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Glossary

ADP	Abiotic depletion potential
AP	Acidification potential
CAPEX	Capital Expenditure
CED	Cumulative energy demand
CI	Composite Indicator
D1	Deliverable 1
eLCA	Environmental Life-Cycle Assessment
EP	Eutrophication potential
FU	Functional Unit
GWP	Global warming potential
IPCC	International Panel of Climate Change
kW	Kilo Watt
L	Liter
LCC	Life Cycle Cost
LCIA	Life Cycle Impact Assessment
LCSA-F	Life-Cycle Sustainability Assessment-Framework
MAVT	Multi-Attribute Value Theory
MAUT	Multi-Attribute Utility Theory
MCDA	Multi-Criteria Decision Analysis
ODP	Ozone depletion potential
OPEX	Operational Expenditures
POCP	Photochemical oxidation creation potential
RA	Resilience Assessment
Si	Silicon
sLCA	Social Life Cycle Assessment
SP	Sub-Project
TLCC	Total Life Cycle Costs
TLCR	Total Life Cycle Revenues
VOC	Volatile organic compound

Executive Summary

This Deliverable (D2) documents the finalization and operationalization of the Life-Cycle Sustainability and Resilience Assessment Framework (LCSA-F) for renovation measures in Swiss multi-family buildings, and its implementation in the SUSTAINOVATE decision-support tool. Building on the initial SP1.4 report, which established the conceptual framework conditions, indicator hierarchy, expert-based weighting profile, and the selection of Multi-Attribute Value Theory (MAVT) as aggregation method, the present report translates these elements into a fully specified, tool-ready architecture with pre-modelled data for selected renovation measures and a functioning software prototype.

The final LCSA-F maintains the four-pillar domain structure—environmental life cycle assessment (eLCA), life cycle costing (LCC), social life cycle assessment (sLCA), and resilience assessment (RA)—and the cradle-to-grave system boundaries (A1–C4) and functional unit (“heated area per year of building lifetime”) defined in Deliverable 1. The indicator set comprises 16 criteria and 56 subcriteria covering climate and energy-related impacts (e.g. GWP, CED, acidification, eutrophication, ozone depletion, abiotic depletion), cost components (total life-cycle costs and revenues disaggregated into CAPEX, OPEX, fees, taxes, energy and material sales, rental income, subsidies), social aspects (comfort, indoor air quality, user influence, accessibility, local value creation, cultural heritage, value-chain responsibility), and hazard-specific resilience descriptors for floods, heavy rain/hail, heat- and coldwaves, and blackout/energy shortages. For eLCA and LCC, the framework is now operationalized through explicit LCIA method choices (CML-IA baseline/non-baseline, IPCC 2021 GWP 100a, CED 1.11) and a conventional life-cycle cost structure aligned with sectoral guidelines, together with pre-modelled data for a set of predefined renovation measures (e.g. heat pumps, photovoltaic and solar thermal systems, insulation materials, window replacement options) based on established background databases.

For sLCA and RA, the conceptually defined criteria and subcriteria from the initial framework are retained, but their quantification is delegated to structured user inputs within the tool, reflecting the strong dependence of social and resilience performance on building- and context-specific characteristics. The RA domain operationalizes resilience via phase-specific subcriteria (Absorb and Recovery) across the four selected hazards, systematically exploiting shared building-physics parameters (e.g. wall thickness, materials, insulation, plinth level) where possible, while keeping the overall hierarchy compatible with MAVT’s structural requirements. Additional indicators such as Ecological Scarcity (UBP), Energy Payback Time, Net Present Value (NPV), and Internal Rate of Return (IRR) are made available in the tool for diagnostic and investor-oriented analyses but are purposely excluded from the core composite index to prevent double counting.

SUSTAINOVATE, implemented as a modular R-based web application, embodies the final framework in a practitioner-oriented environment. It guides users through three main modules—baseline building characterization, alternative definition, and MCDA analysis—while embedding the complete hierarchical indicator structure and the expert-derived weighting profile. The weighting interface offers two regimes: (i) a default “expert weights” profile, which reproduces the consensus reached in the second stakeholder workshop and provides a scientifically grounded reference configuration, and (ii) a “custom” profile starting from equal weights that allows users to explore case-specific preferences and conduct sensitivity analyses. The MCDA workflow performs min–max normalization and additive weighted aggregation as specified in the framework and returns not only rankings and scores for the status quo and all renovation alternatives, but also contribution analyses at pillar and sub-criterion level, together with exportable plots for reporting.

Overall, this Deliverable demonstrates that the integrated sustainability-and-resilience framework developed in SP1.4 can be implemented in a coherent, transparent, and computationally tractable way, suitable for real-world decision-support in building renovation. At the same time, it identifies

remaining challenges and future work, including (i) extending the library of renovation measures, indicators and hazards; (ii) testing and refining default data and weight profiles through empirical case studies; and analyzing the robustness of decision recommendations with respect to methodological choices (e.g. normalization, weighting) and stakeholder preference heterogeneity. Addressing these aspects will be critical to fully exploit the potential of LCSA-F and SUSTAINOVATE for supporting large-scale, evidence-based decarbonization and climate-resilient retrofitting of the Swiss multi-family building stock.

1. Introduction

This second deliverable summarizes the development of the final Life Cycle Sustainability and Resilience Assessment Framework and a web-based tool named “SUSTAINOVATE”. The phase of the development of the final framework included following steps:

1. Renovation measures were predefined and selected in collaboration with the accompanying stakeholder group.
2. eLCA and LCC: Data was collected and LCIA results were calculated for all renovation measures
3. LCSA framework was adapted according to the availability of data and the applicability to different user groups.
4. SUSTAINOVATE was programmed and framework structure as well as LCIA results for selected renovation measures were embedded in the tool.

1.1 General changes to initial framework

The final framework indicators are the same as described in the initial framework [1]. Solely, the additional indicators for eLCA and LCC were not included due to impractical implementation in the LCSA tool. The focus was laid on the indicators that are part of the MCDA and the overall LCSA methodology.

2 Renovation measures in focus

Renovation measures were initially selected by screening the literature and the to the time most applied decarbonizing options in Switzerland according to different programs such as “Minergie” [2]. Renovation measures were structured according to different application areas within multi-family buildings and sub-structured in varieties of different types (see 2.1). Data was only collected for eLCA and LCC (see 2.2) as for RA and SLCA all relevant aspects are highly dependent on the actual building and location and need to be defined by the user of SUTAINOVATE.

2.1 Selected renovation measures

As initially described, renovation measures were finally selected in a two-step process. Firstly, different measures were selected by the authors by screening literature and official programs. In a second step, a survey was conducted with the initial list of measures and sent to the accompanying stakeholder group for feedback. Some measures were then deselected, and new measures were included after evaluation of the survey results. The final list of renovation measures is summarized in Table 1 and Table 2.

2.2 Data collection and modelling for renovation measures

Renovation measures were modelled for eLCA and results were calculated for LCC only as background information on environmental life cycle performance or life cycle costs cannot be included easily by tool users and is therefore provided where feasible. All data was collected and modelled according to the system boundaries for eLCA and LCC described in Deliverable 1 (D1) [1].

For eLCA life cycle data could be provided and included fully as renovation measures were defined preliminarily and modelled accordingly. Major sources for modelling renovation measures were the ecoinvent database LCA background database provided by KBOB and treeze Ltd [3], [4]. Due to licence restrictions, details of eLCA models cannot be shared [5]

For LCC different sources were utilized as costs and benefits are not summarized in databases as for the environmental dimension. The sources were mainly websites providing detailed cost information, e.g. Production and installation costs could be collected comprehensively covering all renovation measures. Also end of life costs were easily accessible though approximations were used as defaults.

Table 1: Selected renovation measures, specific technologies and installation types for LCSA framework and SUSTAINOVATE (part 1)

Renovation area	Heating replacement			Photovoltaics	Solar thermal energy
Specific technologies	Brine/ water heat pump (7/15/50 kW)	District heat, natural gas and co-generation	Pellet furnace	Multi-Si	Solar collector, Cu flat plate collector
	Air/water heat pump (7/15/50 kW)	District heat, light fuel oil		Single-Si	
				a-Si	
Infrastructure and auxiliary material	Borehole heat exchanger	Transportation heat, infrastructure	Wood pellets	Inverter (0.5/2.5 kW)	Expansion vessel (80L)
	Cooling agents: Trifluoromethane / HFC – 152a		Silo for pellets	Mounting system	Hot water tank (600/2000L)
	Removal of boilers			Electrical installation	Pump (40kW)
Installation types	Different borehole depth			Flat-roof	
				Slanted-roof	
				Facade	

Table 2: Selected renovation measures, specific technologies and installation types for LCSA framework and SUSTAINOVATE (part 2)

Renovation area	Insulation	Building technologies		
Specific technologies / materials	Cellulose	Sunshades, aluminium	Green Roof	Window replacement
	Glass wool			
	Stone wool			
	Polystyrol (EPS)			
	Polystyrol (XPS)			
	Polyurethane			
Infrastructure and auxiliary material				Frame (wood / wood & metal)
Installation types	Installation: mortar		Flat roof	Double glazing
	Installation: Blowing			Triple glazing

Additionally, taxes, subsidies and fees as well as energy costs vary significantly between cantons and even communities. In the case of varying prices, costs or revenues default values were collected and included with the option to enter own and more precise values for the specific building, location or energy and waste disposal provider.

3 Final LCSA Framework and indicators

Regarding indicator selection and aggregation options, only few changes were made as mentioned in 1.1. The focus was laid on the comprehensive LCSA methodology without separate indicators. The four dimensions and the MCDA approach are recapitulated in this chapter.

3.1 eLCA

The eLCA criteria are mainly based on CML-IA baseline and non-baseline LCIA methods, using EU25+3 (EU-25, Iceland, Norway, Switzerland) as the reference system. Cumulative Energy Demand (CED) is calculated using Cumulative Energy Demand 1.11, and Global Warming Potential (GWP) follows IPCC 2021 GWP 100a. Included impact categories and subcriteria:

- GWP: fossil, biogenic, and land use change CO₂-eq. emissions.
- CED: energy demand from renewable and non-renewable sources
- Land and water impacts: acidification (AP) and eutrophication (EP).
- Atmospheric impacts: ozone depletion (ODP) and photochemical ozone creation (POCP).
- Resource use: abiotic depletion (ADP) of elements.

Further details can be found in D1 [1]

3.2 LCC

The Life Cycle Cost (LCC) assessment includes two main criteria: **Total Life Cycle Costs (TLCC)** and **Total Life Cycle Revenues (TLCR)**. TLCC covers both market and non-market costs — specifically CAPEX, OPEX, CO₂ fees, disposal fees, and taxes. TLCR similarly includes market and non-market revenues: material sales, energy sales, rental income, and subsidies. Further details can be found in D1 [1]

3.3 sLCA

There were no changes made compared to the initial framework in D1 nor specific data collected. All sLCA indicators are directly quantified with a specific scale by the user of SUSTAINOVATE.

3.4 RA

Resilience is interpreted as the time-dependent behavior of a building's performance variable (e.g., indoor temperature, service availability) during and after a disruptive event (e.g., flood, heatwave, blackout) [6]. This behavior is typically represented through a resilience curve, which captures the degradation of performance, the ability to withstand impacts, and the recovery trajectory back to (or beyond) a reference state. To make resilience measurable and comparable across alternatives, literature commonly decomposes the curve into a set of resilience dimensions (also referred to as functions, abilities, capacities). These dimensions are not universal; they depend on study objectives and system boundaries [7], [8], [9], [10], [11].

In RENOWAVE, resilience is modelled through three consolidated phases that describe the evolution of the building performance during and after a disruptive event, namely Pre-Event, Absorb, and Recovery. The Pre-Event phase refers to measures that reduce risk and vulnerability before the occurrence of a disruption [12]. The Absorb phase captures the building's capability to limit performance degradation during the event, for instance through structural properties, envelope characteristics, and backup measures that help maintain essential functions [7]. The Recovery phase

describes the capability and speed with which performance and services can be restored after the disruption, acknowledging that restoration depends both on building-related features and on external constraints such as the expected disruption duration or the availability of resources needed for repair [7]

Given the focus of RENOWAVE on identifying reasonable renovation measures for existing multifamily buildings, Pre-Event measures are not explicitly assessed within the tool. These measures are typically associated with planning, siting, or broader risk mitigation strategies and are therefore considered largely independent from the renovation alternatives evaluated. Consequently, the resilience assessment in RENOWAVE is operationalized through subcriteria that are meaningful for retrofit decision-making and that represent the Absorb and Recovery phases.

For each hazard type considered in the tool, a preliminary set of candidate subcriteria was compiled and then refined to a final, tool-ready subset. The final selection was informed by stakeholder feedback collected during dedicated workshops (see D1 for details) [1]. The resulting subcriteria sets are structured by resilience phase and are intended to provide measurable proxies for the building's behavior under disruption, enabling a consistent comparison of renovation alternatives across multiple hazards.

3.4.1 Floods

Flood resilience is represented through Absorb-related indicators that describe the building's ability to withstand floodwater impacts and limit damage, as well as Recovery-related indicators that capture practical constraints affecting restoration [13], [14], [15], [16]. The Absorb subcriteria include plinth level (relative elevation of the building), drainage (capacity and slope conditions supporting water outflow), and envelope/structural properties such as floor covering, wall material, and wall thickness, which influence resistance to water ingress and pressure. The Recovery phase is represented through resource availability and personnel in place, reflecting that rebuilding and repair times are strongly affected by the availability of construction materials and workforce.

3.4.2 Heavy rain and hail

For heavy rain and hail events [17], [18], [19], Absorb subcriteria focus on envelope and building components exposed to impact and moisture, including doors material, wall material, floor covering, and window type, capturing differences in resistance against water penetration and hail damage. Recovery is again represented through resource availability and personnel in place, consistently accounting for the role of material supply and workforce capacity in post-event restoration.

3.4.3 Heat- and coldwaves

Thermal resilience under extreme temperature conditions [6], [20], [21], [22], [23], [24] is operationalized through Absorb indicators that represent the building's capability to maintain indoor conditions within acceptable ranges. These include active and passive measures such as thermally active building systems, thermally loadable air supply systems, and envelope characteristics including wall thickness, wall material, and insulation and/or light surface (albedo). For the Recovery phase, resilience is represented through expected adverse thermal conditions, i.e., the expected number of days with critical thermal conditions, which serves as an indicator of the likely persistence of stress and the resulting recovery horizon.

3.4.4 Blackout and energy shortages

Resilience to electricity disruptions [25], [26], [27], [28] is captured by Absorb subcriteria describing the ability to maintain critical functions during outages. These include the electricity autarchy level (degree of self-sufficiency), and backup options for essential services such as backup for electricity, backup for water, and backup for heating. Since thermal comfort during outages also depends on

passive building behavior, envelope-related subcriteria (wall thickness, wall material, insulation and/or light surface (albedo)) are included to reflect the building's capacity to buffer indoor temperatures when active systems are impaired. The Recovery phase is represented by expected blackout shortage duration, which indicates the likely disruption time horizon and informs recovery needs and constraints.

3.5 MCDA

RENOWAVE adopts an MCDA approach to support the comparison of renovation alternatives across heterogeneous information types and domains (e.g., environmental, economic, social, and resilience-related indicators) [29]. In this context, Multi-Attribute Value Theory (MAVT) was selected as the methodological basis because it provides a transparent, intuitive, and computationally efficient way to aggregate multiple criteria into a single, decision-ready score, while keeping the link between input data, stakeholder preferences, and final recommendations explicit (see Report 1 for the method selection rationale and the overall MCDA workflow) [1], [30]. MAVT is implemented in RENOWAVE through an additive value model, commonly referred to as the Weighted Sum Model or Simple Additive Weighting (SAW), which is widely used for scoring and ranking decision problems [31]

Let A_i denote an alternative ($i = 1, \dots, n$) and let $j = 1, \dots, m$ denote the (sub)criteria used for evaluation at a given level of the hierarchy. RENOWAVE computes an overall score S_i for each alternative as [32]

$$S_i = \sum_{j=1}^m w_j \cdot r_{ij}$$

where w_j is the weight of criterion j , with $\sum_j w_j = 1$, and $r_{ij} \in [0,1]$ is the normalized score of alternatives i on criterion j . The same aggregation logic is applied consistently within the hierarchical structure of the framework, meaning that subcriteria can be aggregated to criterion-level scores, and criterion-level scores can then be aggregated into the overall alternative score, ensuring traceability from individual indicators to the final ranking.

Because criteria may be expressed in different units and measurement scales, RENOWAVE transforms raw performances x_{ij} into a common dimensionless scale by applying a linear utility (value) function operationalized via min–max normalization [33]. For each criterion j , the observed minimum and maximum values across the analyzed alternatives are denoted x_{ij}^{min} and x_{ij}^{max} , respectively. The normalized score r_{ij} is computed as:

- Benefit criteria (higher is better):

$$r_{ij} = \frac{x_{ij} - x_{ij}^{min}}{x_{ij}^{max} - x_{ij}^{min}}$$

- Cost criteria (low is better):

$$r_{ij} = \frac{x_{ij}^{max} - x_{ij}}{x_{ij}^{max} - x_{ij}^{min}}$$

This implementation implies that differences in performance are mapped linearly into differences in preference on the [0,1] scale, enabling direct comparability and aggregation across criteria. The resulting overall score is therefore a weighted combination of normalized criterion performances, reflecting both the technical performance of each alternative and the relative importance assigned to each criterion.[34]

Weights w_j represent preferences regarding the relative importance of (sub)criteria [34]. In RENOWAVE, the tool provides two options for defining the weighting scheme: (i) users can adopt the stakeholder-derived weights obtained through the participatory activities (see Report 1 for details [1], or (ii) they can specify their own weights to reflect case-specific priorities. In both cases, the selected weights are applied within the MAVT additive aggregation to compute overall scores and generate a ranking of renovation alternatives consistent with the chosen preference profile.

4 SUSTAINOVATE – Tool description

4.1 Overview and Purpose

SUSTAINOVATE (Sustainable and Resilient Renovation) is an interactive decision-support tool developed to support decision-makers in the assessment and comparison of building renovation strategies. The tool is designed to structure decision-making in contexts where multiple objectives coexist and may conflict (e.g., reducing environmental impacts while controlling costs, improving social performance, and increasing resilience to disruptions).

The core functionality is implemented through an MCDA workflow that enables to consider a wide variety of aspects, e.g. environmental, socio-economic, etc., in a transparent manner [35]. The MCDA workflow enables the user to (i) define a baseline building configuration and a set of renovation alternatives; (ii) compute/compile criterion values for each option; (iii) express preferences through a hierarchical weighting scheme; (iv) obtain a transparent ranking and an explanation of what drives the ranking through contribution analyses.

SUSTAINOVATE is implemented as an R Shiny application [36] with a modular structure. It can be used through an online instance (for demonstration and stakeholder interaction) or run locally from the project repository in an R environment. From a system perspective, the tool integrates one of the main families of MCDA methods, i.e., composite indicators (CI). CI, or indices, are single scores given by the aggregation of the performance of the alternatives and the preferences of the decision makers (e.g., [37]. In the SUSTAINOVATE Tool a Multi-Attribute Value Theory (MAVT) method is considered for the construction of CI due to its simplicity and transparency (e.g., [38]. The MAVT is a ranking method that develops a single score for each alternative by aggregating using an additive method, i.e., Weighted Sum [39], the normalized criteria and their weights. The normalized criteria values are obtained by means of value functions, which in case of SUSTAINOVATE are considered linear, i.e., a MIN-MAX normalization method [40].

4.1.1 The SUSTAINOVATE Tool User Interface (UI) structure

The SUSTAINOVATE Tool architecture is presented in Figure 1. In practical terms, the tool is organized into three main modules: Building Data, Alternatives, and MCDA Analysis (MCDA input matrix, weights, and results).

- **Building Data:** This module allows the user to enter the key information describing the current building (status quo), including the practical data required to characterize its baseline conditions.
- **Alternatives:** In this module, the user defines one or more renovation alternatives. Each alternative is configured within a dedicated panel to specify the relevant assumptions and intervention settings.
- **MCDA Analysis:** This module supports the comparative assessment of the building's sustainability and resilience by applying MCDA. The user evaluates the status quo against the

selected renovation alternatives through the definition of the MCDA input matrix and weights, and by reviewing the resulting rankings and performance scores.

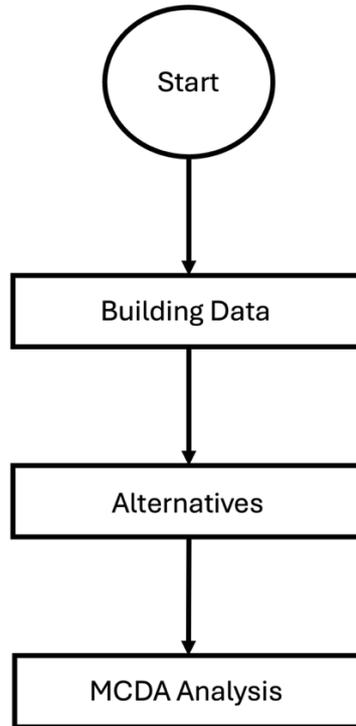


Figure 1: Structure of the User Interface (UI) of the SUSTAINOVATE Tool.

4.2 SUSTAINOVATE Tool

This section presents how to use the SUSTAINOVATE Tool following the modules defined in Figure 1. In section 4.2.1 the Building Data block is discussed including all possible features in this page. Furthermore, section 4.2.2 discusses how the alternatives should be developed for further analysis. Finally, in section 4.2.3 the actual MCDA analysis is presented.

4.2.1 Building Data

Once the SUSTAINOVATE Tool started, the user is redirected to the Starting Page (Figure 2). The page provides a concise description of the tool’s purpose and scope, authorship, and contact details. It serves as an entry point for stakeholders, and the “Start Using the Tool” button opens the operational part of the application.

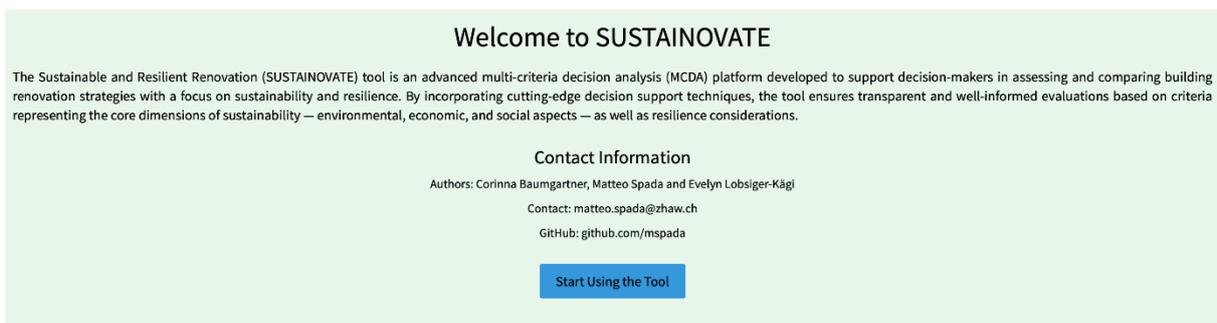


Figure 2: Starting Page as shows once the user runs the SUSTAINOVATE Tool.

Once clicked to “Start Using the Tool”, the user is redirect to the Building Data page (Figure 3). The page shows on top, from left to the right, the name of the tool, a button to hide the sidebar and a mail

icon linked to the e-mail address of the developer. The sidebar includes the pages of the tool, and the active one is highlighted.

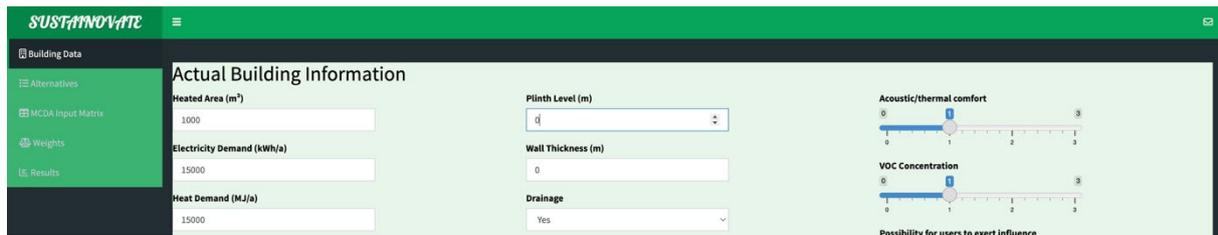


Figure 3: Dashboard of the SUSTAINOVATE Tool.

The Building Data page defines the baseline (reference) case, which serves as the benchmark for comparing renovation alternatives. It collects the information needed to describe the current building (status quo) in a structured and reproducible way, ensuring that all subsequent results are anchored to a consistent reference configuration Figure 4. Inputs include core numerical descriptors (e.g., heated area and energy demands), building attributes relevant to resilience and renovation feasibility (e.g., plinth level, wall thickness, drainage, materials, and other relevant construction features), and social or qualitative proxy criteria captured through slider-based inputs (e.g., comfort, VOC concentration, accessibility, and local value creation). By combining quantitative descriptors with qualitative proxies, the baseline definition allows the assessment to account not only for energy-related aspects but also for broader sustainability and resilience dimensions that are often difficult to represent through purely technical parameters. Once all available information has been entered, the user should click “Save Building Data”, located at the bottom-left of the screen, to store the baseline configuration and proceed to the next page (Figure 4).

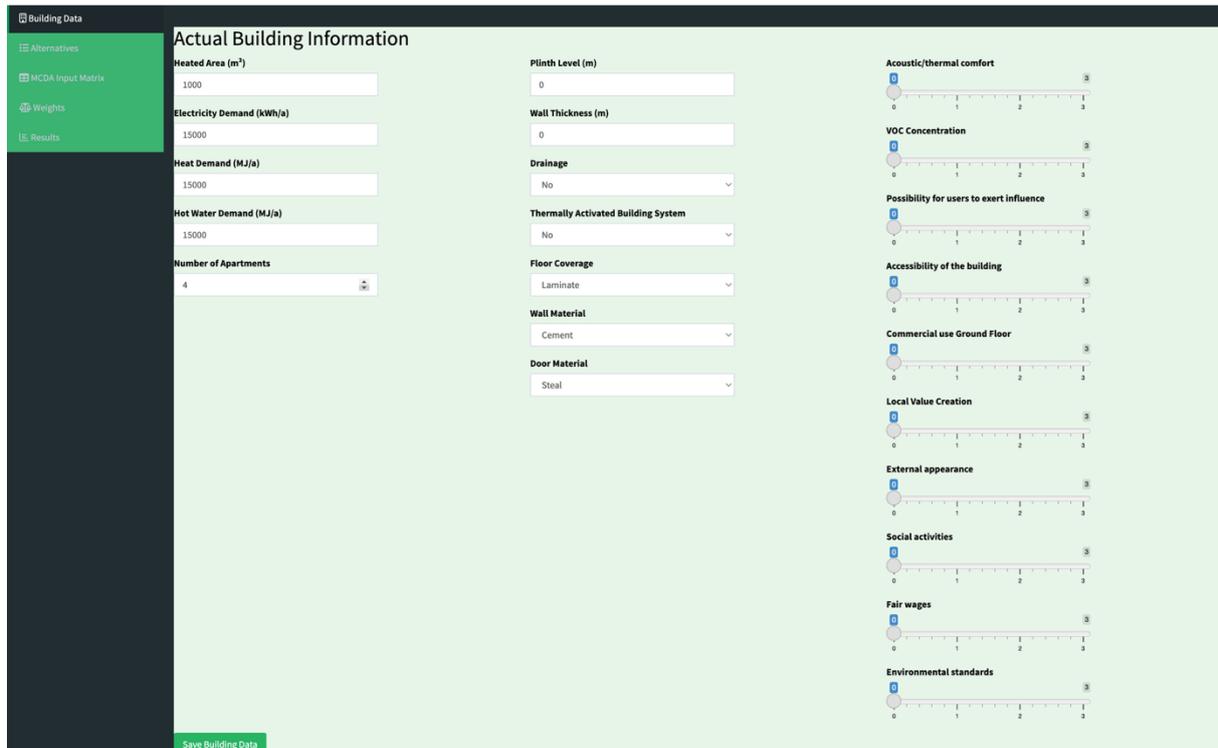


Figure 4: Building Data page including all the input requested by the tool to the user.

4.2.2 Alternatives

Once the Building Data are saved, the user can proceed to the Alternatives page by clicking on it on the sidebar (Figure 3). In the Alternatives page, the user defines the number of renovation alternatives

and configures each option in a dedicated panel. When entering this page, the user first specifies how many alternatives should be considered by entering the number in the corresponding field and clicking “Update Tabs”. The interface then generates the required set of configuration panels, enabling the user to populate and refine each alternative (Figure 5).

Within each panel, the user can define and combine multiple renovation measures and associated parameters, such as PV type/area/location, heat pump type and sizing, district heating connection, insulation measures and target U-values, window type/number/size, shading and green-roof options, and solar thermal solutions. In addition to selecting “Potential Renovation Measures”, the page also allows the user to adjust selected inputs that may differ from the baseline assumptions, including social or qualitative proxy criteria captured via sliders (e.g., comfort, VOC concentration, accessibility, and local value creation) as well as resilience- and feasibility-related building attributes (e.g., plinth level, wall thickness, drainage, materials, and other relevant construction features). This is useful when an alternative implies changes beyond purely technical measures (for instance, improvements in accessibility or materials affecting resilience performance). Once all alternatives have been defined, the user clicks “Submit Alternatives” to finalize the configuration and proceed to the evaluation step (Figure 5).

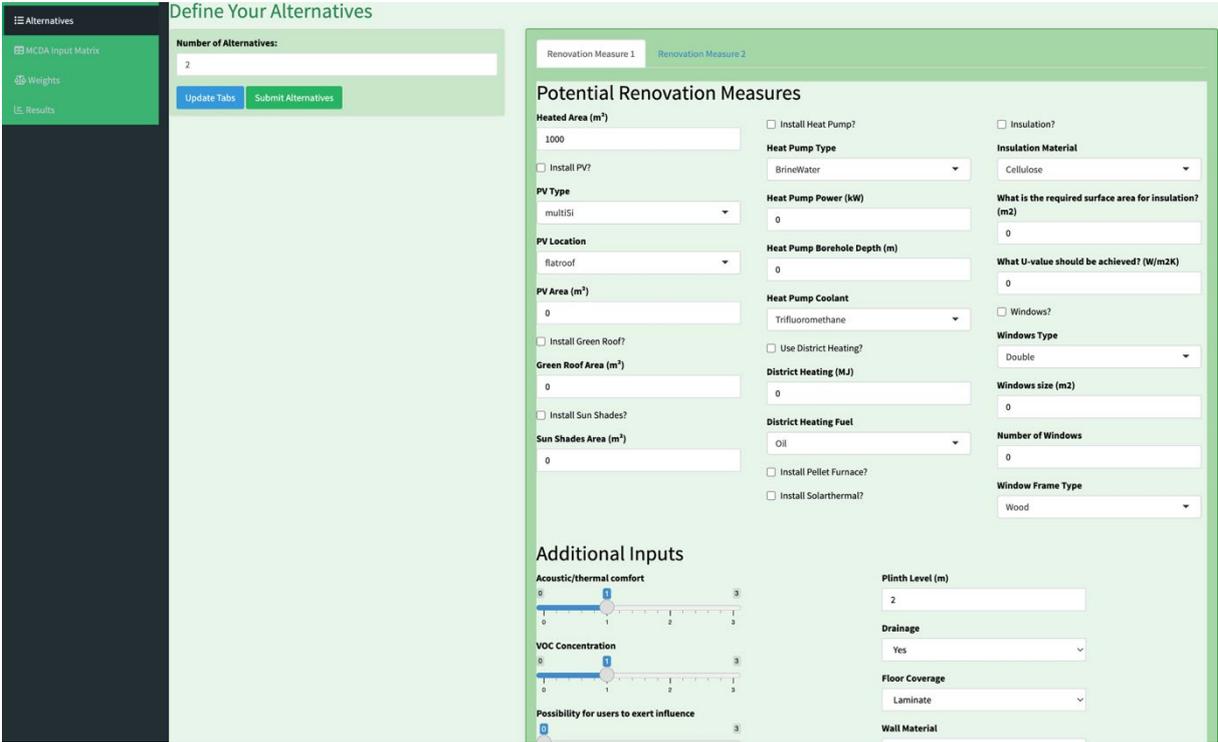


Figure 5: Alternatives page including all the input requested by the tool to the user.

4.2.3 MCDA Analysis

Once all the input data required by the MCDA analysis are saved, the user can proceed to the MCDA Analysis module of the SUSTAINOVATE Tool (Figure 1). This module comprises three pages in the tool, the MCDA Input Matrix page (section 4.2.3.1), the Weights page (section 4.2.3.2) and the Results page (section 4.2.3.3).

4.2.3.1 MCDA Input Matrix

This page consolidates all previously entered information into the MCDA performance (input) matrix, which acts as the model’s reference dataset before the MCDA is executed (Figure 6). In this table, rows represent the baseline/reference case and the defined renovation alternatives, while columns

represent the selected criteria covering sustainability- and resilience-related dimensions (see Report 1 [1]), which are estimated using the information given by the user (see section 4.2.1 and section 4.2.2). By structuring the inputs in a single, consistent matrix, the tool makes explicit what is being compared and ensures that the subsequent weighting and aggregation steps are based on a clearly traceable dataset.

The matrix is presented as an interactive table that supports searching, sorting, and quick inspection of values. Operationally, it is primarily used to verify that the dataset is complete and plausible (e.g., no missing entries, consistent units and ranges, and no unintended carry-over from the baseline), to inspect how alternatives differ across criteria (highlighting trade-offs and expected improvements or deteriorations), and to ensure full transparency regarding what enters the MCDA model. In practice, this page serves as a final quality-control step: it allows the user to validate inputs and confirm that the baseline and all alternatives are represented as intended before moving to the weighting and results pages.

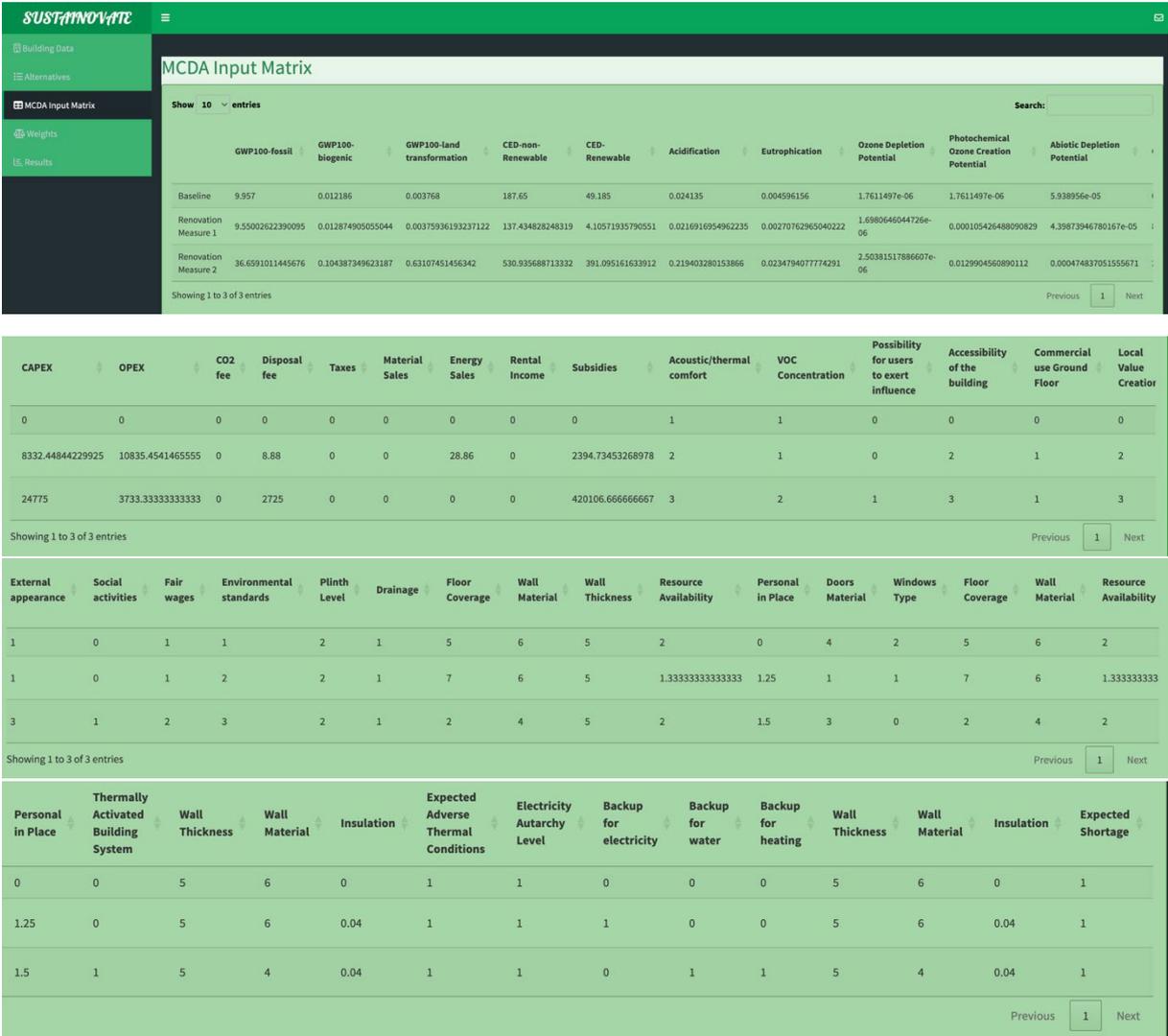


Figure 6: MCDA Input Matrix page as shown to the user once all the information for the building status quo and the renovation alternatives is provided.

4.2.3.2 Weights

This page enables preference elicitation through slider-based inputs and provides two weighting profiles: Default and Custom. Under Default, the weighting scheme reflects the preferences elicited from stakeholders during the workshops and is used as the recommended reference configuration for the assessment. Under Custom, the user starts from an equal-weights profile and can then adapt the weights freely to reflect alternative priorities or explore different decision perspectives ().

The weighting logic follows the tool’s hierarchical structure, which is both visible and directly actionable. Users can first set the relative importance of the main pillars (eLCA, LCC, sLCA, RA) and then refine the weighting scheme by adjusting sub-criteria weights, thereby translating high-level priorities into more detailed preference structures. By making these trade-offs explicit and easy to manipulate, the page supports stakeholder alignment and facilitates sensitivity-style exploration, allowing users to test how robust the ranking is to changes in value judgements and weighting assumptions.

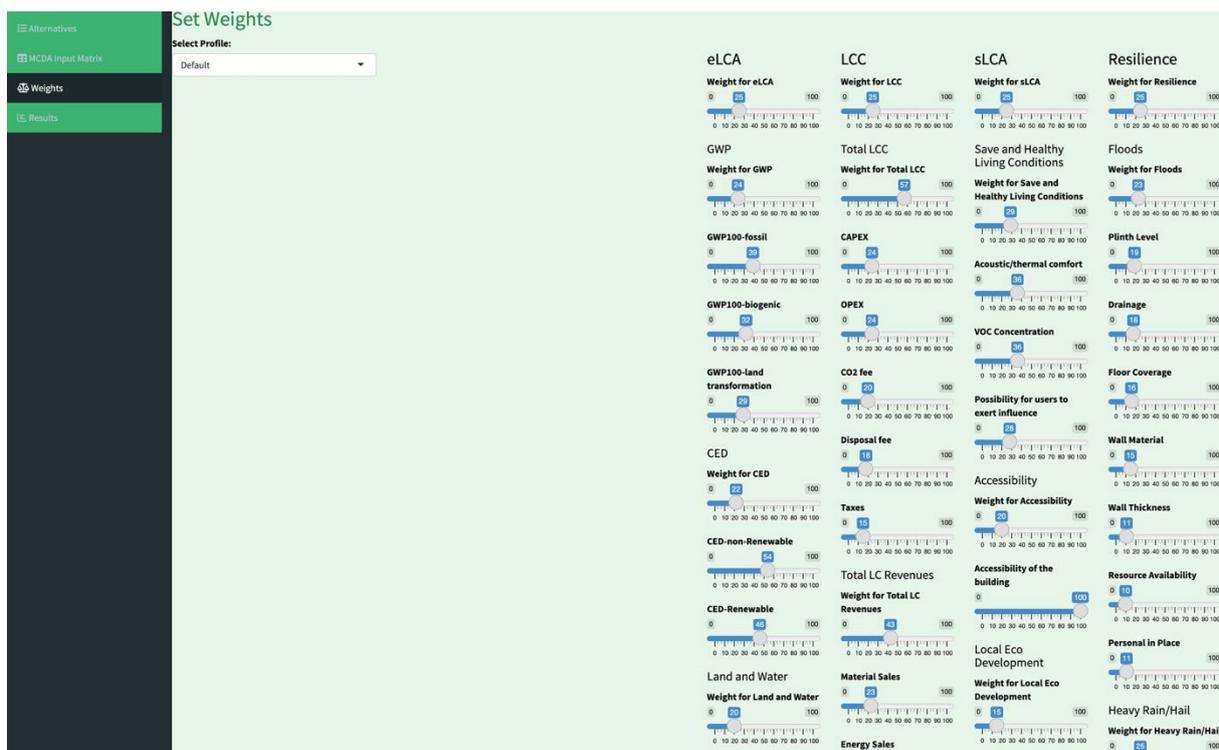


Figure 7: Snapshot of the Weights page of the SUSTAINOVATE Tool.

4.2.3.3 Results

The MCDA evaluation is executed from the Results page. When entering the page, the user is prompted to start the analysis by clicking the “Analyze” button, which runs the MCDA pipeline (Figure 8). In the current implementation, this consists of a Min–Max normalization of the criteria followed by aggregation through a Weighted Sum model (see section 3.5), using the weights defined in the previous step.



Figure 8: Results page once the user enters it.

Once the analysis is triggered, the page dynamically generates and displays three plots (Figure 9) that summarize both the overall performance and the underlying drivers. First, the page reports the final MCDA scores for the baseline/status quo case and all renovation alternatives, enabling a direct comparison and ranking of options. Second, it provides a higher-level contribution breakdown that shows how each main pillar (eLCA, LCC, sLCA, RA) contributes to the overall score, making trade-offs across major sustainability and resilience dimensions explicit. Third, it offers a lower-level contribution breakdown that highlights which sub-criteria are responsible for performance differences between alternatives, supporting a more diagnostic interpretation of the results.

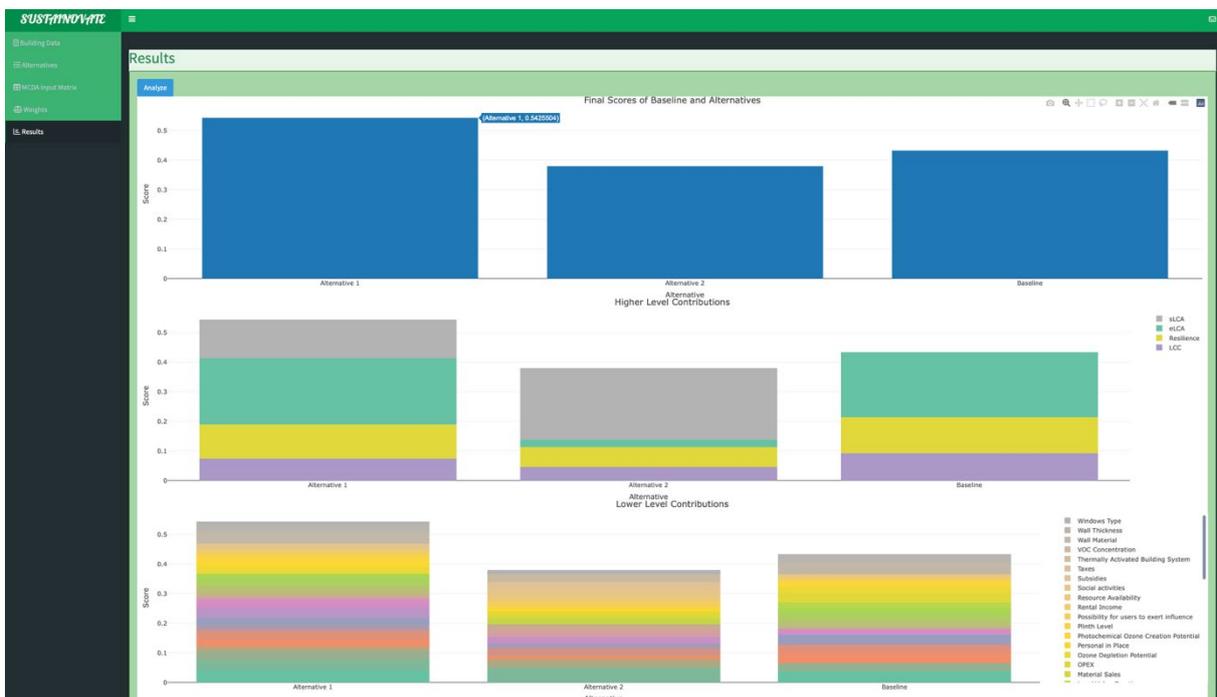


Figure 9: Results page after the user clicked on “Analyze”. Three plots show (i) overall score of the alternatives; (ii) main pillars (eLCA, LCC, sLCA, RA) contribution to the overall score of the alternatives; (iii) sub-criteria contribution to the overall score of the alternatives.

For usability and reporting purposes, each plot is interactive and can be exported by the user: clicking the camera icon on the plot interface downloads the corresponding figure (Figure 10). Overall, the Results page supports both selection (via transparent scoring and ranking) and explanation (via contribution breakdowns), aligning the analysis with typical reporting requirements where recommendations must be documented and justified in a traceable manner.

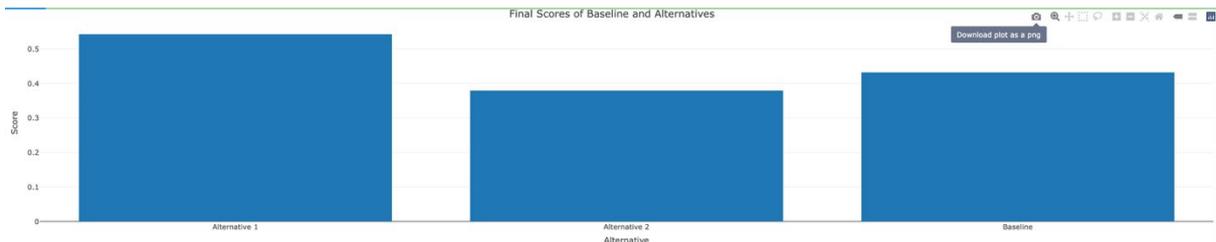


Figure 10: Option to download the resulting plot by clicking on the camera icon.

5 Conclusions and next steps

This report presents the development and consolidation of a Life-Cycle Sustainability and Resilience Assessment Framework (LCSA-F) and its operationalization in the SUSTAINOVATE decision-support tool for renovation measures in Swiss multi-family buildings. The work builds directly on the initial framework defined in the first Deliverable of SP1.4, where the overall system boundaries, functional unit, domains, criteria, and subcriteria as well as the default weighting profile and the MCDA method were established. In the present Deliverable, this conceptual foundation is translated into a fully specified LCSA framework with pre-modelled data for selected renovation measures and a functioning tool that can be used by practitioners for case-specific assessments.

In the initial report, the framework conditions were aligned across all four pillars—environmental LCA (eLCA), life cycle costing (LCC), social LCA (sLCA), and resilience assessment (RA)—through a first stakeholder workshop that led to the adoption of cradle-to-grave system boundaries (A1–C4) and a common functional unit of “heated area per year of building lifetime”. A hierarchical indicator structure with 4 domains, 16 criteria and 56 subcriteria was derived from an extensive literature review and expert judgement, covering key environmental impacts (e.g. GWP, CED, acidification, eutrophication, ozone depletion, resource use), cost components (TLCC, TPCR), social aspects (comfort, accessibility, local economic development, cultural heritage, social responsibility), and hazard-specific resilience indicators (e.g. floods, heavy rain/hail, heat- and coldwaves, blackouts). In a second expert workshop, this structure was complemented by a default weighting profile based on normalized expert preferences and the Multi-Attribute Value Theory (MAVT) was selected as most appropriate MCDA approach, ensuring a consistent, value-based aggregation of heterogeneous indicators into composite scores.

Building on this foundation, the final framework focuses on those indicators that can be implemented robustly in a practical tool while keeping consistency with the initial specification. For eLCA, CML-IA and related methods (including IPCC 2021 GWP 100a and CED 1.11) were chosen, and life-cycle inventories for predefined renovation measures (e.g. heat pumps, PV, insulation systems, windows) were modelled using databases such as ecoinvent and KBOB, with results aggregated to the agreed impact categories. For LCC, a conventional life-cycle cost scope was operationalized with CAPEX, OPEX, fees, taxes, and revenues (energy sales, material sales, rental income, subsidies) aligned to the same A1–C4 structure, using market data and allowing for regional differentiation via user-editable defaults. sLCA and RA remain strongly building- and context-dependent; therefore, their criteria and subcriteria defined in the initial framework are kept conceptually unchanged but are quantified in the tool by user inputs through structured scales rather than pre-calculated data, preserving methodological consistency while ensuring applicability.

The SUSTAINOVATE tool, implemented as an R-Shiny application, embeds this final framework and enables its use in real decision processes. Users can define a baseline building, configure multiple renovation alternatives by combining predefined measures, and populate the MCDA input matrix with both modelled and user-provided data. The weighting module offers two profiles: (i) a default expert-based profile derived in the initial Deliverable and (ii) a custom profile starting from equal weights, thereby directly operationalizing the preference structures developed earlier. The results module executes the MAVT-based MCDA pipeline (min–max normalization and weighted sum aggregation) and visualizes rankings as well as contribution analyses at pillar and sub-criterion level, which improves transparency on trade-offs and drivers of performance.

Taken together, the two Deliverables document a coherent progression from conceptual design to operational implementation of a first-of-its-kind framework that jointly addresses sustainability and resilience in the context of renovation, rather than new construction. The initial report defines the theoretical basis—system boundaries, indicator hierarchy, weighting logic, and MCDA method—while the present report translates these elements into a usable tool with embedded data for selected measures and tailored interfaces for stakeholders. Remaining limitations concern data availability and confidentiality for some eLCA models, context-sensitive parameters in LCC, and the need for user expertise when scoring social and resilience indicators. Future work should therefore focus on validating the framework and the tool with real building case studies, refining indicator definitions where needed, extending the measure library and hazard coverage, and exploring integration with other RENOWAVE tools and processes to support large-scale, robust decision-making for the decarbonization and climate-resilient transformation of the Swiss building stock.

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