are taken into account, the NPV may be called the net present cost (NPC). The NPV should be a single figure that takes account of all relevant future incomes and expenditure over the period of analysis. This is the standard criterion for deciding whether an alternative can be justified on economic principles. If the NPV is zero, the benefits equal the costs, with that, it is economically neutral.

Eq. 6
$$X_{NPV} = \sum (Cn \times q) = \sum_{n=1}^{p} \frac{CN}{(1+d)^n}$$

With:
- X_{NPV}: Net Present Value
- Cn: Cost in year n
- q = Discount factor
- d = Expected real discount rate per annum
- n = Number of years between the base date and the occurrence of the cost
- p = The period of analysis

As stated above, the following additional LCC indicators can be applied depending on the relevance for the stakeholders:

- **Payback period:** time at which cumulative savings offset the investment (all costs and savings occurring after payback are usually ignored). This indicator can be useful to compare large and small investments, as well as to assess the time period during which an investment is at risk.
- **Net savings:** difference of present values between the LCC of different alternatives. If positive, the project is considered cost-effective (the higher the net savings, the most economically viable).
- **Savings-to-investment ratio:** ratio of future (net) savings over the additional costs. If greater than one, the alternative is cost-effective.
- **(Adjusted) internal rate of return:** compound rate of interest that, when used to discount the costs and benefits over the period of analysis, makes costs equal to benefits when cash flows are reinvested at a specific interest rate. This indicator can be used to compare alternatives or to test the discount rate value that would lead to a NPV of zero.
- **Annual cost or annual equivalent value:** uniform annual amount equivalent to the project net costs, taking into account the time value of money throughout the period of analysis. This indicator can be useful when the natural replacement cycle is not an exact multiple of the period of analysis.

LCC calculation can be done via simple office tools like Excel but can also be supported via dedicated tools. In REGEN, the RE Suite software solution developed by DEMO will be applied to evaluate the LCC indicators for interventions related to buildings. RE Suite is a software for real estate information management that integrates a wide range of functions across various modules and tools, including LCC. With RE LCC tool, it is possible to associate the economic information with BIM (Building Information Modeling) models, allowing for rapid LCC estimations of different building intervention options. It offers flexibility by accommodating various analysis periods and user-defined parameters such as inflation rate and discount rate. Additionally, RE LCC features a BIM viewer for building visualization, providing not only a clear representation of the building's physical and functional characteristics, but also a tool for quantity take-off. Thus, in REGEN, RE Suite is employed to conduct LCC analysis to compare interventions and support informed decision-making.

For the evaluation of trees, NBenefit$ will be applied. Indeed, the tool combines LCA and LCC evaluation. It provides an estimation of the financial costs associated with the implementation and management of the nature-based solution over its entire life cycle.

6.2.2 Required input data

Similarly to LCA, the required data to perform LCC depends on the evaluated intervention. For any kind of studied systems, some economic parameters (discount rate, analysis period, inflation rate) are always required.

- All interventions:
  - Economic parameters: discount rate, analysis period, inflation rate.
- Building energy efficiency improvement
  - Construction costs related to the installation or replacement of building components, including professional fees, work costs, materials / components costs, taxes costs.
  - Building operation costs, before and after the intervention, including the rent costs (if relevant), insurance costs, regulatory costs, utility costs, taxes costs.
  - Building maintenance costs, before and after the intervention, including the management costs, reparation, refurbishments or replacement costs, cleaning costs, taxes costs.
  - Building end-of-life costs, before and after the intervention, including disposal inspection costs, disposal and demolition costs, taxes costs.
- Energy system change
  - Initial investment costs related to system upgrade and replacement (e.g., PV panel or heat pump installation, district heating network extension), including design costs, labour costs, material costs, installation fees, permit costs, taxes costs.
  - Operating costs related to system management, including energy costs (e.g., electricity, gas, biomass, etc.), system monitoring and control costs, taxes costs.
  - Maintenance costs, including periodic service fees, repair costs, inspection fees, taxes costs.

- End-of-life costs, including dismantling costs, recycling costs, disposal costs, taxes costs.

- Reuse of building components
    - Disassembly costs related to reusable components, including labour costs, equipment costs, cleaning costs, inspection costs, taxes costs.
    - Transport and storage costs related to transporting reusable components to construction site or for temporary storage, including labour costs, equipment costs, fuel costs, rental fees of storage place, taxes costs.
    - Rehabilitation/repair costs related to recover the components' condition to meet project specifications, including cleaning costs, repairing costs.
    - Installation costs related to installing reusable building components, including labour costs, equipment costs, taxes costs.
- Pedestrian / cycling path improvement
    - Design costs related to initial planning, including engineering design costs, permit costs.
    - Construction costs related to improvement activities, including site preparation costs, labour costs, material costs, equipment costs, taxes.
    - Operation and maintenance costs, related to regular activities, including cleaning costs, lighting costs, inspection costs, repair costs, and taxes.
- Nature-based solutions (trees)
    - Implementation costs: site preparation, seedling cost, labour costs, machinery use.
    - Operational costs: irrigation (water cost, the frequency can be fixed ex ante or as a function of climatic conditions); pruning costs (frequency, number of operators, time per operator, operator cost, machinery use); cost of disposal of waste (pick up, blowers, transport); cost of waste treatment.
    - End of life costs: tree removal costs: (number of operators, time per operator, operator cost, machinery used); cost of disposal of waste (pick up, blowers, transport); cost of waste treatment.

As for LCA, the quality of LCC results is higher if the collected data are geographically, temporally, and technically representative of the specific studied system. Due to significant regional differences in construction and utility costs, users must carefully consider the quality and relevance of their data. The representativeness of cost data can be categorized into four levels, ranked from least to most representative:

- Generic or default national or EU data
- Older or less geographically specific benchmark / average data from similar projects or estimates obtained from contractors and suppliers
- Recent tender and market estimates from other similar projects
- Current tender and market estimates based on offers from contractors and suppliers

Some databases can be used to fill data gaps, such as European Construction Costs and National Costs Databases (like BCIS from UK; BEDEC from Spain; ASPEN from Belgium; BKI and OSCAR from Germany).

6.2.3 Threshold definition for sustainable urban regeneration

As mentioned in section 6.2.1, several LCC indicators can be used to evaluate the economic feasibility of building intervention options. For example, an intervention option is considered economically viable compared to the baseline when its NPV is lower, the payback period is shorter, or the net savings are positive.

Among these LCC indicators, it is important to select those relevant to the specific needs of the project and stakeholders.

NPV and payback period are the most broadly used LCC indicators for supporting strategic decisions in both the public and private sectors. Beyond these absolute-value indicators, REGEN also includes net savings to clearly communicate relative economic benefits among alternative interventions (Table 24).

However, interpreting LCC results requires careful consideration of uncertainties inherent in the assessment. According to NEN-ISO 15686-5:2017, several issues should be considered address the potential sources of uncertainty in LCC analysis. These include for example, future costs fluctuations in energy and material prices, the implementation of new taxes or subsidies, changes in market conditions, technological advancements that may affect system performance and maintenance plan.

In addition, particular attention should be paid to key assumptions that significantly influence the results, including discount rates, the period of analysis, repair and replacement cycles, and cost data. Variations in these parameters can lead to high degree of uncertainty and may alter the economic performance of intervention options.

Table 24: AFUR thresholds for LCC indicators

Indicator	Threshold
Net present value (NPV)	< baseline
Payback period	< baseline
Net savings	>0

Co-funded by the European Union

7 Summary

The following table summarizes the list of indicators considered within AFUR, their requirements in terms of models / tools and data, and the applicable thresholds. For data requirements, two levels of assessment are suggested depending on data availability and associated efforts: minimum level (particularly relevant for screening evaluation of the baseline situation) and advanced level (increasing the quality of the results).

Table 25: Summary of AFUR indicators and their calculation principles

Category	Indicator	Unit	Required model	Minimum data		Advanced data		Thresholds
				Required data	Potential data sources	Required data	Potential data sources	
Energy	Annual thermal energy demand per m²	kWh/m²/yr	Energy simulation (e.g. ICL, RENOSTOCK)	Cadastral building information	Municipality	1) EPC 2) Energy bills or energy monitoring	1) Municipality 2) Energy meters or inhabitants	Class C / Class A
	Annual thermal energy demand per inhabitant	kWh/inh/yr		-	-	Previous line + Census data	See previous line + Municipality	-
	Renewable energy share	%	None	Energy supply statistics	Eurostat, national energy institutes…	Energy supply per building	Buildings energy bills	T45%
Material Circularity	Share of construction waste recycled	%	None but building scanning tools can be used to estimate the potential (e.g. GT LAB Assessment)	Waste flow amount and destination	Regional statistics, specific	Waste flow amount and destination tracking during works	Construction/retrofitting waste management bills	70% / 90%
	Share of reused building elements	%		Building components	Regional statistics, specific	Building components tracking during works	Construction/retrofitting waste management bills	1.5% / 20%
Modal split	Share of daily transport by car	%	If available, traffic model	Mobility behaviour surveys, traffic data	Municipality, Eurostat	Mobility patterns	Sensors	No threshold, to be checked with local regulation / policies
	Share of daily transport by public transport	%						
	Share of daily transport by P2W	%						
	Share of daily transport by soft / active mobility	%						
Accessibility	Walkability within 15 min. to services	%	GeoJSON site's model	Open street map networks and services; Digital Surface Model file; GIS addresses; General Transit Feed Specification.	Municipality, transport company.	Inhabitants feedback on their habits.	Surveys, interviews with inhabitants	75% total number of maximum services are accessible (15)
	Walkability within 15 min. to public transport	%	GeoJSON site's model					
	Bikeability within 15 min. to services	%	GeoJSON site's model					
	Average number of public transport nodes depending on their type and their frequencies within 15 minutes) [3 categories]	#	GeoJSON site's model					3 public transports accessible with av. frequency ≤ 10' OR 5 with av. frequency ≤ 15'
	Safe Pedestrian Streets	%	GeoJSON site's model	Open street map networks and services; Digital Surface Model file; Street data (footpath's width)	Municipality, open-source data	Field observation	Municipality	Average street score of 75%
Outdoor thermal comfort	UTCI	°	GIS treatment	GIS characterization of exterior surfaces; Local weather files	Municipality, open-source data	Field observation	Municipality	
Land use	Soil permeability index	-	GIS treatment	GIS characterization of exterior surfaces	Municipality, open-source data	Field observation	Municipality	0.5
	Soil biodiversity index	-						0.5

Life cycle assessment (LCA)	Climate change	kg CO_2 eq	LCA tool and related database (e.g. Brightway2 and ecoinvent, SimaPro, LCA for Experts, OneClickLCA, NBenefit$)	Depending on the intervention, e.g.: - Building energy efficiency > energy and insulation material flows - Energy system change > energy and supply infrastructures flows - Reuse of building components > Mass flows and their fate - Pedestrian / cycling path > Modal split and road infrastructures flows - Nature-based solutions > Components and their operation flows	Consumption flows based on other modelled indicators, municipality planning data	Same as for minimum level but with more details about the specific value chain (e.g. location of suppliers)	Measured data, bills, or sensors	Application of AESA methodology to allocate planetary boundaries to the studied system
	Ozone depletion	kg CFC-11 eq						
	Human toxicity, cancer	CTUh						
	Human toxicity, non-cancer	CTUh						
	Particulate matter	Disease incidences						
	Ionising radiation, human health	kBq U^{235}						
	Photochemical ozone formation	kg NMVOC eq						
	Acidification	mol H^+ eq						
	Eutrophication, terrestrial	mol N eq						
	Eutrophication, freshwater	kg P eq						
	Eutrophication, marine	kg N eq						
	Ecotoxicity, freshwater	CTUe						
	Land use	-						
	Water use	m^3 world eq deprived water						
	Resource use, minerals and metals	kg Sb eq						
	Resource use, fossil	MJ						
Socio-economic	Energy poverty	%	Energy simulation (e.g. ICL, RENOSTOCK)	- Population income - See energy category	- Eurostat, municipality	- Population income - See energy category	- Surveys and monitoring	< 10%
	Housing affordability	%	GIS treatment if relevant	- Population income - Dwellings costs	- Eurostat, municipality	- Population income - Dwellings costs	- Publicly available statistics for rent and purchase prices (national, municipality, real estate data bases), surveys	< 40%
	Risk of gentrification	-	GIS treatment if relevant	Temporal trends for: - Educational attainment - Real estate value - Population income	- Eurostat, municipality	Additional parameters could be considered: population ethnicity, age, vacant buildings, businesses, crime rate...		-
LCC	Net present value	€	LCC model (e.g. DEMO, Nbenefit$)	LCC follows a similar data collection scope as LCA but focuses on financial data, such as costs across the life cycle	Financial reports, databases	Probability distributions or variances of LCC data, e.g., costs, maintenance intervals, service lifetimes, etc.	Literature, expert insights, experience from previous similar projects	< baseline
	Payback period	Year						< baseline
	Net savings	€						>0

Conclusions

This document presents the Assessment Framework for Urban Regeneration (AFUR), which aims at evaluating the relevance and impacts of regeneration interventions in a holistic manner to support decision-makers.

From an initial diagnosis (applied to REGEN demo sites in deliverable D3.1) to the combined evaluation of regeneration scenarios (applied to REGEN demo sites in D4.1), AFUR can be applied to understand the advantages and disadvantages of various regeneration strategies: building energy efficiency increase, energy system improvement, building components reuse, soft mobility fostering and nature-based solutions deployment.

AFUR indicators cover energy, material circularity, modal split, urban accessibility, outdoor thermal comfort, land use, life cycle assessment, economic accessibility and life cycle costing aspects. These indicators can be selected depending on the relevance for the specific context. However, we want to stress that it is important to reflect as much as possible all potential effects of studied scenarios and to consider both environmental and socio-economic aspects.

To be aligned with regeneration objectives, the interpretation of these indicators is not only relative, i.e. in comparison to a baseline scenario, but is also based on ambitious thresholds coming from EU instruments (e.g. EU Taxonomy, EU policy targets, European certification schemes) or from state-of-the-art literature (e.g. planetary boundaries, review of energy poverty definitions).

The calculation of these indicators requires more or less efforts, with sometimes the need of software tools. Within REGEN, specific tools are applied but AFUR evaluation could also rely on similar tools. In order to make the assessment framework replicable, two levels of data requirements are defined, the minimum level relying mostly on easily accessible data. The latter will be in particular applied for the evaluation of virtual cases within the project (D4.3).

While AFUR provides a guidance to support urban regeneration with a science-based quantitative evaluation, we are aware that the methodology described in this report is not fully comprehensive but can be used as first approach. The concept can be enriched depending on the specific issues of the studied area, available data and expertise.

Bibliography

Andersen, C.E., Petersen, S., Ryberg, M., Molander, L.L., Birkved, M. (2024). Ten questions concerning absolute sustainability in the built environment. Building and Environment 251, 111220. https://doi.org/10.1016/j.buildenv.2019.106633

Bai, X., Hasan, S., Andersen, L.S. et al. (2024). Translating Earth system boundaries for cities and businesses. Nature Sustainability 7, 108–119. https://doi.org/10.1038/s41893-023-01255-w

Bartzokas-Tsiompras, A., Bakogiannis, E., Nikitas, A. (2023). Global microscale walkability ratings and rankings: A novel composite indicator for 59 European city centres. Journal of Transport Geography. https://doi.org/10.1016/j.jtrangeo.2023.103645

Basu, N., Oviedo-Trespalacios, O., King, M., Kamruzzaman, L.D., Haque, M. (2023). What do pedestrians consider when choosing a route? The role of safety, security, and attractiveness perceptions and the built environment during day and night walking. https://doi.org/10.1016/j.cities.2023.104551

Bjørn, A., Chandrakumar, C., Boulay, A.-M., et al. (2020). Review of life-cycle based methods for absolute environmental sustainability assessment and their applications. Environmental Research Letters 15(8), 083001. DOI 10.1088/1748-9326/ab89d7

City of New York (2010). Active Design Guidelines: Promoting Physical Activity and Health in Design. http://www1.nyc.gov/assets/planning/download/pdf/plans-studies/active-design-guidelines/adguidelines.pdf.

Dodd, N., Donatello, S., & Cordella, M. (2021a). *Level(s) indicator 2.1: Bill of Quantities, materials and lifespans: introductory briefing, instructions and guidance (Publication version 1.1)*. European Commission – Joint Research Centre.

Dodd, N., Donatello, S., & Cordella, M. (2021b). *Level(s) – A common EU framework of core sustainability indicators for office and residential buildings (Publication version 1.1)*. European Commission – Joint Research Centre.

Dodd, N., Donatello, S., & Cordella, M. (2021c). *Level(s) indicator 6.1: Life cycle costs user manual: introductory briefing, instructions and guidance (Publication version 1.1)*. European Commission – Joint Research Centre.

Durmisevic, E., Guerriero, A., Boje, C., Domange, B., & Bosch, G. (2021). Development of a conceptual digital deconstruction platform with integrated Reversible BIM to aid decision making and facilitate a circular economy. Proc. of the Joint Conference CIB W78-LDAC, 2021, 11–15. http://itc.scix.net/paper/w78-2021-paper-090

MacArthur, E. (2015). Circularity indicators: An approach to measuring circularity. Methodology. http://dx.doi.org/10.1201/9781003204381-10

Goodwin, K., Wiedmann, T., Chen, G., The, S.H. (2021). Benchmarking urban performance against absolute measures of sustainability – A review. Journal of Cleaner Production 314, 128020. https://doi.org/10.1016/j.jclepro.2021.128020

International Organization for Standardization ISO 14040/44 (2006). Environmental management – Life cycle assessment – ISO 14040: Principles and framework; ISO 14044: Requirements and guidelines.

International Organization for Standardization ISO 15686-5 (2017). Buildings and constructed assets - Service life planning - Part 5: Life cycle costing.

Kneifel, J., & Webb, D. (2022). *Life cycle costing manual for the Federal Energy Management Program – NIST Handbook 135, 2022 edition*. Washington-DC, US: Applied Economics Office, Engineering Laboratory.

Kromand, J.B., Tilsted, J. P., Bjørn, A. (2025). Developing sufficiency-based sharing principles for absolute environmental sustainability assessment using decent living standards and planetary boundaries. Sustainable Production and Consumption 54, 516–529. https://doi.org/10.1016/j.spc.2025.01.008

Lund, M.N., Schjerbeck, A.K., Bjørn, A. (2025). Using absolute environmental sustainability assessment and mid-to-endpoint modeling to identify the most relevant impact categories to include in a building LCA. Building and Environment 278, 112985. https://doi.org/10.1016/j.buildenv.2025.112985

Ministerio de Transportes, Movilidad y Agenda Urbana. (2021). Recomendaciones para la aplicación de la orden ministerial TMA/851/2021, de 23 de julio, por la que se desarrolla el documento técnico de condiciones básicas de accesibilidad y no discriminación para el acceso y la utilización de los espacios públicos urbanizados. https://sid-inico.usal.es/wp-content/uploads/2022/01/guia_accesibilidad.pdf

Officials NA of CT, National Association of City Transportation Officials, Officials NA of CT (2016). Global Street Design Guide. Island Press;. http://globaldesigningcities.org/publication/global-street-design-guide/.

Raworth, D. (2017). Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist, Chelsea Green Publishing, 2017

Rhoads, D., Solé-Ribalta, A., Borge-Holthoefer, J. (2022). The inclusive 15-minute city: Walkability analysis with sidewalk networks. Computers, Environment and Urban Systems. https://doi.org/10.1016/j.compenvurbsys.2022.101936

Rockström, J., Steffen, W., Noone, K., et al. (2009). Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society 14, 32.

Ryberg, M.W., Andersen, M.M., Owsianiak, M., Hauschild, M.Z. (2020). Downscaling the planetary boundaries in absolute environmental sustainability assessments - A review. Journal of Cleaner Production 276, 123287. https://doi.org/10.1016/j.jclepro.2020.123287

Sala, S., Benini, L., Crenna, E., Secchi, M. (2016). Global environmental impacts and planetary boundaries in LCA. EUR 28371 EN, JRC technical report. doi:10.2788/64552

Sala, S., Crenna, E., Secchi, M., Sanyé-Mengual, E. (2020). Environmental sustainability of European production and consumption assessed against planetary boundaries. Journal of Environmental Management 269, 110686. https://doi.org/10.1016/j.jenvman.2020.110686

Annex

Annex I - Example tools for urban modelling

No	Category	Name	Description	Role in REGEN	Link
1	Energy	IES Intelligent Community Lifecycle tools	GIS level Digital twin platform services for energy	Urban energy simulation	IES Live | IES
2		Renostock	GIS level tool for energy modelling	Urban energy simulation	Research centre | Technological development | Tecnalia
3		EnergyPlus	Generic tool for energy modelling	-	EnergyPlus
4		Tabula	Building archetypes database	Dataset	TABULA WebTool
5		Ashrae	Energy database	Dataset	ASHRAE Standards and Research Project Data Repository
6	Material Circularity	MCI Calculator	Excel-based tool for material take-off and circularity calculation following the MCI methodology	-	Material Circularity Indicator | Ellen Macarthur Foundation
7		GTBLab Reuse Potential tools	BIM-based software tools at for reuse and adaptability of buildings	Building level circularity support	European Laboratory for Green Transformable Buildings | circular building

Co-funded by the European Union

			analysis and decision-support		
8		Digital Deconstruction	BIM-based platform for building deconstruction management	Building level circularity support	DDC Platform
9	Modal split	Dinycont	People counter tool using advanced software and sensors	Pedestrian monitoring	People count | Dinycon
10	Accessibility	Open Trip Planner	Passenger information and transportation network analysis services	-	OpenTripPlanner
11		Open Route Service	Computation of routes for all means of transportation	Compute walking and cycling time	openrouteservice
12		QGIS/QuickOSM	GIS platform for visualisation and management of datasets	GIS Visualisation tool	Download · QGIS Web Site
13		QuickOSM	QGIS plugin for OpenStreeMap data integration	Download OpenStreetMap datasets	QuickOSM — QGIS Python Plugins Repository
14	Outdoor thermal comfort	IES iCD	Energy analysis tool	Thermal comfort model	iCD Scalable Energy Analysis | Products | IES
15	Life cycle assessment (LCA)	Brigthway2 libraries	Open-source python libraries for LCA modelling	Intervention LCA modelling	Brightway LCA Software Framework — Brightway documentation

16		Ecoinvent	Database with LCA processes	Datasets	ecoinvent - Data with purpose.
17		NBenefit$	Nature-based solution for green areas design, management and impact quantification	NBS intervention LCA modelling	
18		OpenLCA	Generic LCA tool	-	https://www.openlca.org/
19		OneClickLCA	Generic LCA tool	-	https://oneclicklca.com/
20		LCA for Experts	Generic LCA tool	-	https://sphera.com/product-stewardship/life-cycle-assessment-software-and-data/lca-for-experts/?nab=1
21		SimaPro	Generic LCA tool	-	https://simapro.com/
22	LCC	RE Suite	Real estate management tool focused on costing	LCC modelling	RE Suite

Annex II - Accessibility - Service Categories[14]

SERVICE - HEALTH

Key	Value	Key	Value	Key	Value
amenity	hospital	amenity	dentist	amenity	veterinary
healthcare	hospital	healthcare	dentist	healthcare	physiotherapist
amenity	clinic	healthcare:speciality	orthodontics	craft	laboratory
healthcare	clinic	amenity	pharmacy	healthcare	alternative
amenity	doctors	healthcare	pharmacy		
healthcare	doctor	amenity	baby_hatch		

SERVICE – EDUCATION

Key	Value	Key	Value	Key	Value
amenity	childcare	amenity	college	amenity	dancing_schoo
amenity	kindergarten	amenity	language_school	amenity	prep_school
amenity	school	amenity	driving_schoo		
amenity	university	amenity	music_school		

SERVICE – CULTURE

Key	Value	Key	Value	Key	Value
tourism	museum	amenity	library	amenity	arts_centre
tourism	gallery	amenity	public_bookcase	tourism	artwork
amenity	theatre	amenity	planetarium	amenity	studio

SERVICE – SHOPS

Key	Value	Key	Value	Key	Value
shop	supermarket	shop	video	shop	jewelry
shop	convenience	shop	video_games	shop	sports
shop	general	shop	music	shop	water_sports
shop	kiosk	shop	radiotechnics	shop	fishing
shop	bakery	shop	doors	shop	hunting
shop	butcher	craft	furniture	shop	scuba_diving
shop	seafood	shop	appliance	shop	sewing
shop	dairy	shop	electrical	shop	department_store
shop	cheese	shop	kitchen	shop	mall
shop	frozen_food	shop	houseware	shop	baby_goods

[14] Service categories extracted from OpenStreetMap Category Lists: https://wiki.openstreetmap.org/wiki/OpenStreetBrowser/Category_list

shop	deli	shop	lighting	shop	florist
shop	pastry	shop	curtain	shop	garden_centre
craft	confectionery	shop	window_blind	shop	doityourself
shop	chocolate	shop	art	shop	hardware
shop	tea	shop	frame	shop	trade
shop	coffee	shop	bed	shop	hairdresser_supply
shop	herbalist	shop	carpet	shop	wholesale
amenity	marketplace	shop	bathroom_furnishing	shop	gas
shop	greengrocer	shop	interior_decoration	shop	paint
shop	farm	shop	antiques	shop	craft
shop	organic	shop	vacuum_cleaner	craft	locksmith
shop	water	shop	furnace	shop	second_hand
shop	nutrition_supplements	shop	fireplace	shop	travel_agency
shop	health_food	shop	candles	shop	musical_instrument
shop	spices	shop	tiles	shop	toys
shop	clothes	craft	pottery	shop	games
shop	boutique	shop	stationery	shop	watches
shop	fashion_accessories	shop	copyshop	craft	leather
shop	fashion	shop	books	shop	gift
shop	shoes	shop	newsagent	shop	variety_store
shop	shoe_repair	shop	anime	shop	party
shop	bag	shop	chemist	shop	swimming_pool
shop	outdoor	shop	cosmetics	shop	bookmaker
shop	dry_cleaning	shop	perfumery	shop	lottery
shop	laundry	shop	beauty	shop	ticket
craft	tailor	beauty	nails	shop	pet
shop	fabric	shop	massage	shop	pet_grooming
shop	computer	shop	hairdresser	shop	photo
shop	electronics	craft	optician	shop	security
shop	mobile_phone	shop	hearing_aids	shop	funeral_directors
shop	hifi	shop	medical_supply	shop	storage_renta

SERVICE – SPORT

Key	Value	Key	Value	Key	Value
leisure	golf_course	sport	athletics	sport	baseball
golf	clubhuse	sport	running	sport	basketball
golf	tee	sport	climbing	sport	handball
golf	hole	climbing	route	sport	volleyball
golf	pin	sport	canoe	sport	beachvolleyball
golf	bunker	sport	rowing	sport	billiards
golf	water_hazard	sport	cycling	sport	golf
natural	water	sport	dog_racing	sport	boules
golf	lateral_water_hazard	sport	equestrian	sport	bowls
golf	green	sport	horse_racing	sport	cricket

golf	fairway	sport	gymnastics	sport	croquet
surface	grass	sport	skating	sport	field_hockey
golf	rough	sport	ice_skating	sport	ice_hockey
golf	driving_range	sport	curling	sport	pelota
leisure	stadium	sport	roller_skating	sport	racquet
leisure	sports_centre	sport	skateboard	sport	table_tennis
leisure	fitness_centre	sport	swimming	sport	tennis
amenity	dojo	sport	scuba_diving	sport	motor
leisure	pitch	sport	skiing	sport	karting
leisure	track	sport	shooting	sport	motocross
amenity	dive_centre	sport	chess	sport	safety_training
leisure	ice_rink	sport	soccer	sport	model_aerodrome
leisure	bowling_alley	sport	australian_football	sport	rc_car
leisure	miniature_golf	sport	american_football	highway	raceway
sport	multi	sport	canadian_football	leisure	swimming_pool
sport	9pin	sport	gaelic_games	leisure	swimming_area
sport	10pin	sport	rugby_league	leisure	fitness_station
sport	archery	sport	rugby_union	leisure	horse_riding

SERVICE – LEISURE

Key	Value	Key	Value	Key	Value
amenity	restaurant	leisure	water_park	amenity	toy_library
amenity	pub	leisure	escape_game	leisure	playground
amenity	bar	leisure	resort	tourism	picnic_site
playground	slide	leisure	beach_resort	leisure	picnic_table
playground	swing	leisure	sauna	amenity	bbq
amenity	cinema	amenity	public_bath	leisure	firepit
leisure	bandstand	leisure	tanning_salon	shop	fishing
tourism	zoo	leisure	dance	leisure	bird_hide
tourism	aquarium	leisure	hackerspace	leisure	amusement_arcade
attraction	animal	leisure	dog_park	amenity	nightclub
tourism	theme_park	railway	minature		

SERVICE – LOCAL SERVICES

Key	Value	Key	Value	Key	Value
amenity	vending_machine	amenity	bank	amenity	post_office
amenity	atm	amenity	payment_centre	amenity	townhall

SERVICE – GREEN SPACES AND NATURE

Key	Value	Key	Value	Key	Value
landuse	forest	natural	bay	natural	bare_rock
landuse	meadow	natural	beach	natural	blockfield
landuse	orchard	natural	cape	natural	cave_entrance
landuse	plant_nursery	natural	coastline	natural	cliff

Co-funded by
the European Union

landuse	vineyard	natural	isthmus	natural	dune
landuse	basin	natural	peninsula	natural	earth_bank
landuse	grass	natural	reef	natural	hill
leisure	park	natural	shingle	natural	peak
natural	fell	natural	shoal	natural	ridge
natural	grassland	natural	spring	natural	saddle
natural	heath	natural	strait	natural	sand
natural	scrub	natural	water	natural	scree
natural	tree_row	natural	wetland	natural	sinkhole
natural	tundra	natural	arch	natural	valley
natural	wood	natural	arete	natural	volcano