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# Reuse-LCA

## Identification of the reduction potential of the environmental impacts of Swiss buildings, through the material reuse

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# Summary

The Reuse-LCA project aims to identify the reduction potential of the environmental impacts of Swiss buildings through material reuse. It investigates how reusing building components can contribute to decarbonizing the building sector. The project adopts a "bottom-up" approach, analysing the effective reuse in real building projects planned and built since 2020. This involved characterizing data and methods applied to a selection of representative case studies across different regions of Switzerland (Geneva/Lausanne, Basel, and Zürich) and various building types (residential, offices, etc.). Eight pilot case studies were selected for in-depth analysis.

A central objective of the Reuse-LCA project was to assess how reuse is integrated into Life Cycle Assessment (LCA) calculations for buildings. The study builds upon new LCA standards and methodologies, such as the SIA 390/1:2025 standard, and incorporated specific considerations for reused materials. The LCA perimeter defined in this project includes the production stage (A1-A3), transport to the construction site (A4), replacements during the use stage (B4), and the end-of-life stage (C1-C4). Notably, the project includes transport to the site (A4), addressing the question of the maximum supply distance for reused products to remain environmentally efficient.

The study characterizes reuse practices and their logistic chains for the selected case studies. This includes detailing the supply chain of reused components, including dismantling, transport, storage, reconditioning, and modification processes. The study quantifies the environmental key performance indicators focusing on GHG emissions, biogenic carbon and the other usual indicators of LCA data in the construction sector. Additional indicators related to the circularity and reuse are also considered: the GHG emission reductions due to reuse, the material intensity and the share of adaptive reuse (preservation rate) and the share of ex-situ or in-situ reuse.

The findings indicate that reusing building components generally decreases upfront emissions (A1-A4). However, the study highlights that the reuse logistic chains, particularly transport, significantly influence the environmental outcomes. The efficiency of reuse, in terms of GHG emissions reduction, is context-dependent and varies based on the type of reused material, the distance of transport, and the processes involved in making the reused component ready for its new use. For instance, reused elements replacing high-carbon new equivalents (e.g., aluminium blinds, PV panels) can allow longer transport distances while still retaining carbon benefits. The study also delves into specific reuse scenarios. For example, the case study of concrete reuse from a deconstruction site demonstrates significant potential for GHG emission reduction compared to new concrete, but this advantage is diminished by transport distance.

The Reuse-LCA project contributes to better understanding the challenges of accounting for reuse in building LCA and suggests the need for more tailored assessments and data. It emphasizes that while reuse is a valuable strategy for reducing the GHG emissions, it should be considered alongside other low-carbon measures in building projects. Perspectives include consolidating data into an LCA tool for reuse and developing operational guides for different building product families.

# Résumé

Le projet Reuse-LCA vise à identifier le potentiel de réduction des impacts environnementaux des bâtiments suisses grâce à la réutilisation des matériaux. Il étudie comment la réutilisation des composants du bâtiment peut contribuer à la décarbonation du secteur du bâtiment. Le projet adopte une approche "bottom-up", analysant la réutilisation effective dans des projets de construction réels planifiés et construits depuis 2020. Cela a impliqué la caractérisation des données et des méthodes appliquées à une sélection d'études de cas représentatives dans différentes régions de Suisse (Genève/Lausanne, Bâle et Zurich) et divers types de bâtiments (résidentiels, bureaux, etc.). Huit études de cas pilotes ont été sélectionnées pour une analyse approfondie.

L'un des objectifs principaux du projet Reuse-LCA était d'évaluer l'intégration de la réutilisation dans les calculs d'écobilan de bâtiments. L'étude s'appuie sur les normes et méthodologies d'écobilan existantes, telles que la nouvelle norme SIA 390/1:2025, et a intégré des considérations spécifiques aux matériaux réutilisés. Le périmètre de l'écobilan défini dans ce projet comprend la phase de production (A1-A3), le transport vers le chantier (A4), les remplacements en cours d'utilisation (B4) et la fin de vie (C1-C4). Le projet inclut notamment le transport vers le chantier (A4), abordant ainsi la question de la distance d'approvisionnement maximale pour que les produits réutilisés restent écologiquement performants.

L'étude caractérise les pratiques de réutilisation et leurs chaînes logistiques pour les études de cas sélectionnées. Cela inclut le détail de la chaîne d'approvisionnement des composants réutilisés, y compris les processus de démantèlement, de transport, de stockage, de reconditionnement et de modification. L'étude quantifie les indicateurs clés de performance environnementale en se concentrant sur les émissions de GES, le carbone biogénique, ainsi que sur les autres indicateurs habituels des données d'ACV dans le secteur de la construction. D'autres indicateurs liés à la circularité et à la réutilisation sont également pris en compte : les réductions d'émissions de GES dues à la réutilisation, l'intensité matérielle et la part de réutilisation adaptative (taux de préservation) et la part de réutilisation ex-situ ou in-situ.

Les résultats indiquent que la réutilisation des composants de construction réduit généralement les émissions initiales (A1-A4). Cependant, l'étude souligne que les chaînes logistiques de réutilisation, en particulier le transport, influencent significativement les résultats environnementaux. L'efficacité du réemploi, en termes de réduction des émissions de GES, dépend du contexte et varie selon le type de matériau réutilisé, la distance de transport et les processus de préparation du composant réutilisé pour sa nouvelle utilisation. Par exemple, le remplacement d'éléments réutilisés par des équivalents neufs à forte teneur en carbone (par exemple, stores en aluminium, panneaux photovoltaïques) peut permettre des distances de transport plus longues tout en conservant les avantages sur les émissions de GES. L'étude examine également des scénarios de réemploi spécifiques. Par exemple, l'étude de cas sur la réutilisation du béton provenant d'un chantier de déconstruction démontre un potentiel significatif de réduction des émissions de GES par rapport au béton neuf, mais cet avantage est atténué par la distance de transport.

Le projet Reuse-LCA contribue à mieux comprendre les défis liés à la comptabilisation du réemploi dans l'écobilan des bâtiments et souligne la nécessité d'évaluations et de données plus adaptées. Il souligne que si la réutilisation est une stratégie efficace pour réduire les émissions de GES fossiles, elle doit être envisagée parallèlement à d'autres mesures bas carbones dans les projets de construction. Les perspectives incluent la consolidation des données dans un outil d'écobilan et l'élaboration de guides opérationnels pour différentes familles de produits de construction.

# Zusammenfassung

Das Projekt Reuse-LCA zielt darauf ab, das Potenzial zur Reduzierung der Umweltauswirkungen von Schweizer Gebäuden durch die Wiederverwendung von Materialien zu ermitteln. Es untersucht, wie die Wiederverwendung von Bauteilen zur Dekarbonisierung des Bausektors beitragen kann. Das Projekt verfolgt einen Bottom-up-Ansatz und analysiert die effektive Wiederverwendung in realen Bauprojekten, die seit 2020 geplant und gebaut wurden. Dazu gehörte die Charakterisierung von Daten und die Anwendung von Methoden auf eine Auswahl repräsentativer Fallstudien in verschiedenen Regionen der Schweiz (Genf/Lausanne, Basel und Zürich) und verschiedenen Gebäudetypen (Wohn-, Bürogebäude usw.). Für eine eingehende Analyse wurden acht Pilotfallstudien ausgewählt.

Eines der Hauptziele des Reuse-LCA-Projekts bestand darin, die Integration der Wiederverwendung in die Berechnung der Ökobilanz von Gebäuden zu bewerten. Die Studie stützt sich auf bestehende Ökobilanznormen und -methoden, wie etwa die neue Norm SIA 390/1:2025, und berücksichtigt spezielle Aspekte für wiederverwendete Materialien. Der Umfang der in diesem Projekt definierten Ökobilanz umfasst die Produktionsphase (A1-A3), den Transport zum Standort (A4), den Austausch während der Nutzung (B4) und das Lebensende (C1-C4). Das Projekt beinhaltet den Transport zur Baustelle (A4) und trägt damit dem Thema maximale Lieferdistanz Rechnung, damit wiederverwendete Produkte ökologisch effizient bleiben.

Die Studie charakterisiert Wiederverwendungspraktiken und ihre Lieferketten für die ausgewählten Fallstudien. Hierzu gehören Einzelheiten zur Lieferkette wiederverwendeter Komponenten, einschliesslich der Prozesse Demontage, Transport, Lagerung, Wiederaufbereitung und Modifikation. Die Studie quantifiziert die ökologischen Leistungsindikatoren mit Schwerpunkt auf den THG-Emissionen, der biogenen Kohlenstoff sowie den anderen üblichen Indikatoren der Ökobilanzdaten im Baubereich. Zusätzliche Indikatoren, die sich auf die Kreislaufwirtschaft und die Wiederverwendung beziehen, werden ebenfalls berücksichtigt: die Verringerung der THG-Emissionen aufgrund der Wiederverwendung, die Materialintensität und der Anteil der adaptiven Wiederverwendung (Erhaltungsquote) sowie der Anteil der Ex-situ- oder In-situ-Wiederverwendung.

Die Ergebnisse zeigen, dass die Wiederverwendung von Bauteilen im Allgemeinen die Erstellungsemissionen reduziert (A1-A4). Die Studie unterstreicht jedoch, dass die Lieferketten für die Wiederverwendung, insbesondere der Transport, einen erheblichen Einfluss auf die Umweltauswirkungen haben. Die Wirksamkeit der Wiederverwendung im Hinblick auf die Reduzierung der Treibhausgasemissionen ist kontextabhängig und variiert je nach Art des wiederverwendeten Materials, der Transportentfernung und den Prozessen zur Vorbereitung der wiederverwendeten Komponente für ihre neue Verwendung. Beispielsweise können wiederverwendete Elemente, die neue kohlenstoffintensive Äquivalente ersetzen (z. B. Aluminiumjalousien, PV-Paneele), längere Transportwege zulassen und gleichzeitig die CO2-Vorteile beibehalten. Die Studie untersucht auch konkrete Wiederverwendungsszenarien. So zeigt beispielsweise die Fallstudie zur Wiederverwendung von Beton von einer Abbruchstelle, dass im Vergleich zu neuem Beton ein erhebliches Potenzial zur Reduzierung der Treibhausgasemissionen besteht.

Das Projekt „Reuse-LCA“ trägt zu einem besseren Verständnis der Herausforderungen bei, die mit der Berücksichtigung der Wiederverwendung in der Ökobilanz von Gebäuden verbunden sind, und unterstreicht den Bedarf an geeigneteren Bewertungen und Daten. Es betont, dass die Wiederverwendung zwar eine wirksame Strategie zur Reduzierung des gebundenen Kohlenstoffs sei, diese jedoch bei Bauprojekten zusammen mit anderen Massnahmen zur Verringerung der THG-Emission betrachtet werden müsse. Zu den nächsten Schritten gehören die Konsolidierung der Daten in einem LCA-Tool für die Wiederverwendung und die Entwicklung von Betriebsleitfäden für verschiedene Bauproduktfamilien.

# Take-home messages

Below are summarized the main take-home messages of the project

- Material reuse in buildings presents a significant opportunity to reduce the environmental impact, particularly GHG emissions, for the construction sector in Switzerland. This is one of the relevant strategies towards achieving net-zero goals which should be assessed using a comprehensive Life Cycle Assessment (LCA).
- The environmental benefits of reuse are highly dependent on the specific context, including the type of material being reused, the condition and required reconditioning efforts, and critically, the transportation distances involved. Transport can offset the initial carbon savings, especially for materials with lower embodied carbon (e.g., biobased and stones).
- Adaptive reuse and in-situ reuse can offer substantial and “easy” GHG emissions targets by minimizing transport and processing requirements. Examples include the preservation of existing structures and the reuse of materials within the same building.
- The choice of the "new equivalent" material against which reused materials are compared significantly influences the calculated environmental savings. A functional equivalency approach, considering the performance, provides a more accurate assessment than a simple material equivalency e.g., for key components like thermal insulation, PV or windows.
- The Reuse-LCA project emphasizes the need to assess the entire reuse chain—transport, transformations, storage, and potential losses—to fully capture its environmental impacts. This requires refined LCA methods and detailed, project-specific data. The new SIA 390/1 standard and the SIA 2032 technical specification are a step forward but are still not fully tailored for assessing reuse in LCA. One key aspect is also the assumptions about future replacements of reused materials as it influences the LCA results and associated savings due to reuse.
- Reuse is only one of several key strategies for designing or renovating a building with a low-carbon perspective. It should not focus only on high-mass elements, but also on components with essential functions, as their reuse can significantly reduce emissions.

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# Abbreviations

GHG: Greenhouse gas emission

HPL: High Pressure Laminate

LCA: Life Cycle Assessment

PENR: Primary energy non-renewable

UBP: Umweltbelastungspunkte

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# 1 Introduction

## 1.1 Natural resources in the building sector

The economic growth of the last decades redefined prosperity, as being equivalent to material wealth and it is, thus, responsible for the degradation of approximately 60% of the world's ecosystems [1]. In Switzerland, around 70% of the environmental impacts of the consumption are linked to the activity of the construction, alimentation and mobility domains, while, around 30% of the total greenhouse gas emissions (GHG) come only from the construction of building materials [2]. The average embodied GHG emissions of the Swiss building stock currently represent 650 kg $CO_{2\text{-eq}}/m^2$, according to the GEPAMOD project [3]. With approximately 25% of these emissions linked to the future replacement of materials according to the DUREE project [4], the GHG emitted only for the construction stage represent, nearly, 500 tons $CO_{2\text{-eq}}/m^2$.These emissions are directly emitted and cannot be reduced, during the building life cycle, unlike the emissions of the operational energy. Furthermore, a recent research conducted at ETH Zürich shows that the cumulative GHG emissions related to the material use due to demolition, refurbishment (waste and new input material) and new construction will continue to increase and will reach around 150-175 Mio tons of $CO_{2\text{-eq}}$, by 2055 [5]. In terms of material mass, buildings represent in average 975 - 1073 Mio tons [6], leading to a material intensity of about 2 tons/$m^2$, given a 490 Mio $m^2$ surface area for the residential building stock. This material stock is expected to increase over time, by approximately 25%-31%, until 2055. It becomes evident that the construction materials represent a significant environmental burden of the total environmental impact of a building, which will continue to grow, mainly, because of the population and per-capita floor area increase [5].

The increasing need for material input leads to the excessive exploitation and consequently the depletion of the material and energy resources, as well as to increased waste production. Peuportier et al. [7] states that 'a significant percentage of the natural resources that are used in industrialized countries are exploited by the building industry', while approximately 88% of the total material flow is apportioned to the industry of the building materials [6]. Concerning the waste linked to the construction domain, only in Switzerland, from about 85 million tons of waste, 84% come from the construction sector, among which around 17 million tons concern demolition waste that are produced every year [2]. Even if recycling is well established, the quantity of the demolition materials that remain unexploited is still significant, i.e., more than 5 million tons, given that annually around 3000 to 4000 buildings are demolished [8].

## 1.2 Circular economy (CE) and reuse of building materials

It is evident that the building sector participates with different ways in the environmental degradation and thus the Swiss energy policy takes actively part in its preservation. The first ambitious goals concern the energy and climate commitment of Switzerland for 2050 with the SIA Energy Efficiency Path (according to the 2000-Watts Society vision) and the recent climate neutrality objective [9]). According to Swiss Federal Office of Energy Vision for 2050 for the Building stock, the energy efficiency must focus to the *'ROSEN' concept, i.e. Reduktion - Reduction, Optimierung – Optimization, Substitution – Substitution, Enreuerbare Energien – Renewable energy, Nachhaltigkeit – Sustainability* [10]. An already well-known concept, which serves this goal, is that of the circular economy; a concept that Switzerland had already adopted from 1980 [11]. According to Ghisellini et al. [12] circular economy and the closed-loop patterns promote the efficient use of the available resources and an interest for the urban and industrial waste. In addition, as stated in Anastadiades et al. [13] circular economy is the key, in order to reach the sustainability goal, since circularity offers the way for more resilient and sustainable buildings and cities [14].

The core principles of the circular economy concept could be explained by the 4R framework [15], which is found to be at the center of the European Union Waste Framework Directive [16]. According to the 4R framework, circular economy can be applied through 'Reduce', *'Reuse'*, *'Recycle'* and 'Recover' techniques. Applying the CE concept in the construction domain would mean redesign – rethink a building concept, minimize the building's energy consumption, reduce the energy resources and waste production, reuse and recycle the materials. Among all these actions, in line with the CE, the reuse of construction materials in the built environment is the less studied method, as stated in Munaro et al [14], who conducted a literature review on the application of the circular economy concept in the building environment. Reuse is defined as *"any operation by which products or components that are not waste are used again for the same purpose for which they were conceived",* according to the EU Waste Framework Directive [16].

The reuse of building materials is an old technique and applications of reuse or repurposing can be found even from the first century, when parts of a Roman temple were used in Al-Mushannaf, in Syria [17]. Reuse has been used throughout history, but it is mainly the past years that has regained its value, primarily, because of the significant benefits, linked to the environment's preservation. In the literature, different definitions exist, concerning the reuse of materials. It is essential to clarify key reuse concepts. Repurposing occurs when a component is reused in a new application *with a different function*, such as a door repurposed as a table. Furthermore, upcycling denotes reuse where the component achieves a higher quality or value in its second life, while downcycling indicates reuse resulting in reduced *quality* or value [17]. The *quality* or *value* means market value, durability, performance (thermal or electric), structural, etc. French regulations provide specific distinctions in the Circular Economy Law (Loi AGEC); "réemploi" refers to the direct reuse of a component *for its original function without it being classified as waste,* whereas "réutilisation" signifies reuse *after the component has formally exited waste status*, potentially involving functional change or preparation. In the European Waste Framework Directive (2008/98/EC) reuse and "preparing for reuse" are two separated concepts based on the same previous definitions.

Several studies have highlighted the benefits of reusing of materials in construction, such as the fact that less natural resources, energy and labour are required compared to the production of new materials, or even recycling and disposal [14]. In addition, by extending the life cycle of the component, the need to produce new materials is minimised, leading to a reduction in waste generation [18]. In addition to the environmental benefits associated with material reuse, several studies have identified other co-benefits associated with a circular economy for building materials and components. Moreno et al. [19] and Verian et al. [20] stated that the material reuse is associated with "financial value, due to cost savings from the use of lower-priced secondary materials". They also mention that the material reuse can be responsible for the creation of jobs and value for network partners [21]. In Switzerland, local initiatives also aim at this goal, such as the association Pro Maison, which serves as a platform for the reuse market and storage mainly of sanitary elements and kitchens, as well as for the social integration of unskilled workers. Finally, material reuse contributes to an innovative approach to architecture where "forms follow availability" [17], [22]. It also contributes to maintaining the identity, the historical value and the craftsmanship of the past buildings [23], while it boosters the creativity of the architects, as well.

## 1.3 Accounting for reuse in the building LCA and ecological savings

Two types of design with reused materials can be distinguished. Upstream reuse design, where the building components are reused in a new building project, and downstream reuse design, which follows the concept of Design for Disassembly/Deconstruction (DfD), ensuring that the components can be separated and reused at the end of the building's life [24]. In addition, there are different ways of delivering the reused building components. They can either be purchased on the *"*reuse market*"* (e.g. through existing platforms such as Materiuum, Salza or Bauteilclick), or come from existing buildings that are to be renovated, transformed or demolished. In the latter case, the reused elements can be used on in the same site (in-situ reuse) or on another site (ex-situ reuse). So far, there is no general agreement on how to allocate the impacts of the above mentioned reuse methods to the different LCA phases [24]. However, in Switzerland, a common methodological approach seems to emerge relatively to this question (see section 2.2). The most common approach to allocating impacts is the cut-off method [25]. Applying the cut-off method for the reused elements means that the environmental impacts of the manufacturing of the element are allocated to the first building life cycle, while no benefits are granted to this first life cycle. Indeed, the benefits are allocated to the second life cycle of the reused element, i.e. the latter is free of the ecological impacts of the manufacturing stage. This approach is, also currently used in the ecoinvent Life Cycle Inventory database (version 2.2, 2016), for the recycled materials and consequently in the Swiss LCA database for the construction sector [25], [26]. The same allocation rule is included in the SN EN 15804, with the only difference being that the reuse and recycling potentials are also included in the D module, which is out of the system boundaries of the building LCA [27]. Thus, using the cut-off approach for reuse offers consistency to the current LCA data & standards. Recent studies, concerning the integration of the reused elements in the LCA, are based more or less on this method. For example, a method developed by a private engineering office in France, (G-ON method) [28] is based on the cut-off allocation rule and included the following phases, in order to integrate the reuse in the LCA calculations : transportation of the component to the storage site, all the different energy consumptions for the conditioning of the component and its transport to the new construction site for its reuse. In addition, K. Pfäffli [29] proposed three alternatives for the integration of the reuse in the LCA calculations, in a study on a lightweight building extension. Method 1 ("Teilamortisation") considers a residual ecological impact from the first life cycle, if the building element is reused before the end of its amortization period (service life), while method 2 ("Zusatzaufwand") considers no partial amortization and the following impacts are added: impacts of dismantling, transport to the storage site, impacts of the treatment of the reused element (e.g. painting, additional cover), transport to the building site and the on-site construction. Method 3 ("Wie neu") considers all reused materials, as new, using the existing Swiss LCA data (KBOB). Method 2 is the closed to the SIA 2032:2020 perimeter and thus it is considered as the most relevant choice, from the author.

The other allocation methods for the considering reuse in LCA calculations differ in their scope. A recent comparative study, analysed the following methods, except the cut-off method, which were originally, developed for recycled products : the end-of-life method, the distributed allocation method, the European Commission's Environmental Footprint method and the degressive method [24]. Each method allocates impacts to different time horizons of the reused element, i.e. to its first, intermediate or final life cycle and therefore the methods are not directly comparable. In addition, there is uncertainty about the number of reuse cycles and the realisation of future reuse potential that has already been calculated and included in today's calculations. As a result, these methods present mainly theoretical environmental benefits that cannot necessarily be identified and defined in practice and do not correspond to reality.

Different studies in Switzerland and at international level have, already, quantified the potential ecological benefits of reuse. Eckelman et al. demonstrated that the GHG emissions can be reduced up to 50% for a steel building when reused is applied, compared to a traditional building [17]. T. Malmqvist et al. showed that there is a potential of a 70%-80% environmental gain, depending on the LCA indicator studied, when reuse is employed [30]. In addition, Minunno et al. showed that there is an approximately 28% saving in terms of global warning potential when reuse is applied, compared to a traditional design for a case study [31]. Eberhardt et al. proved that there is up to 60% of environmental saving, when components are reused for three times [32]. It should be also noted that reuse can be more beneficial over recycling. W.Y. Ng et Chau showed that, by calculating the energy saving potential, between recycling, reuse and incineration, the reuse was more beneficial for the doors and windows than recycling [33]. For the roof constructions, wall finishes and internal walls the reuse was competing recycling and, in some cases, reuse could be more beneficial than recycling. Finally, Minunno et al. showed that there is a 39% saving in terms of greenhouse gas emissions, when comparing to the recycle option [31].

Moreover, in practice recent examples of building projects with reuse confirm the significant ecological savings related to the re-use strategy. A first recent example concerns the project "La Grande Halle de Colombelles" in France, which integrated 20% in mass of reused materials like windows, suspended ceiling, lavatory sink, WCs, heaters, timber, doors and tiles [28]. According to the LCA study, 25 tons $CO_{2\text{-eq}}$, were economized by the reuse. These emissions correspond to 580 $m^2$ of a 16 cm concrete wall, or 212'000 km by car. In Denmark, a row house that included reused windows for the huge window façade, resulted in 96% of $CO_2$ savings, compared to using new glass. In addition, solid wood was retrieved for the flooring, as well as 1400 tons of concrete waste, which was used to produce recycled concrete, saving 12-15% $CO_2$ [32] Furthermore, in New Zealand, already in 2012, an office building was rebuilt, by using the existing building's floor slab and cross beam structure. In the end, the building successfully recycled or reused 77% of demolition waste and 92% of the construction waste [34]. In Switzerland, the Hall K.118, in Winterthur, was renovated and vertically extended, using as much as possible, materials from nearby demolition sites [29]. For the K.118 transformation, approximately 38% of the total building weight came from reused materials, such as steel beams, windows and sheet – metal panes [24]. An initial LCA study, conducted by K. Pfäffli, partner of this study, showed important gains in terms of GHG emissions. By using 15% of reuse and 20% of adaptive reuse, of the total building weight, there were approximately 500 tons of GHG emissions saved. These emissions correspond to the emissions of the manufacturing stage of a small energy-efficient multi–family house (MFH). In other words, these emissions correspond to the ones of the operational energy of the Hall K.118 until 2080.

## 1.4 Problem statement and objectives

As shown by the previous background information, the reuse of components presents clear benefits and it is one of the measures to decarbonize the building sector towards a net zero goal by 2050. The question arises as to how important reuse can be in this context and how reuse can contribute to the achieve the net zero goal. Based on the state-of-the-art, different research perspectives can be drawn:

- Analysis of reuse potential using "top-down" approach with prediction and estimation from the "offer side" at the stock level of the country or at a more local level (e.g., for a city).
- Analysis of the effective reuse potential using a "bottom-up" approach of individual pilot projects which are effectively planned and built (demand-side reuse).

While "Top-down" or predictive approaches has been tackled in a parallel SFOE project [35] and within a PhD thesis of ETH Zürich, partner of this study [36], this study follows a "Bottom-up" approach based on case studies looking at the effective reuse in real projects (see Figure 1). The initial questions from this project are the following:

- How to assess reuse in the LCA calculations for buildings?
- What are the current shares of the different types of reuse in building projects based on recent pilot case studies?
- What are the GHG emissions reduction achievable per type of components and per building layers and at the building level for the whole life cycle of the buildings (material related impacts)?
- Finally, how to determine the contribution of reuse in the panel of the different "low carbon" measures in building projects?

The purpose of this project is to characterise data, method and apply them on a selection of representative case studies that have been planned and built since 2020 to better characterise reuse trends and issues for a representative buildings sample in the light of the new SIA 390/1 standard [27].

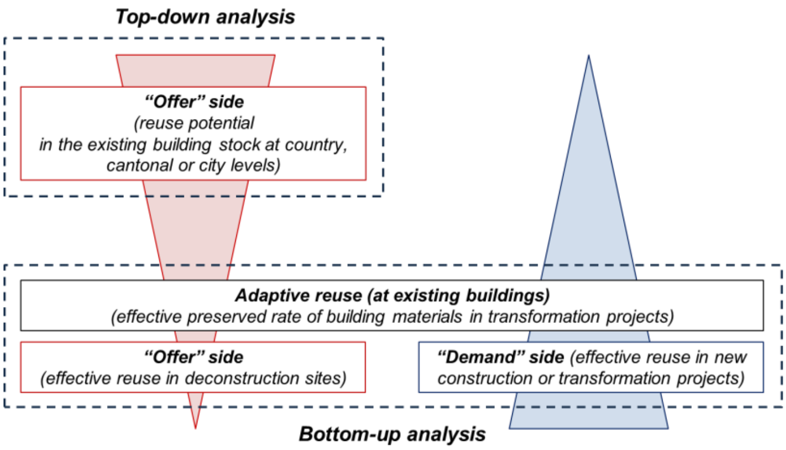



Figure 1: The two scales of analysis to characterise the reuse of materials in the Swiss building stock.

This study will look at the today's effective reuse nowadays either from the building coming to a dismantling or for a new project (new construction or a transformation). The detailed objectives are the following:

- Characterization of the effective reuse in new projects (new construction or transformation) for a set of building elements based on the analysis of pilot building case studies under planning & construction in Switzerland.
- Characterisation on the reuse logistic chains to better understand the intensity of transport/logistic for each reused component (only for ex-situ reuse).
- Characterisation of the environmental key performance indicators for the embodied impacts of buildings, including the quantification of the material intensity, the GHG emissions as well as the GHG emissions' reduction due to reuse and the biogenic carbon storage.
- Translate results as graphical webpage as a mean of disseminate the LCA results to a larger audience and showcase the reuse GHG emissions' reduction in specific built contexts
- Investigate additional topics about reuse in partnership with the Industrial Services of Geneva (SIG) with the potential environmental saving and its trade-offs with the thermal performance of the building envelope (for windows frame) and the critical topic of concrete reuse in a recent dismantling project in Romandie.

## 1.5 Structure of the report

Figure 2 presents the conducted activities which are reported in this report. The definition of the methodology is part of chapter 2. Chapter 3 presents the characterisation of building projects (new construction or transformation/renovation) mainly reflecting demand-side reuse while one building project deals with the offer side at the deconstruction site. The reuse characterisation is presented with graphical and detailed logistic chains. Then, chapters 4 and 5 report and discuss the material intensity with the different shares of reuse as well as the chosen LCA indicators.

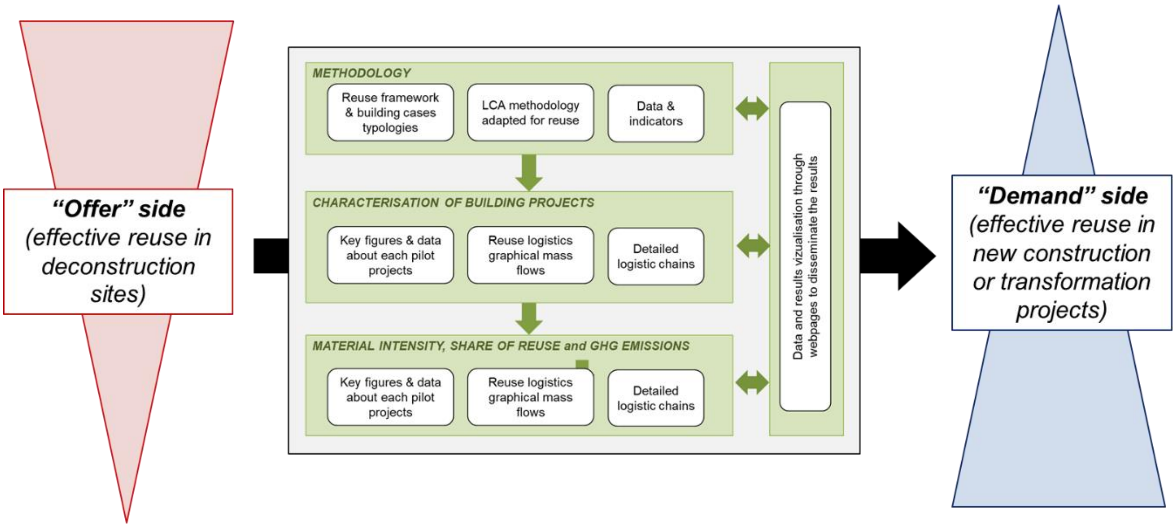



Figure 2: Overall structure of the project with "offer" and "demand" sides as well as the different parts of the study.

# 2 Procedure and methodology

## 2.1 Reuse framework and building case studies typologies

Different types of “reuse” strategies exist in buildings. The graphical representation in Figure 3 shows the different materials flows going out of a building dismantling (in red) in opposite to the incoming flows of materials and elements (virgin or reused) in a project of new construction or transformation of an existing building (in blue).

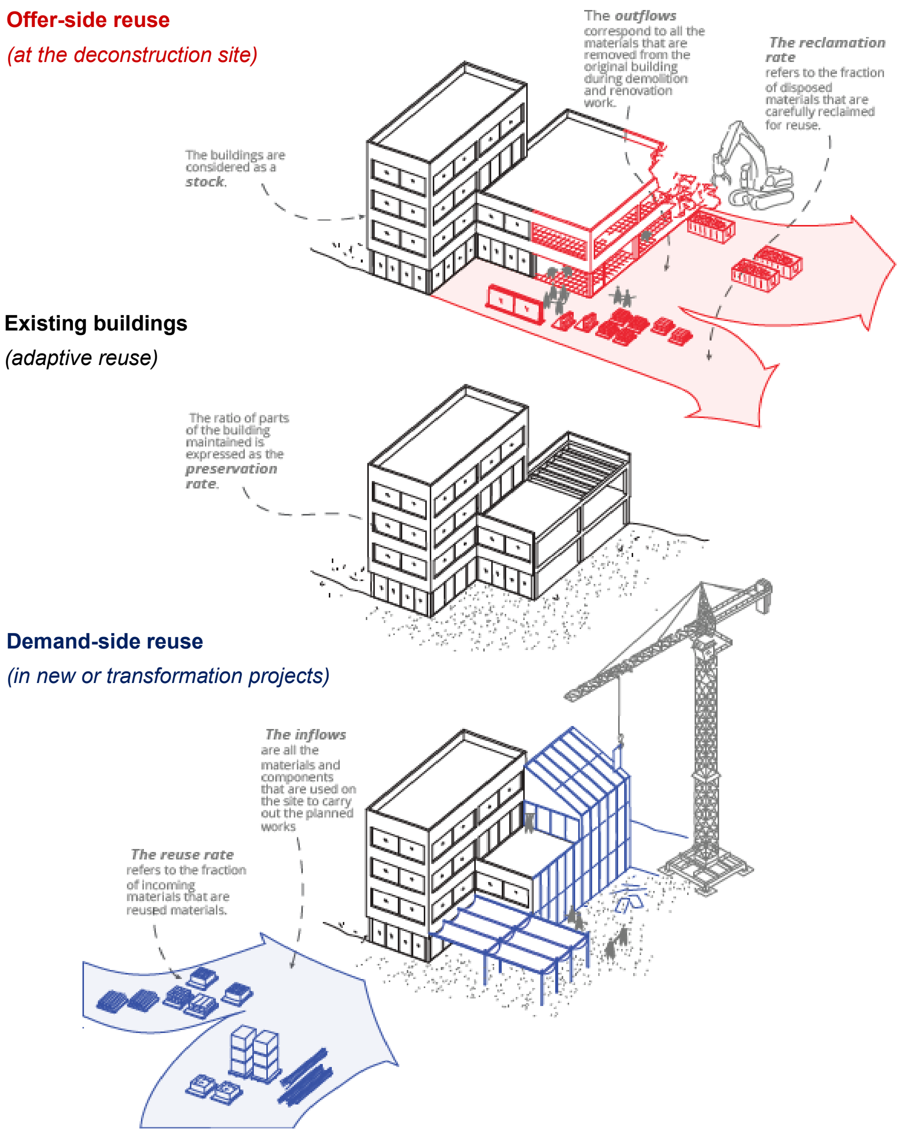



Figure 3: Graphical representation of the preservation, reclamation and reuse rate definition in different contexts: building dismantling (top), existing building (middle) and building transformation and extension (bottom), adapted from the European Interreg NWE FCBRE project [37]

This reuse framework helps the procedure of the different building case studies selection. Finally, there are not so many current examples of whole buildings with reuse strategies available in Switzerland. As this project does not consider theoretical case studies, the search and selection were limited to what was available at the time of the project (2021-2024). Most case studies concerned reuse strategies for demand-side projects (new or transformation of buildings) as graphically represented in blue in Figure 3. The gathered sample of case studies is finally a good balance of mixed typologies (residential, offices…), projects (new, existing and transformation) as well as locations with 4 in Romandie and 4 in Basel and Zürich regions. Only one case study reports from the offer-side on a selective dismantling at the end-of-life of a building. Similarly, one case study only deals with a so-called energy-related renovation with a specific analysis on the adaptive reuse of windows frame. The chapter 3 gives more information and characterisation about each project and the reuse strategy and logistic chains.

Table 1: Brief characteristics of the different selected case studies according to the reuse framework

| Context | Project type (case studies) | Geographical region |
|---|---|---|
| **Demand-side reuse** | Transformation | Basel region (BS + BL) |
| **Demand-side reuse** | New construction | |
| **Demand-side reuse** | New construction | Zürich region (ZH) |
| **Demand-side reuse** | Transformation and vertical extension | |
| **Demand-side reuse** | Transformation | Romandie (GE + VD) |
| **Demand-side reuse** | Transformation | |
| **Offer-side reuse** | Building structure dismantling<br>(for concrete reuse) | |
| **Existing building**<br>(with only adaptive reuse) | Energy-related renovation<br>(reuse of existing windows frame) | |

For demand-side reuse, a reuse rate indicator can be calculated as the reused building elements inflow (ex-situ if sourced from another site or place, else in-situ if reused locally) entering a construction divided by the total building elements inflow (reused and new):

$$Reuse\ rate\ [\%] = \frac{Effective\ in\text{-}situ\ and\ ex\text{-}situ\ reused\ building\ element\ quantity\ [kg]}{Total\ building\ element\ quantity\ inflow\ [kg]} \quad \text{Eq. 1}$$

The reuse rate does not include the preserved quantity of building elements from an adaptive reuse. For example, such adaptive reuse takes place in a building renovation when the structure of the building is kept as it is in the original state. For these cases, a preserved rate can be calculated for assessing the share of preserved building elements (equivalent to the share of adaptive reuse) in the total material stock of a building, such as:

$$Preserved\ rate\ [\%] = \frac{Effective\ adaptively\ reused\ building\ element\ quantity\ [kg]}{Total\ building\ element\ quantity\ in\ the\ final\ construction\ [kg]} \quad \text{Eq. 2}$$

In this project, the preserved rate is equivalent to the share of adaptive reuse and expressed in [%].

## 2.2 Decomposition per building layer

The LCA data and results for virgin or reused components are structured according to five building layers each one representing an area of influence for a specific building planer. For example, the GHG emissions of the structure of a building can mostly be optimized by the civil engineer, while the thermal envelope is on the hands of the building physicist and the technical systems on the HVAC, sanitary and electrical engineers. The Figure 4 presents the graphical illustration of this decomposition.

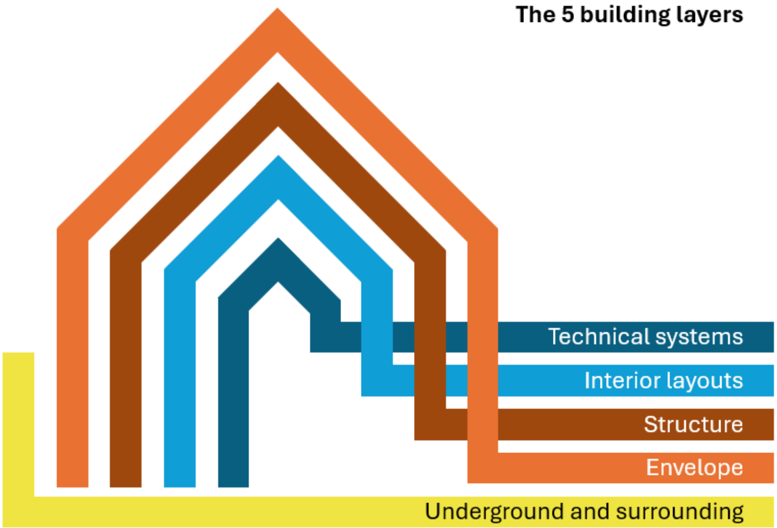



Figure 4: Representation of the 5 building layers of a building

## 2.3 LCA methodology for buildings with reuse

Building Life Cycle Assessment (LCA) methodology defined in the SIA 2032 technical book and in the SIA 390/1 standard is used as a basis for all calculations [38]. The Figure 5 (adapted from the SIA 2032:2020 [49]) illustrates the conventional building life cycle perimeter completed with upstream and downstream reuse activities highlighted in green to contextualise circular practices in construction.

The functional unit of the building defined in LCA is "to provide thermal comfort to occupants in accordance to SIA 380/1, during a 60-year amortisation time according to SIA 390/1 which is equivalent to the reference study period (RSP) in SN EN 15978, normalised per square meter of energy reference area (ERA[1])". Results are expressed as LCA indicators **per $m^2_{ERA}$**.

While the SIA 2032 technical specification and SIA 390/1 standard form the basis for all building LCA calculations, they do not give explicit calculation rules for integrating reused construction products except the default values of 20% of the equivalent new material in the SIA 390/1 for pre-project phase. To address this gap, the methodology incorporates additional rules that are described in the next sections.

[1] The energy reference area (ERA) takes into account all the surfaces that need to be heated or cooled inside the building, and it constitutes the reference surface for expressing the heating demand of a building, according to SIA 380/1.

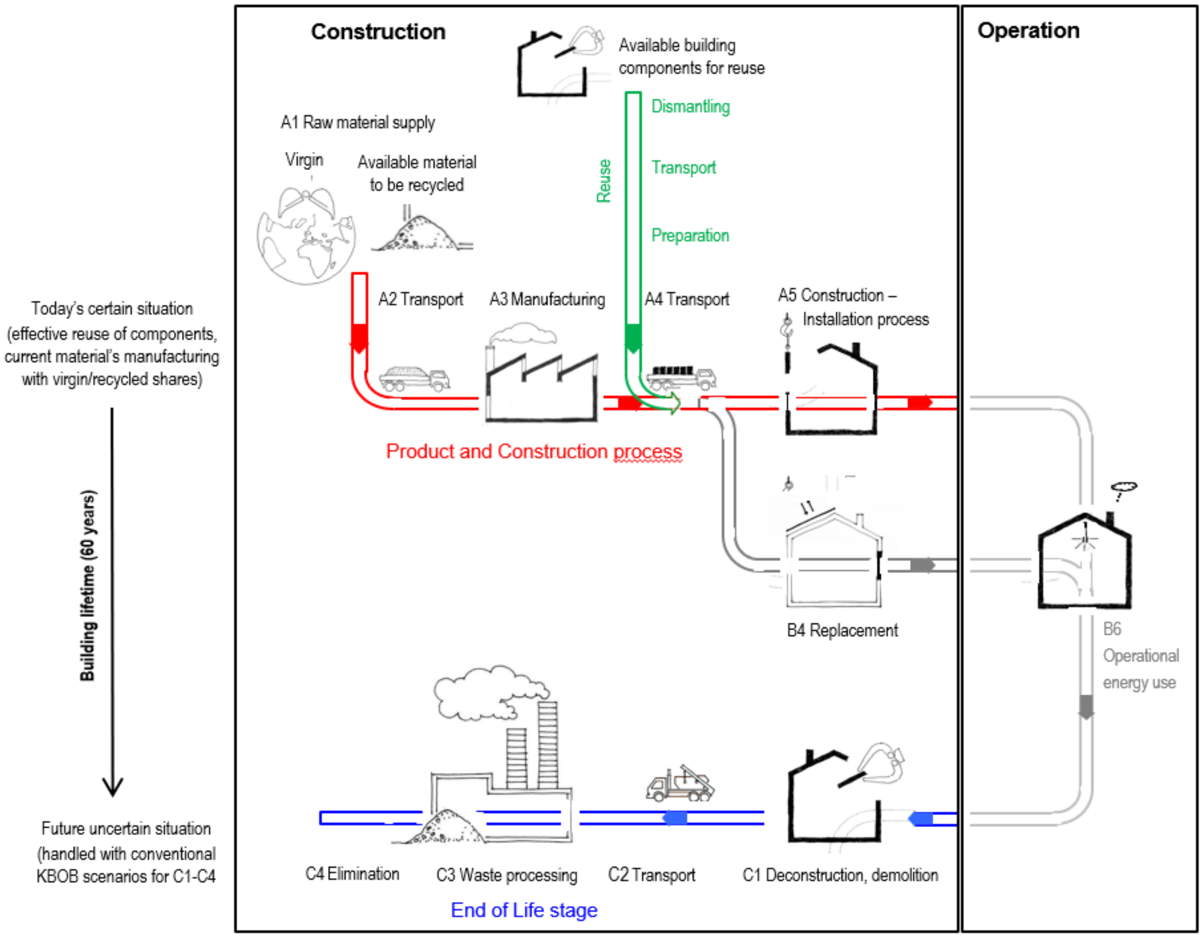



Figure 5: Graphical illustration of the building life cycle with the upstream and downstream flows for reuse adapted from the SIA 2032:2020 [49] technical book.

### 2.3.1 Existing methods for modelling reused elements in LCA

The Reuse-LCA project builds upon recent initiatives for modelling reused elements in building LCA calculation. They are described hereafter.

#### A. Reuse-LCA Zürich Workshop (2021)

In November 2021, a workshop with Reuse-LCA partners and Katrin Pfäffli extended the SIA standard to reuse practices, building on Pfäffli's 2020 study. A consensus was found about a methodology named "additional expenditures" (or "current processes"). This approach includes and environmentally assesses all processes from a product's *end-of-waste* status to reuse:

- Disassembly, transports (to storage/workshop), storage, reconditioning (e.g., cleaning, repairs), and modifications (e.g., painting, assembly).
- Excludes amortized burdens from past manufacturing.
- Accounts for future disposal of the reused products (modules C1 to C4).

Two variants of this method were assessed in Pfäffli's study (2020):

- Variant A: includes the transport to the construction site.

- Variant B: excludes transport to site to align with SIA 2032 standard.

**B. SFOE Net-Zero GHG Emissions Project (November 2024)**

As part of SFOE project's « Net Zero GHG emission in the building area » (*« Netto-Null Treibhaugasemissionen im Gebäudebereich »*) [39], the "additional expenditures" method was endorsed for modelling the reuse in building LCA. This aligns with Switzerland's 2050 net-zero goal by adhering to the *"truth of emissions"* principle, ensuring transparent carbon budget tracking.

**C. UVEK DQRv2 Database Protocol (November 2023)**

The protocol of the UVEK DQRv2 database (the background database for the Swiss LCA data for the construction sector) published in November 2023 states that "efforts of dismantling, transports and refreshing/repair are processes attributed to the new/next life cycle of reused products and components" [40].

**D. Swiss LCA data for construction: KBOB Rules v7.1 (June 2024)**

The June 2024 KBOB guidelines (Section 6.10) specify [25]:

- Reused elements' burdens include transport (to storage/preparation), preparation, consolidation, and future disposal.
- The dismantling activity is excluded (*"Reused building elements leave the perimeter of their original building without harming the environment"*), conflicting with the UVEK DQRv2 Database Protocol's statement previously described including dismantling in the reuse life cycle.

**E. SIA 390/1 (February 2025)**

The SIA 390/1 [38] integrates guidelines for accounting for reused products but only for the pre-project phase. The burdens of a reused product are estimated as 20% of those of the equivalent new product with the same material composition.

### 2.3.2 Definition of the LCA perimeter

The "Construction Domain" perimeter defined by SIA 390/1 includes the production stage (modules A1 to A3), replacements during the use stage (module B4), and the end-of-life stage (modules C1 to C4) according to the SN EN 15978 standard. However, activities related to transport to the site (A4) and construction processes (A5) are excluded. In contrast, this project includes the transport to the site (A4) as indicated in Table 2. The on-site construction activities are not accounted for except the ones that directly relate to reused products. In that case, some preparation works are accounted for in the production phase A3 even if they physically occur on the building site.

Table 2: Life cycle stages included in the "Construction domain" in SIA 2032 and in the Reuse-LCA project. The phases marked with (x) are neglected in SIA 2032.

| Stages according to EN 15804+A2 | Production stage | | | Construction stage | | Use stage | | | | | | | End-of-life | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw material supply | Transport to manufacturing | Manufacturing | Transport to construction site | Construction-process | Use | Maintenance | Repair | Replacement | Refurbishment | Operational Energy Use | Operational Water Use | Deconstruction | Transport | Waste processing | Disposal |
| | A1 | A2 | A3 | A4 | A5 | B1 | B2 | B3 | B4 | B5 | B6 | B7 | C1 | C2 | C3 | C4 |
| SIA 2032:2020 | x | x | x | (x) | (x) | | | | x | | | | x | x | x | x |
| **Reuse-LCA** | **x** | **x** | **x** | **x** | | | | | **x** | | | | **x** | **x** | **x** | **x** |

To maintain compatibility with SIA 2032's scope, results from module A4 are presented separately from the production stage (A1-A3). The LCA perimeter defined in the Reuse-LCA project is shown on Figure 6 in comparison to the perimeters defined in the existing methods identified in previous section 2.3.1.

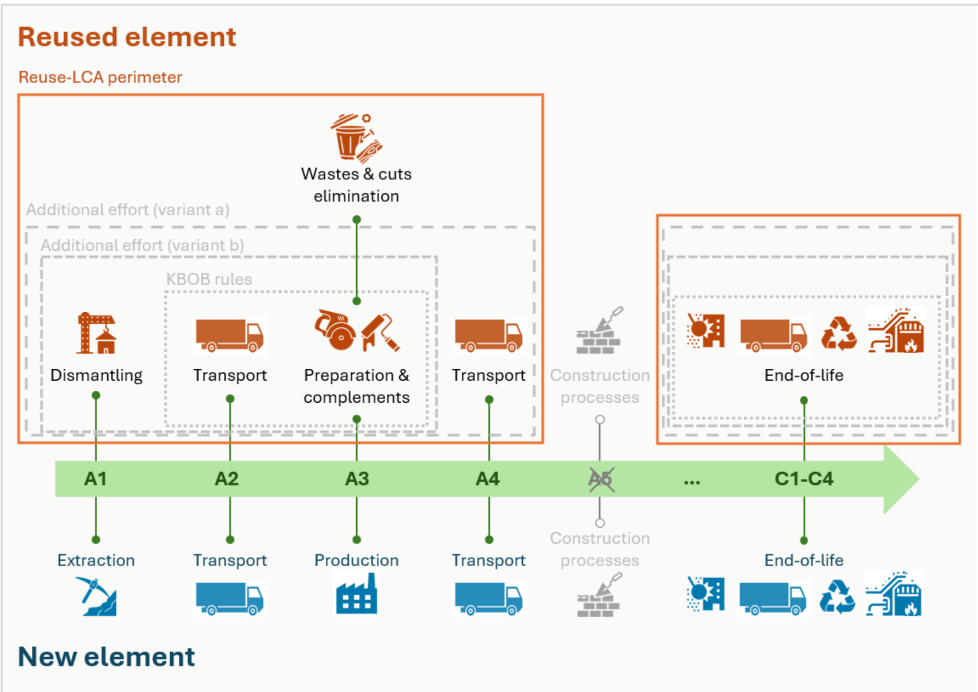



Figure 6: LCA perimeters from identified methods Additional efforts (Pfäffli 2020) and Swiss LCA data for construction/KBOB rules (grey dashed boxes), and the chosen LCA perimeter in the Reuse-LCA project (orange box)

**Transport in reuse logistics**

The primary goal of this research is to quantify the environmental benefits *and* burdens of reuse practices ensuring a comprehensive scope to prevent burden shifting. By including the transport to site (A4 module) in the assessment, the Reuse-LCA project aims to address a frequent question regarding circular practices: *"What is the maximum supply distance for reused products to remain environmentally efficient?"* [41]. Project-specific data, such as the distance from supply and the type of vehicle, are used whenever available. In cases of data gaps and for new building products, default assumptions are based on the Database Protocol UVEK 2022 [40]:

- 50 km default transport distance (plant to site)
- Diesel 16-32 t. lorry emissions, with an average load factor (LCA dataset from the KBOB)

**Boundary definitions and activity allocation**

Reuse-related activities (e.g., cleaning, retrofitting) are accounted for until components meet *"new-equivalent"* readiness, even if performed on-site. These processes are allocated to **Module A3** (manufacturing stage) regardless of physical location.

**Waste and Material Loss Accounting**

The calculation scope explicitly includes the disposal of wastes generated during the preparation for reuse: losses from cutting operation, disposed auxiliary materials (old screws, nails, or paint), are modelled using KBOB elimination LCA datasets. They are included analogously to the production's waste in manufacturing process of new products, as required by SN EN 15804+A2 (in module A3). When detailed data are unavailable, a default mass loss of 10% is assumed for divisible materials.

### 2.3.3 Baseline LCA calculation

The total LCA of the building is calculated using Eq. 3:

$$LCA^{total} = LCA^{production\,(A1-A3)} + LCA^{transport\,(A4)} + LCA^{replacement\,(B4)} + LCA^{end-of-life\,(C1-C4)} \quad \text{Eq. 3}$$

The environmental impact of the production and end-of-life of all the new materials and technical systems are derived from Swiss LCA data in the construction sector [25].

Data and calculation in this project and their relations with the SIA 390/1:2025 standard:

The LCA data of construction materials or elements are used directly without annualizing the LCA data according to the service life (i.e., the amortization time in SIA 2032) as considered in e.g., SIA 2032 Appendix D.

This is justified by the choice to allocate in this project, emissions at the timing when they occur.

By doing so, it is possible to calculate the LCA of the upfront emissions, the LCA due to the replacement stage and the LCA of the end of life. All LCA results are calculated in absolute values and scaled to $m^2$ of energy reference area of the building. Finally, each absolute LCA results (for construction, replacement, end-of-life) can ultimately be reported per year, as the SIA 390/1 standard requires, by dividing the LCA results by 60 years, the reference study period for building LCA in Switzerland.

For reused elements, project-specific logistics data collected from the partners are prioritised in the calculation of the $LCA^{production\,(A1-A3)}$ and $LCA^{transport\,(A4)}$. Data gaps are filled using KBOB background LCA data supplemented with literature, EPDs, or searches on industry practices. The end-of-life of a reused element $LCA^{end-of-life\ (C1-C4)}$ is calculated based on its material composition.

### 2.3.4 Replacement scenario and service life of reused elements

In the SIA 2032 calculation, the LCA of the replacement stage is simplified as in (Eq. 4):

$$LCA^{replacement\ (B4)} = \left(LCA^{production\ (A1-A3)} + LCA^{end-of-life\ (C1-C4)}\right) \times k \qquad \text{Eq. 4}$$

Where $k$, the replacement rate during the reference study period is (Eq. 5):

$$k = \frac{RSP}{SL} - 1 \qquad \text{Eq. 5}$$

*RSP:* Reference study period of 60 years (SN EN 15978);

*SL:* Service life of the component (SIA 2032).

Applying equations 2 and 3 means, that the first manufacturing LCA data automatically applies for the second manufacturing during the replacement stage. Applied to two identical products, one being newly manufactured and one being reused, it means that the first one will be replaced using the LCA of the new manufacturing while the second will have a reused equivalent which creates a bias in the building LCA. Indeed, reused component having "systematic" savings in future replacement result in an overestimation of the potential benefits of reused products over a building's life cycle. Future replacements by reused products are currently not foreseeable based on today's situation but may occur at some point. But both new or reused products should apply the same future replacement scenario. This also aligns with KBOB and SIA 2032 end-of-life modelling, where scenarios, representing actual national average practices, are applied consistently to each product category no matter the product is originally virgin, recycled or reuse at the manufacturing stage.

In this project, consistent and identical assumptions are applied for the future replacement and end-of-life of each product category unlike the choice implicitly made in the new SIA 390/1 standard due to the use of amortized values for the LCA of construction materials in SIA 2032: **reused products are replaced by new equivalent components** (defined per section 2.3.5) as reported in the table below.

Table 3: Chosen assumptions for the LCA of the manufacturing, replacement and end-of-life stages of a building product in Reuse-LCA project

| Upfront GHG emissions | Future GHG emissions | |
|---|---|---|
| Manufacturing stage | Replacement stage | End-of-life stage |
| LCA of the building component (new)<br>LCA of the building component (reuse) | Same scenario for new and reuse | Same scenario for new and reuse |

This allows to handle the replacement of each component, new or reused, in the same way i.e., with an identical scenario of new product or new equivalent. Hence, the adopted calculation of the replacement stage follows the Eq. 6:

$$LCA^{replacement\ (B4)} = \left( \sum_{i}^{n} LCA_i^{production\ (A1-A3)} + LCA_i^{end-of-life\ (C1-C4)} \right) \times k \qquad \text{Eq. 6}$$

$$\text{with} \quad LCA^{production\ (A1-A3)} = \begin{cases} LCA^{A1-A3}_{new\ equivalent} & \text{if reused} \\ LCA^{A1-A3}_{new\ product} & \text{if new product} \end{cases}$$

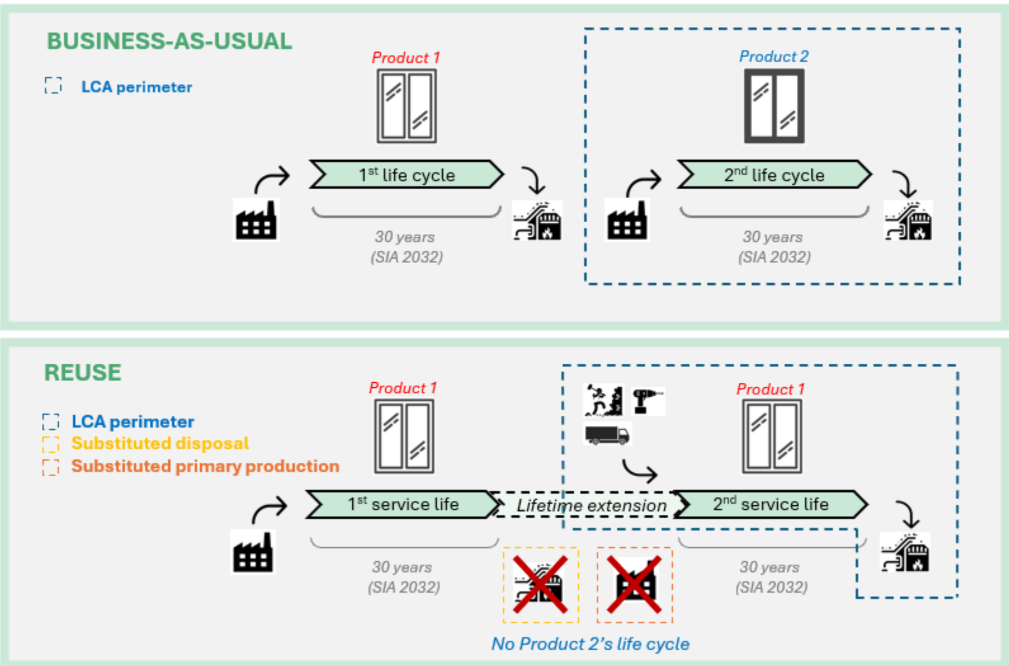
And for each construction element $i$ in the building.

As a conventional assumption, reused products are assigned the same service life as new equivalents (per SIA 2032 service lives), though degradation risks may shorten their functional lifespan [55].

### 2.3.5 Calculation rule for the potential GHG emissions reductions due to reuse

Reuse extends a product's service life, reducing primary production and waste management needs [57]. For example, a window providing 60 years of service in a *business-as-usual* scenario would require two new windows (Figure 7). While useful for "green claims" or carbon credits[2,3], these "avoided impacts" rely on hypothetical baselines and value choices, introducing variability. Furthermore, these potential benefits happen beyond the building system's boundary and are outside the scope of the building life cycle in LCA. They should appear solely in a D module according in SN EN 15978 and must be separated from effective LCA impacts.

In Reuse-LCA project, GHG emissions reductions from reuse are assessed for informative purpose. However, their calculation has key limitations which are transparently described hereafter. Two key value choices explain their variability and uncertainty: the calculation boundaries, and the definition of the substituted new equivalent products.




[2] https://registry.riverse.io/projects/RIV-2023-PROJ-7
[3] https://label-bas-carbone.ecologie.gouv.fr/la-methode-renovation

Figure 7: Comparison of the business-as-usual and upstream reuse life cycles and LCA perimeters. Example of the service provided by a window during 60 years

**Calculation boundaries for GHG emissions reductions**

The reuse of a product happens between two building systems that can be considered as two separated perimeters and their combination (depicted on Figure 8):

- Offer side: avoided disposal burdens from a building dismantled and offering its elements to the reuse market.
- Demand side: avoided new production from a building that is constructed and incorporating reused products.
- Combined ("Both"): total potential reductions from both sides.

The Reuse-LCA project adopts the **demand-side perimeter** for consistency with its focus on upstream reuse in new construction and transformation projects. Impact reductions are calculated as:

$$I_{potential\ reduction} = I_{reuse}^{production\ \ A1-A3} + I_{reuse}^{transport\ A4} + I_{reuse}^{end-of-life\ C1-C4} - I_{new\ equivalent}^{production\ \ A1-A3} - I_{new\ equivalent}^{transport\ A4} - I_{new\ equivalent}^{end-of-life\ C1-C4} \quad \text{Eq. 7}$$

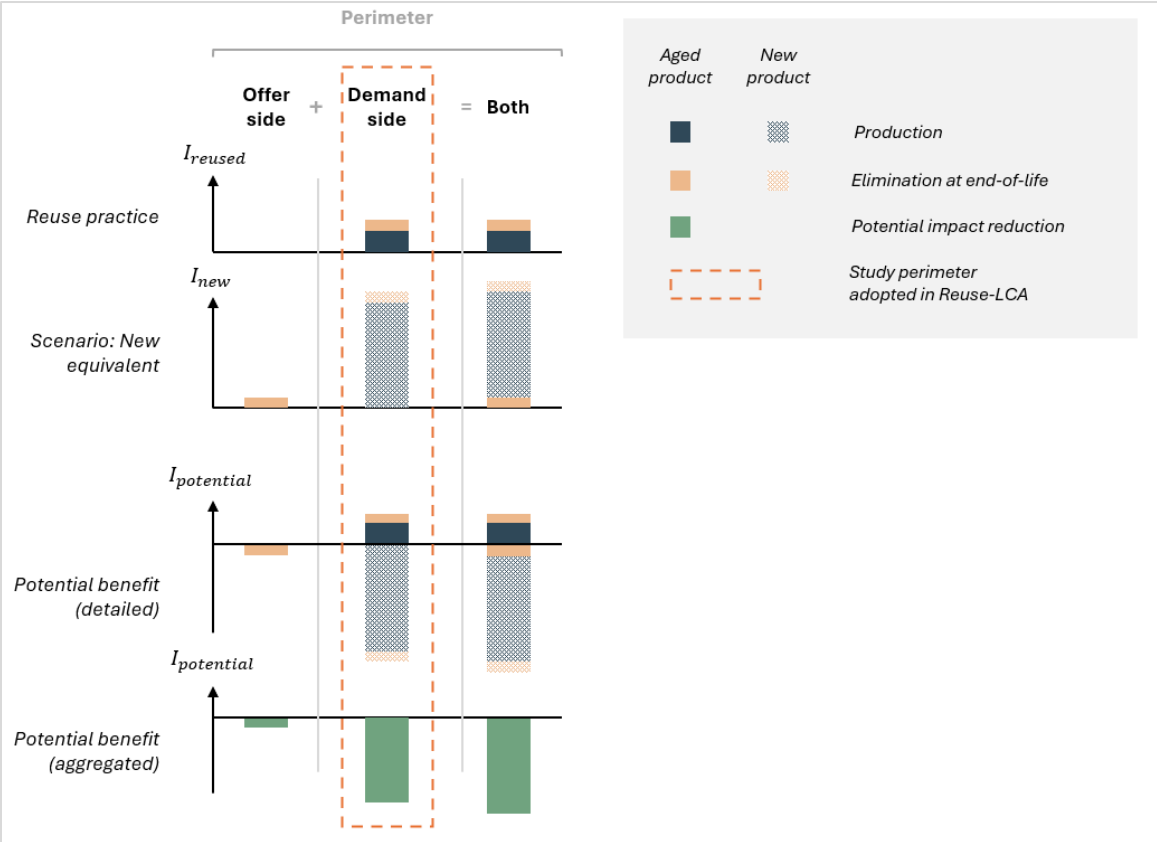



Figure 8: Illustration of potential GHG emission reduction calculated according to different perimeters or points of view

### Defining the substituted new equivalent

Defining the new product that would be substituted due to reuse relies on hypotheses and value choices. Three approaches exist that can be combined:

- **Material equivalency**: substituted new product has the same material composition than the reused.
- **Function equivalency**: substituted new product offers the same functional performance as the reused. It can include thermal, acoustic, structural properties, power output, etc.
- **Economic or market equivalency**: substituted new product is based on market practices, representing an average product in the market for a given category or the cheapest option.

Pfäffli (2020) and SIA 390/1 non-explicitly define the substituted new product as material equivalency to the reused product. This approach contains limitations:

- The offer for reused products is limited: a designer may not have free choice about the material of a salvaged product, e.g., window shutter, panels, etc.
- Reused products are aged and reflect manufacturing practices or trend from the past. Today's equivalent products may have been produced with different materials type or quantity

The French "Label Bas Carbone Méthode Rénovation" published in 2024 [42] combines functional and market equivalency, using median LCA values for substituted products as a market mix. Specific reuse projects and substituted new product are decoupled, creating standard reference values for GHG emissions reductions calculation to all building projects.

Identifying the best approach for each product category is not part of this report. Rather, the following methodology is adopted:

- Material equivalency is the primary principle because simplicity and data availability.
- Functional adjustments are applied where relevant e.g., to thermal insulation material (conductivity in W/m/K), photovoltaic panels (peak power in Wp including degradation), and windows (U-value in W/m²/K).
- Service life is equal for reused product and new equivalents product (SIA 2032 values).

Impact reduction in production stage is quantified as:

$$Avoided_{eq.\ primary\ production} = LCA_{Sub(A1-A3)} - LCA_{Reuse(A1-A3)} \qquad \textbf{Eq. 8}$$

where

$$LCA_{Sub} = LCA_{New} * Q_{Reuse} \qquad \textbf{Eq. 9}$$

$LCA_{Sub(A1-A3)}$ is the cradle-to-gate impact of the substituted equivalent new product.

$LCA_{Reuse(A1-A3)}$ is the impact of the reused product accounting for the current reuse activities (see 0).

$LCA_{New}$ is the life cycle impact of a generic new product based on material equivalency

$Q_{Reuse}$ is the functional quality ratio (0 to 1), accounting for age/state (for thermal insulation, PV panels, and windows).

### 2.3.6 Transport distance threshold calculation

To assess whether transportation emissions negate reuse benefits, a maximum allowable distance of transport to site is calculated. This metric defines the farthest a reused element can travel while maintaining emissions parity with its new equivalent. The formula is:

$$\text{Limit distance [km]} = \frac{GHG_{New\ (A1-A4\ +C1-C4)} \text{ - } GHG_{Reused\ (A1-A3+C1-C4)} [\text{kg } CO_2\text{-eq.}]}{\text{Mass [t]} \times \text{Transport emissions factor [kg } CO_2\text{-eq./tkm]}}$$

Where:

- $GHG_{New\ (A1-A4\ +C1-C4)}$ includes A1-A4 and C1-C4 impacts
- $GHG_{Reused\ (A1-A3+C1-C4)}$ includes A1-C3 and C1-C4 impacts
- $Mass$ = reused element mass [t]
- Transport emissions factor is based on the KBOB LCA data of a diesel 16-32 t. lorry (0,181 kg $CO_2$-eq./tkm)

### 2.3.7 Calculation rules for biogenic carbon storage in buildings

Biogenic carbon storage refers to the temporary sequestration of atmospheric $CO_2$ in bio-based construction materials (e.g., wood, hemp, straw). These materials absorb $CO_2$ during biomass growth and store it until decomposition or combustion. Stored carbon is quantified as kg biogenic C, where 1 kg biogenic C = 3,67 kg $CO_2$. While temporary storage can "buy time" for decarbonization efforts, recent studies highlight limitations: storage durations <1,000 years do not neutralize equivalent fossil $CO_2$ emissions (Brunner et al., 2024). In the LCA field several methods have been developed and no consensus have been found on integrating this temporality [43], [44], [45].

A parallel project “Net-Zero GHG emission in the building sector” [46] also recommends to keep separate the biogenic carbon storage from the life cycle GHG emissions. Climate benefits are conditioned to *legally binding permanent* storage. The biogenic carbon content of construction products expressed in a separate indicator in kg of biogenic C. The Reuse-LCA is consistent with the SIA 390/1 that applies the same rule.

## 2.4 LCA data

General building materials and technical systems are represented using the Swiss LCA data for the construction sector shortly named as the **KBOB 2009/1:2022** datasets also in this report [25]. Aggregated data are disaggregated for *specific reused components* (e.g., sanitary equipment, thermal systems) to reflect their unique supply chains.

For reused products, the LCA integrates:

- **Project-specific data** (shared by partners): Time, energy, material inputs for dismantling, preparation, storage, and modification.
- **Transport distances** (A4 module)

Due to variability in data quality and completeness across projects, **validated default data** fill gaps in missing activity (e.g., energy use during reconditioning).

## 2.5 LCA indicators

The primary environmental assessment relies on standard indicators from KBOB 2009/1:2022 [25], see in Table 4. They are supplemented by mass flow and circularity metrics presented in Table 5. The supplementary indicators provide critical insights into the reuse performance.

The additional indicators include first the material intensity, a rather simple indicator that allows to get a quick idea of the amount of mass flow in the building. The two linked indicators are the shares of reused components separated in two with first the ex-situ/in-situ reuse and second the adaptive reuse. Both were already introduced in section 2.1 when presenting the reuse framework and case studies typologies. The adaptive reuse rate indicator depicts the preservation rate of building elements in a building transformation project. Together with these mass flow indicators, another one is defined and based on the GHG emissions reduction due to these different types of reuses. It is mostly based on material equivalent approach.

Even though a single focus and analysis is made on the results of this report on the life cycle fossil GHG emissions, all KBOB indicators are calculated, and the results are also presented in webpages of Reuse-LCA case studies (cf. chapter 8) i.e., for the total environmental impact as ecopoints UBP21 or for the primary energy non-renewable (PENR).

Table 4: Included indicators of the KBOB 2009/1:2022 indicators in this study

| **Multicriteria** | **Single scope impact assessment** | | **Inventory flow** |
|---|---|---|---|
| **Ecopoints UBP'21** **UBP** | **Primary energy non renewable** **kWh oil-eq** | **Fossil greenhouse gas emissions** **kg $CO_2$-eq** | **Biogenic carbon content** **kg C** |
| Ecopoints 2021 (UBP'21) quantify environmental burdens from the use of material and energy resources, land and freshwater use, emissions in air, water and soil, emission from waste treatment and noise from traffic. The assessment based on ecological scarcity. | Non-renewable energy (grey energy) indicates the cumulative energy of fossil and nuclear energy consumption and wood from deforestation of primary forests. | The greenhouse effect assesses the cumulative effects of different greenhouse gases in relation to the main substance CO2. The greenhouse effect is quantified on the basis of the warming potential referred to in the IPCC Fifth Assessment Report (2013). Biogenic CO2 is considered to have no impact on the climate. Its global warming potential is 0 kg CO2-eq/kg. CO2 emitted by airliners has a greenhouse potential of 2.5 kg CO2-eq/kg (RFI factor 2.5). | Biogenic carbon content quantifies the biogenic carbon contained in building materials and components (e.g. window frames), expressed in "kg C". |

Table 5: Additional indicators defined to better reflect the building projects with reuse strategies

| **Informational indicator** | **Mass flow and circularity indicators** | | |
|---|---|---|---|
| **Emissions reduction due to reuse** **kg $CO_2$-eq** | **Material intensity (MI)** **kg** | **reuse rate (ex-situ/in-situ)** **%** | **preserved rate (adaptive reuse)** **%** |
| Fossil GHG emissions reduced due to the use of reused materials compared to an equivalent new material. *Remark: this indicator does not depict any effective savings but give a rather rough estimation based on material equivalency due to the applied reuse strategies in a building* | Cumulative mass of all materials involved in a building, encompassing the **inflow materials** (new and reused materials introduced), and the **preserved material stock** (existing materials retained). | Proportion of reused materials or building elements expressed as a percentage of the **total inflow materials**. | Proportion of existing buildings materials or components retained |

## 2.6 Benchmarks for GHG emissions (carbon budgets)

Only the GHG emissions of the Construction domain are analysed in this study for different buildings in view of existing benchmarks. The other indicators will be calculated and only compared across the different case studies as no benchmarks exist or are defined in the SIA 390/1 standard or other documentations.

The GHG emissions will be compared with current benchmarks from the SIA 390/1:2025 ambitious and base indicative values. These values are only given as informative values in the standard and there are no requirements in SIA 390/1 to comply with these values i.e. a building can emit more than the indicative value for the construction domain as far as it complies with the target value for the construction, operational energy (exploitation), and mobility (if relevant) domains.

In this study, for the sake of clarity, the ambitious and base indicative values for the Construction domain are respectively named target and limit values for the Construction domain in the case studies results in chapter 4. The next table clearly presents the terminology, the used values in the context of this project and in relation to the SIA 390/1.

Table 6: Explanation of the different scope, terminology and reported values in the benchmarks between this study and the SIA 390/1

| Criteria for the benchmark | SIA 390/1 | This study |
|---|---|---|
| SIA 390/1 domains | All (i.e. construction, exploitation, mobility) | Only the construction domain |
| Terminology of the benchmark of the construction domain | Indicative value (base)<br>Indicative value (ambitious) | Limit value<br>Target value |
| Unit of the indicator in the benchmark | Annualized value in $kgCO_2e/(m^2.an)$ | Absolute value in $kgCO_2e/(m^2)$ |
| Example of value for new construction | $9.0\ kgCO_2e/(m^2.an)$<br>$6.0\ kgCO_2e/(m^2.an)$ | $540\ kgCO_2e/m^2$<br>$300\ kgCO_2e/m^2$ |
| Example of value for transformation | $5.0\ kgCO_2e/(m^2.an)$<br>$4.0\ kgCO_2e/(m^2.an)$ | $300\ kgCO_2e/m^2$<br>$240\ kgCO_2e/m^2$ |

From a LCA calculation point of view, as presented in this chapter, both SIA 390/1 and this study choices use the same data (i.e. Swiss LCA data for the construction sector from KBOB/ecobau) and both calculate the same indicative value according to the terminology of the standard. In this study, the only differences are the choice to report absolute values for the LCA results (in $kgCO_2e/m^2$) as well as the use of a different terminology for the indicative values as mentioned above. But all data and results are strictly comparable between the two approaches.

# 3 Case studies and reuse practices characterisation

This research analyses eight exemplary building projects representing the current state-of-the-art in material reuse practices within the Swiss construction sector. The selected case studies are situated in three key Swiss urban regions (Geneva/Lausanne metropolitan area, Basel and Zürich regions) and correspond to varied building typologies. Table 7 presents the selected projects characteristics.

Table 7: Summary of the eight case studies

| | K.118 | Hobelwerk D | Kosmos | ELYS |
|---|---|---|---|---|
| Pilot case studies |  |  |  |  |
| Canton | **ZH** | **ZH** | **BL** | **BS** |
| Owner | Stiftung Abendrot | Mehr Als Wohnen Genossenschaft | Primeo Energie | Immobilien Basel-Stadt |
| Project type | Transformation and vertical extension | New building | New building | Transformation |
| Building type | Office and workshops | Residential, office | Office and training | Cultural and commercial |
| Floors and underground | 5 floors, no underground | 4 floors, no underground | 3 floors, no underground | 3 floors + 2 underground floors |
| Re-use strategy | Preservation of existing structure, ex-situ reuse | Ex-situ reuse | Ex-situ reuse | Adaptive reuse of the structure, ex-situ reuse, in-situ reuse |
| Scope of analysis in Reuse-LCA | Whole building LCA (construction) | Whole building LCA (construction) | Whole building LCA (construction) | Prefabricated south façade (construction) |
| Studied surface area | 1’416 m² of ERA | 2’261 m² of energy reference area (ERA) | 720 m² of energy reference area (ERA) | 509 m² of façade |
| | **MixCity** | **Chauchy** | **Fayards** | **PPN Tour 107** |
| Pilot case studies |  |  |  |  |
| Canton | **VD** | **VD** | **GE** | **GE** |
| Owner | Steiner | Cooperative | Fondation HBM Jean-Dutoit | Caisse de Pension Etat de Genève |
| Project type | Deconstruction | Transformation with in-situ and ex-situ reuse | Energy renovation | Transformation |
| Building type | Office | Residential | Residential | Office |
| Floors and underground | 2 floors | 4 floors, no underground | 6 floors | 18 floors, 2 underground floors |
| Re-use strategy | Existing building with a selective dismantling/reuse of the concrete structure | Conservation of structure, site-to-site reuse | In-situ reuse of windows frame (compared to full replacement) | Adaptive reuse of the structure and in-situ reuse |
| Scope of analysis in Reuse-LCA | Reclaimed concrete slabs (construction) | Whole building LCA (construction) | Windows frames reuse (construction and operation) | Whole building LCA (construction) |
| Studied surface area | 728 m² of reused concrete slabs | 548 m² of energy reference area (ERA) | 25’545 m² of energy reference area (ERA) over 5 buildings | 7’932 m² of energy reference area (ERA) |

The eight buildings selected for this study are innovative construction projects that explicitly incorporate low-carbon, reuse, or preservation design principles. Selection occurred through a continuous process during the project timeline to ensure inclusion of emerging best practices in sustainable construction. Seven of these exemplary projects have been documented in the SIA Tracés magazine, acknowledging their recognition as pioneering examples within the Swiss construction sector. The Table 8 provides direct links to articles or project documentation.

Table 8: Webpages mostly from the SIA Tracés magazine showcasing the different pilot building case studies

| **Building case studies** | **Link to the SIA Tracés article or equivalent websites** |
|---|---|
| K. 118 | Kopfbau K.118 |
| Hobelwerk | Hobelwerk Haus D |
| Kosmos Primeo Energy | Re-use: offenere Abläufe, aber auch Stärkung des Handwerks |
| ELYS | Prix SIA: ELYS, Basel |
| MixCity | MixCIty: pétanque, plancha et réemploi |
| Chauchy | "Chauchy: du commun à la communauté" |
| PPN Tour 107 | "Réemploi: le projet pilote Pointe Nord livre ses enseignements" |

In the subsequent subsections, reuse strategies and circular construction characteristics are specifically examined in terms of reuse material inflows and supply for each case study.

## 3.1 K.118: reuse in transformation and vertical extension

Figure 9 : View of the K.118 building

https://www.insitu.ch/projekte/196-K118-kopfbau-halle-118

| | |
|---|---|
| **Canton** | ZH |
| **Owner** | Stiftung Abendrot |
| **Project type** | Transformation and vertical extension |
| **Building type** | Office and workshops |
| **Studied surface area** | 1'416 $m^2$ ERA |
| **Floors and underground** | 5 floors, no underground |
| **Re-use strategy** | Preservation of existing structure, ex-situ reuse |
| **Scope of analysis in Reuse-LCA** | Whole building LCA (construction) |
| **Phase** | Completed in 2021 |

The K.118 project, located in Winterthur (ZH), is a transformation and vertical extension of the former Sulzer factory carried out by the architectural firm *Baubüro in situ* for the Stiftung Abendrot foundation. The aim of the project is to demonstrate that it is possible to preserve and extend a building it with a maximum of reused materials salvaged from deconstructions, while maintaining a high-performance, aesthetically pleasing building. The re-use strategy lead by the architectural firm in cooperation with Zirkular GmbH and ZHAW (Zurich University of Applied Sciences), was at the heart of the project, with an approach that involved adapting the design to the materials recovered, thus reversing the usual design process. The search for reusable components was carried out within a 90 km radius and **more than 20 categories of elements** were reused.

Originally a three-storey building, it was extended to six storeys with the addition of a structure made of reused steel beams from Lysbüchel in Basel. In addition to preserving the existing structure and reusing a large amount of materials, the architects preferred to use low environmental impact materials for the new components wherever possible. For example, the façade of the vertical extension is made of prefabricated wooden wall insulated with straw and incorporates reused windows.

A total of 430 tons of elements have been reused ex-situ and from the preservation of existing elements (mass installed). The reuse supply chains of the ex-situ elements spread out within a 90 km radius, which lead to weighted average distance of supply by truck of 116 km as indicated in Table 9. The preserved elements include the exterior wall made of bricks and steel beams (343 m²) and the ground floor slab made of reinforced concrete (82 t.).

Table 9: Mass of reused materials installed and weighted average distance of supply in the K.118 project

| **Tons of reused materials** | | **Distance of supply (weighted average)** | **Overall reused material loss rate** |
|---|---|---|---|
| Preserved / adaptive reuse | Ex-situ | | |
| 283 t. \| 200 kg/m² ERA | 147 t. \| 104 kg/m² ERA | 116 km | 8% |

The reuse mass flow map in Figure 11 shows the supply chain of each reused component and is supplemented by Table 10 for more detail by reused component. Some of the most important elements to be reused include (expressed as mass installed):

- Steel beams for the structure of the vertical extension (63 t.)
- Granite natural stone slabs (11 t.)
- Wooden panels as interior fittings (9.6 t.)
- Wooden structure for roof (8 t.)
- Parquet for interior fittings (7.8 t.)
- External steel staircase (5.8 t.)
- Rockwool insulation for roof (5.5 t.)
- Trapezoidal steel sheets for the interior ceilings in the vertical elevation (4.2 t.)
- Photovoltaic panels (2 t.)
- Trapezoidal aluminium sheets for the exterior cladding in the vertical elevation (2 t.)

Figure 10 : View of the interior of the vertical elevation in the K.118 building showing several reused products - the steel sheet cladding on the ceiling, the windows, the steel beams for the structure of the elevation and the floorboards.

*© Martin Zeller*

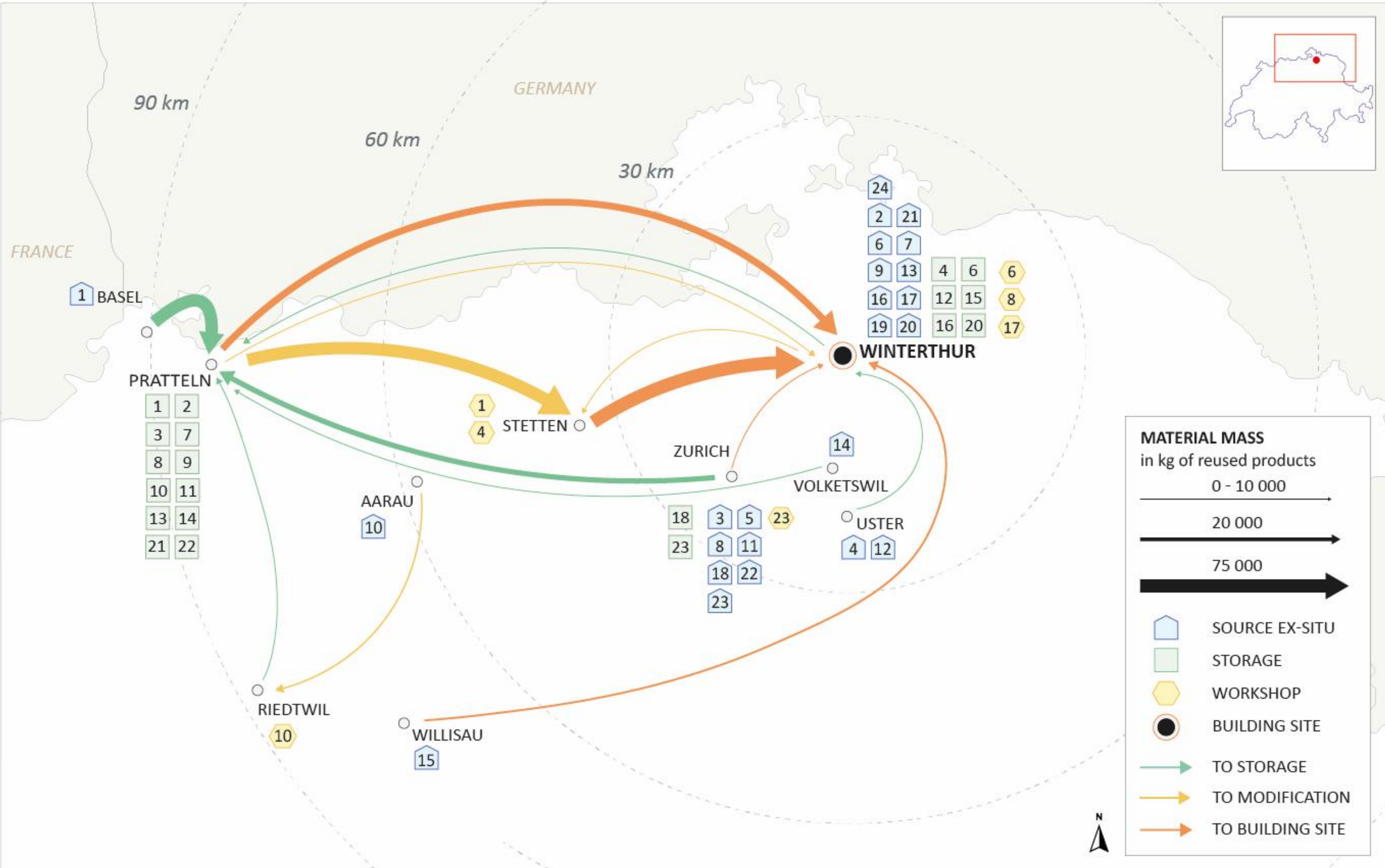



Figure 11: Mass flow map of reused products in the project K.118

Table 10: Detail of logistic chains of reused components for the K.118 building

| n° | Component | Distance in km as: *Total* (*to storage* / *to workshop* / *to site*) | Mass | Use | Description of the supply chain |
|---|---|---|---|---|---|
| 1 | Steel beams | 119 (14 / 57 / 48) | 63.0 t. | Vertical elevation's structure | 17 years old, collected at the Coop distribution centre in Lysbüchel, Basel, stored at the Coop distribution in Pratteln. The number of secondary beams was doubled and 50% of the secondary beams were shortened. Concrete encasement as fire protection (partial) in a steel construction company in Stetten. |
| 2 | Trapezoidal steel sheets | 169 (72 / 0 / 97) | 4.2 t. | Interior ceilings in elevation's floors | Collected in Winterthur, stored in Pratteln. |
| 3 | Steel gratings and stairs | 166 (75 / 0 / 95) | 5.8 t. | External staircase | 31 years old, dismantled from the Orion office building in Zurich, stored in the warehouse of the Coop distribution centre in Pratteln. |
| 4 | Steel beams IPE 120 | 135 (25 / 55 / 55) | 3.8 t. | External staircase | Dismantled from the Zellweger textile machinery factory in Uster, stored in Winterthur and processed into welded floor frames in Stetten. |
| 5 | Windows, double glazing and wood frame | 32 (0 / 0 / 32) | 1 t. | Façade | 7 years old, sourced in Zurich. |
| 6 | Industrial windows, double glazing, 12-panes, aluminium frame | 11 (1 / 5 / 5) | 1.9 t. | Façade | Collected from the Sulzer Areal site in Winterthur, stored in Tössallmend storage, cleaned, fittings adjusted, seals at the bottom replaced. |
| 7 | Windows, triple glazing and metal frame | 205 (110 / 0 / 95) | 1.2 t. | Façade | 14 years old, collected in Winterthur and stored in Pratteln. |
| 8 | Casement windows, triple glazing, aluminium frame | 178 (77 / 97 / 5) | 3.7 t. | Façade | Casement windows with top-light aluminium frames and triple glazing collected from the Orion office building in Zurich, stored in the warehouse of the Coop distribution centre in Pratteln, cleaned and seals replaced at the timber construction company in Winterthur. |
| 9 | Insulation panel, expanded polystyrene | 195 (100 / 0 / 95) | 0.8 t. | Flat roof | 15 years old, collected at the Ziegler print shop in Winterthur, stored at the Coop distribution centre in Pratteln. |
| 10 | Wooden structural elements | 216 (64 / 57 / 95) | 2.3 t. | Flat roof | Collected in Aarau, modified in Riedtwil and stored in Pratteln. |
| 11 | Granite natural stone slab | 169 (74 / 0 / 95) | 15.3 t. | Balcony and interior walls claddings | 31 years old, collected from the Orion office building in Zurich, stored in the warehouse of the Coop distribution centre in Pratteln. |
| 12 | Interior door, solid timber leaf and steel frame with top light | 30 (25 / 0 / 5) | 1.3 t. | Interior | Collected from Zellweger textile machine factory in Uster, stored in Tössallmend storage in Winterthur. Door leaves repainted. |
| 13 | Exterior doors 1 | 205 (110 / 0 / 95) | 0.3 t. | Façade | 2 years old, stored in Pratteln. |
| 14 | Exterior doors 2 | 182 (87 / 0 / 95) | 0.5 t. | Façade | 20 years old, stored in Pratteln. |
| 15 | Plywood boards | 75 (0 / 0 / 75) | 9.6 t. | Interior wall cladding | Collected from Hunziker temporary buildings in Willisau. 3-ply spruce plywood boards, 27 mm thick. Cut to size and planed. |
| 16 | OSB panel | 10 (0 / 0 / 10) | 5.0 t. | Exterior wall | 5 years old, sourced near Winterthur. |

| n° | Component | Distance in km as: *Total (to storage / to workshop / to site)* | Mass | Use | Description of the supply chain |
|---|---|---|---|---|---|
| **17** | Spruce floorboards | 10 (1 / 4 / 5) | 7.8 t. | Interior flooring | Collected from Winterthur, stored in an old bus depot warehouse in Winterthur, cleaned and de-nailed at the timber construction company in Winterthur. |
| **18** | Photovoltaic panels | 28 (3 / 0 / 25) | 2.4 t. | Technical system | 24 years old, collected from a Siemens site in Zurich-Albisrieden, stored at the Aargauerstrasse warehouse 3 km away. New other PV system components must be considered (mounting structure, inverter, electric installation). |
| **19** | Ceramic washbasin | 5 (0 / 0 / 5) | 0.3 t. | Technical systems | 10 pieces collected from BauTeiLaden in Winterthur. |
| **20** | Radiators | 2 (1 / 0 / 1) | 1.0 t. | Technical systems | Collected from Winterthur, stored in an old bus depot warehouse in Winterthur |
| **21** | Trapezoidal aluminium sheet | 195 (100 / 0 / 95) | 2.0 t. | Façade cladding | 18 years old, collected from Ziegler print shop in Winterthur, stored in Coop distribution centre warehouse in Pratteln. |
| **22** | Steel handrail | 119 (71 / 0 / 48) | 0.5 t. | External staircase | Aged 28 years, collected in Zurich and stored in Pratteln. |
| **23** | Aluminium mailbox | 28 (0 / 8 / 20) | 0.08 t. | Other | 12 compartiments letter boxes collected from Letzigraben housing development in Zurich, stored in Aargaustrasse storage in Zurich, cleaned, parts spared, locks replaced in apprentice workshop. |
| **24** | Rockwool | 0 (0 / 0 / 0) | 6 t. | Flat roof | In-situ reuse of the rockwool insulation originally under the roof of the building |

## 3.2 Hobelwerk Haus D: reuse in a new construction

Figure 12 : View of the Hobelwerk Haus D
https://www.zirkular.net/projekt/hobelwerk-haus-d

| | |
|---|---|
| **Canton** | ZH |
| **Owner** | Mehr Als Wohnen Genossenschaft |
| **Project type** | New building |
| **Building type** | Residential, commercial |
| **Studied surface area** | 2'261 m² ERA |
| **Floors and underground** | 4 floors, no underground |
| **Re-use strategy** | Ex-situ reuse |
| **Scope of analysis in Reuse-LCA** | Whole building LCA (construction) |
| **Phase** | Completed in 2023 |

The Hobelwerk is a new urban development project on the site of the former Kälin & Co. AG in Winterthur for the Mehr Als Wohnen cooperative, comprising of five new buildings covering 15'000 m² of residential, commercial and communal spaces. Hobelwerk Haus D, one of the five new buildings, is studied in the Reuse-LCA project for its design using reused materials.

Pascal Flamer Architectes developed the building design to provide sufficient flexibility for the integration of reused products. The team first identified the building elements that could potentially be replaced by reused products, based on criteria such as availability, environmental benefits, constructive feasibility and visibility. Ten categories of products were defined. The components were researched and evaluated by a team of 'component hunters' formed by baubüro in situ and Zirkular, the reuse planners, who oversaw the search, evaluation and procurement of components. After validation, the planner coordinated the dismantling, transport and storage of the materials, and prepared information sheets for the architect.

A total of 23.8 tons of elements have been reused ex-situ (mass installed). The reuse mass flow map in Figure 14 shows the supply chains spread out within a 90 km radius but most of the elements were sourced nearby in a radius of 30 km and stored in Bassersdorf. That leads to weighted average distance of supply by truck of 43 km as indicated in Table 11.

Table 11: Mass of reused materials and weighted average distance of supply in the Hobelwerk Haus D project

| Tons of reused materials | Distance of supply (weighted average) | Overall reused material loss rate |
|---|---|---|
| Ex-situ | | |
| 24 t. \| 11 kg/m² ERA | 43 km | 7% |

The Table 12 describes the supply of reused component in details. Some of the most important elements to be reused include (expressed as mass installed):

- Ipé wood panels for exterior cladding (7.3 t.)
- Stone tiles (7.7 t.)
- Granit outdoor flooring (4 t.)
- Interior wooden doors, 64 pieces (3 t.)
- Windows (62 pieces) and shutters (96 pieces) (4.5 t.)

Figure 13 : View of a balcony of the Hobelwerk Haus D building showing the reused wooden floorboards.

*© Pascal Flammer*

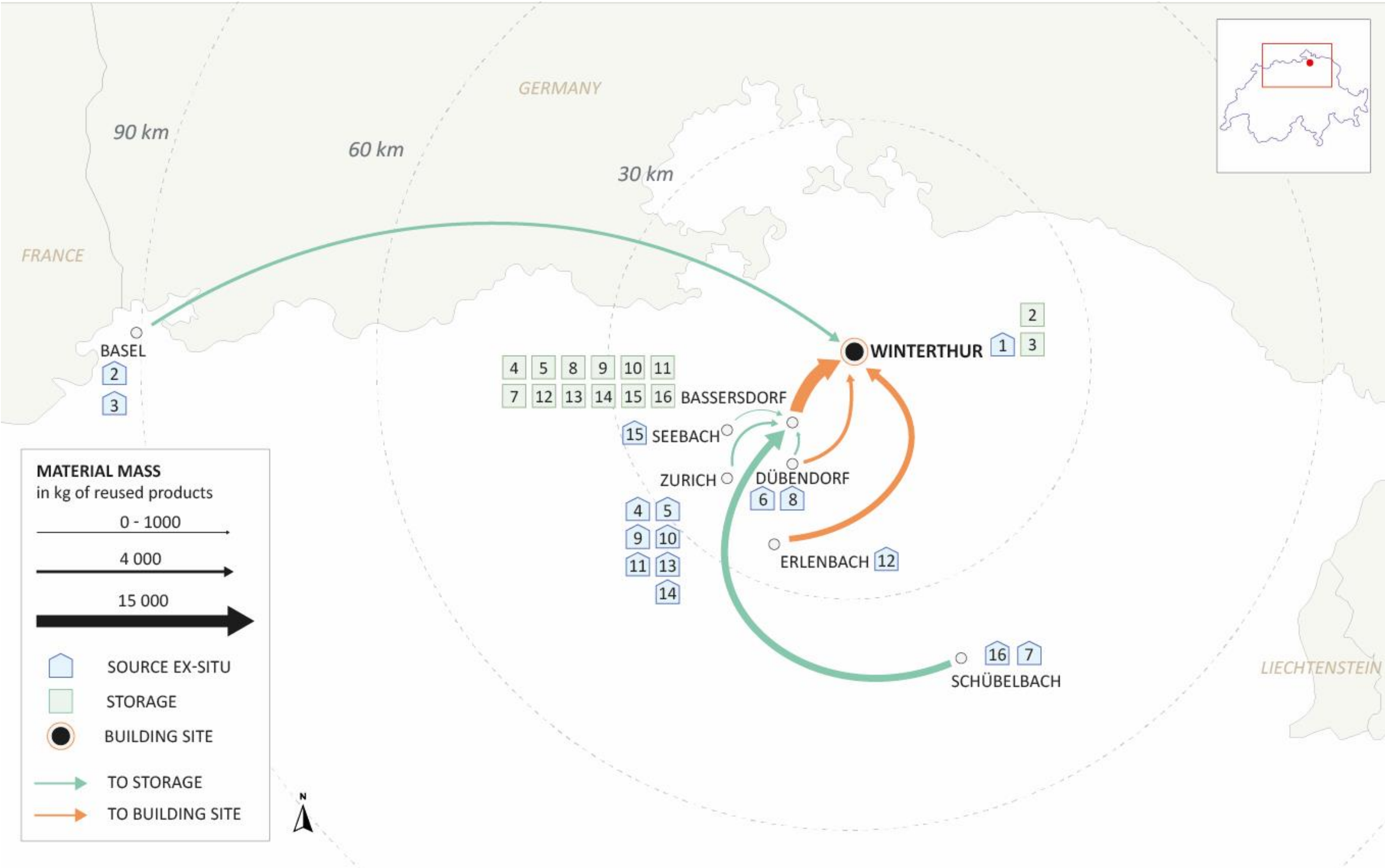



Figure 14: Mass flow map of reused products in the project Hobelwerk Haus D

Table 12 : Detail of logistic chains of reused components for the Hobelwerk building

| n° | Component | Distance in km as:<br><br>*Total (to storage / to site)* | Mass | Use | Logistic chain’s description |
|---|---|---|---|---|---|
| **1** | Trapezoidal aluminium sheets | 1 (0 / 1) | 0.4 t. | Façade cladding | 34 years old, dismantled from a building in Winterthur Grüze, will be used for facade cladding |
| **2** | Windows a, double glazing, steel frame | 95 (94 / 1) | 0.7 t. | Façade | 12 years old, dismantled from a building in Basel, stored in Winterthur |
| **3** | Windows b, double glazing, steel frame and aluminium shutters | 95 (94 / 1) | 3.5 t. | Façade | 12 years old, dismantled from a building in Basel, stored in Winterthur |
| **4** | Windows c, double glazing, steel frame and blinds | 27 (16 / 11) | 0.3 t. | Façade | 4 years old, dismantled from a building in Zurich Manegg, stored 18 months in Bassersdorf |
| **5** | Grating | 24 (13 / 11) | 0.9 t. | Balcony | Dismantled from a building in Polizeigefängnis Zurich, stored 6 months in Bassersdorf |
| **6** | Granite plates | 17 (0 / 17) | 4.1 t. | Exterior space flooring | 30 years old, dismantled from a building in Dübendorf |
| **7** | Stone tiles | 61 (50 / 11) | 7.7 t. | Interior cladding and flooring | Construction surplus from a building in Schübelbach, stored 12 months in Bassersdorf, will be used on floor and wall in bathrooms |
| **8** | Interior door | 22 (11 / 11) | 3.0 t. | Interior | 30 years old, dismantled from a building in Dubendorf, stored 18 months in Bassersdorf |
| **9** | Ceramic washstand | 24 (13 / 11) | 0.5 t. | Technical system | 9 years old, dismantled from a building in Zurich, stored 18 months in Bassersdorf |
| **10** | Storage cabinet | 24 (13 / 11) | 0.6 t. | Other | 9 years old, dismantled from a building in Zurich, stored 18 months in Bassersdorf |
| **11** | WC | 24 (13 / 11) | 0.04 t. | Technical system | 9 years old, dismantled from a building in Zurich, stored 18 months in Bassersdorf |
| **12** | Ipé wood | 40 (0 / 40) | 7.3 t. | Balcony flooring | 14 years old, dismantled from a building in Erlenbach, reused for balcony flooring |
| **13** | Sliding doors | 24 (13 / 11) | 0.9 t. | Interior | 9 years old, dismantled from a building in Zurich, stored 18 months in Bassersdorf, reused as exterior doors |
| **14** | Handhold WC | 24 (13 / 11) | 0.003 t. | Other | 9 years old, dismantled from a building in Zurich, stored 18 months in Bassersdorf |
| **15** | Mailbox | 20 (9 / 11) | 0.004 t. | Other | Dismantled from a building in Seabach, stored 18 months in Bassersdorf |
| **16** | Chalkboard | 105 (50 / 55) | 0.3 t. | Other | Dismantled from a building in Schubelbach, stored 18 months in Bassersdorf, reused as kitchen wall cover |

## 3.3 Kosmos: reuse in a new construction

Figure 15 : View of the Primeo Energie Kosmos building © Beat Ernst

| | |
|---|---|
| **Canton** | BL |
| **Owner** | Primeo Energie |
| **Project type** | New building |
| **Building type** | Office and education |
| **Studied surface area** | 720 m² ERA |
| **Floors and underground** | 3 floors, no underground |
| **Re-use strategy** | Ex-situ reuse |
| **Scope of analysis in Reuse-LCA** | Whole building LCA (construction) |
| **Phase** | Completed in 2022 |

The Kosmos building is a new building in Münchenstein (BL) designed by Rapp architectural office for the Swiss energy company Primeo Energie built to celebrate its 125$^{th}$ anniversary. The 3-storey building serves as an electricity museum and offer spaces for events and training. The structure is made of timber frame with spans of approximately 7,50m. The ground slab and the foundation are made of concrete containing recycled aggregates and insulated with recycled foam glass gravel. A special feature of this building is that it is surrounded by a steel structure made from elements of reused electricity utility poles, reminiscent of a Faraday cage. Around **18 categories of products** have been reused in the project. The sources are mainly building deconstruction nearby but also includes leftover stocks or factory rejects which are considered as reused products in this study.

A total of 50.4 tons of elements have been reused. The mass flow map of reused products in Figure 17 shows a radius of supply up to 150 km from the construction site but most of the products are sourced in radius of 30 km. The weighted average supply distance is 77 km because of the high quantities of steel utility poles sourced from Brugg (80 t. before being cut and 65 km), and the 13 tons of HPL panels sourced at Morges (150 km). Information was lacking about the origin of five elements which are indicated by an asterisk (*) in the Table 14. A default supply distance by truck of 50 km has been considered for these products.

Table 13: Mass of reused materials and weighted average distance of supply in the Kosmos project

| Tons of reused materials | Distance of supply (weighted average) | Overall reused material loss rate |
|---|---|---|
| Ex-situ | | |
| 50 t. \| 70 kg/m² ERA | 77 km | 57% (75% for the steel sections poles only, 20% for all others) |

The Table 14 describes the supply of reused component in details. Some of the most important elements to be reused include (expressed as mass installed):

- Steel sections from electric utility poles reused as external "Faraday cage" (21 t.)
- HPL panels from construction surplus reused as façade cladding (7.9 t.)
- Interior wooden doors, 64 pieces (3 t.)

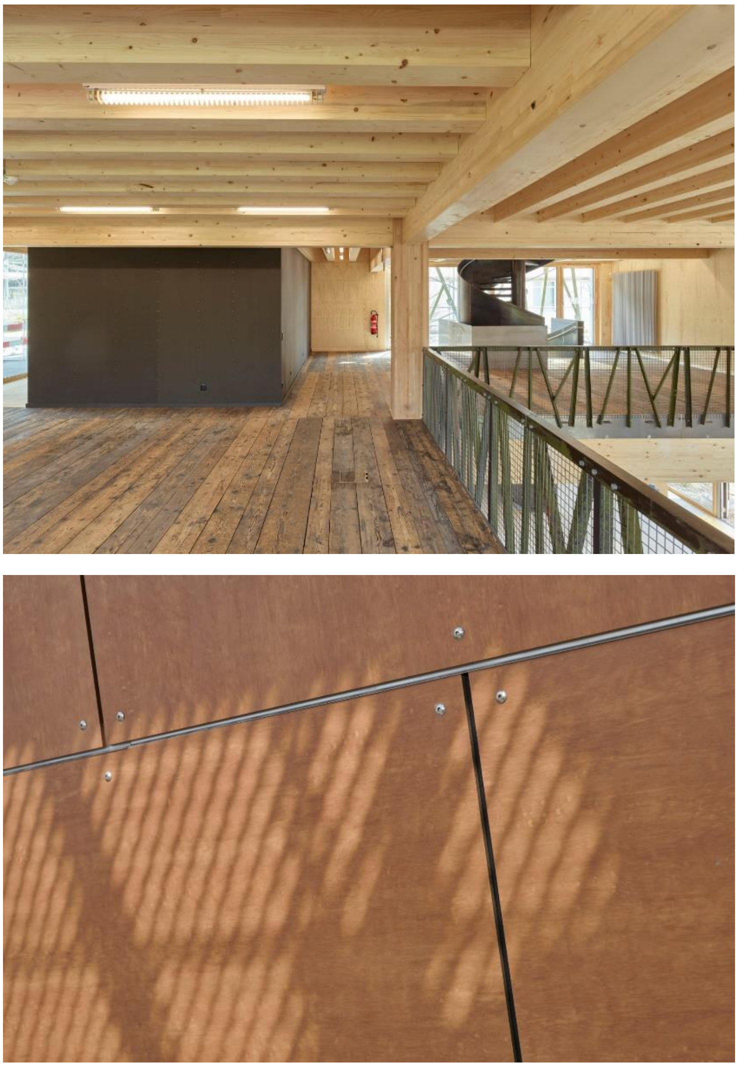


Figure 16 : View of the interior of the Kosmos building showing the reused wooden floorboards (top) and view of the reuse of the HPL panels as façade cladding (bottom).

© *Beat Ernst*

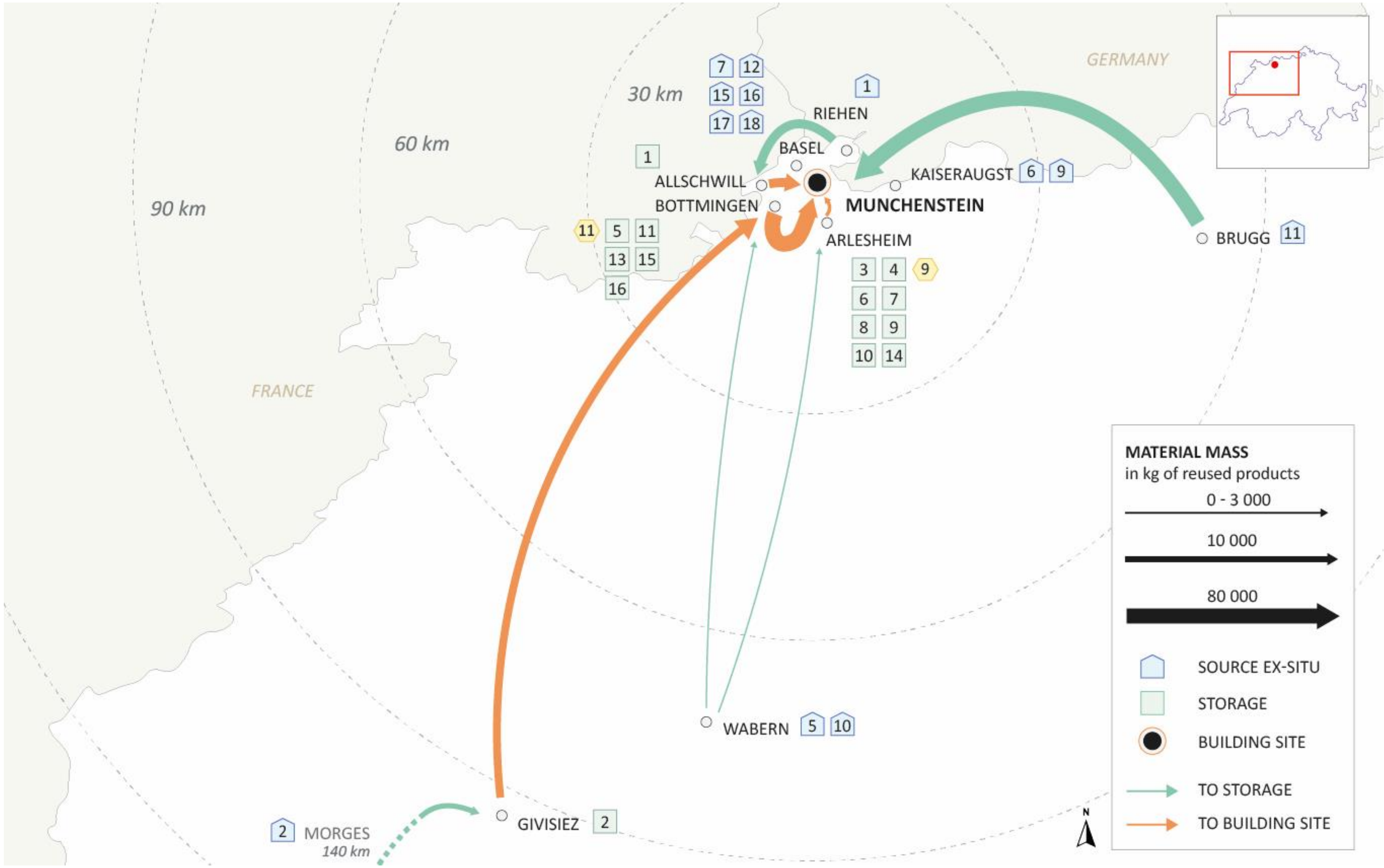



Figure 17: Mass flow map of reused products in the project Primeo Energie Kosmos

Table 14 : Detail of logistic chains of reused components for the Primeo Energie Kosmos building

| n° | Component | Distance in km as: *Total (to storage / to site)* | Mass | Use | Logistic chain's description |
|---|---|---|---|---|---|
| **1** | Stone slabs | 22 (12 / 11) | 13.5 t. | Flat roof flooring | Dismantled from other building, partially supplied by Jos Schneider Ag in Riehen, stored by contractor, reused for the flat roof terrace. |
| **2** | HPL panels | 216 (87 / 129) | 7.9 t. | Façade cladding | Construction surplus from a big housing project around Morges, stored by Ray SA in Givisiez. |
| **3** | OSB panels | 52* (50* / 2) | 1.7 | Interior wall covering | Construction surplus from other sites construction supplied by STAMM Bau AG. |
| **4** | MDF panels | 52* (50* / 2) | 2.4 | Interior wall cladding | Construction surplus from other sites construction supplied by STAMM Bau AG. |
| **5** | Ceramic plates | 107 (102 / 5) | 1.8 | Interior wall covering in bathrooms | Construction surplus supplied by Bernasconi company in Wabern, stored in a warehouse in Botmingen by Primeo Energie for 6 months. |
| **6** | Toilet doors 1 | 16 (14 / 2) | 0.060 | Bathrooms | 98 years old, 2x toilet doors collected from a deconstructed building in Kaiseraugst. Grinded, painted, with new handles and locks assembled. |
| **7** | Toilet doors 2 | 21 (8 / 13) | 0.090 | Bathrooms | 98 years old, 3x toilet doors collected from a deconstructed building in Basel. Grinded, painted, with new handles and locks assembled. |
| **8** | MDF panels off-cuts | 52* (50* / 2) | 0.1 | Partition wall in bathrooms | Off-cuts from the MDF panels reused on site |
| **9** | Wood cladding | 16 (14 / 2) | 0.3 | Interior flooring | 98 years old, collected from a deconstructed building in Kaiseraugst, and supplied by Bootshaus Kaiseraugst. Panels were oiled. |
| **10** | Stone cladding | 102 (800 / 2) | 0.4 | Interior flooring | 2 years old, sourced in Wabern and stored in Arlesheim. |
| **11** | Steel sections | 65 (60 / 5) | 20.8 | Faraday cage surrounding the building (esthetical) | Aged 60 years dismantled electric utility poles near Brugg, 80 t. supplied by Swissgrid *via* Thommen Recycling, stored in a warehouse in Botmingen by Primeo Energie for 6 months. Sections were cut, holes drilled for new connections, new bolts, sanded and painted with transparent paint. |

| | | | | | |
|---|---|---|---|---|---|
| **12** | Kitchen | 10 (0 / 10) | 0.3 | Other | 5 elements kitchen including lower and upper cabinets, and refrigerator, supplied by Rhystadt AG. |
| **13** | Photovoltaic panels | 55* (50* / 5) | 0.4 | Technical systems | 20 years old, 54x modules supplied by Avnetron AG, stored for 9 months in Bottmingen. |
| **14** | Dressing | 52* (50* / 5) | 0.2 | Other | - |
| **15** | WC | 9 (4 / 5) | 0.3 | Bathrooms | 20 years old, collected at a deconstruction and supplied by Rhystadt AG, stored by Primeo Energie in a warehouse. |
| **16** | Urinals | 9 (4 / 5) | 0.08 | Bathrooms | 20 years old, collected at a deconstruction and supplied by Rhystadt AG, stored by Primeo Energie in a warehouse |
| **17** | Washtub | 10 (0 / 10) | 0.01 | Bathrooms | 5 years old, collected at a deconstruction and supplied by Rhystadt AG, installation done on same day as dismantling. |
| **18** | Sinks | 10 (0 / 10) | 0.06 | Bathrooms | 5 years old, collected at a deconstruction and supplied by Rhystadt AG. |

## 3.4 ELYS: reuse in a new facade made of prefabricated modules

Figure 18 : View of the Elys building



| | |
|---|---|
| **Canton** | ZH |
| **Owner** | Immobilien Basel-Stadt |
| **Project type** | Transformation |
| **Building type** | Cultural and commercial |
| **Studied surface area** | 509 $m^2$ of façade |
| **Floors and underground** | 3 floors and 2 underground floors |
| **Re-use strategy** | Adaptive reuse of the structure, ex-situ reuse, in-situ reuse |
| **Scope of analysis in Reuse-LCA** | Prefabricated south façade (construction) |
| **Phase** | Completed in 2021 |

The building "ELYS" was constructed in 1982 in the Lysbüchel district of Basel. Formerly used as an industrial bakery and a distribution centre for a Swiss supermarket company, the building is transformed into a cultural and commercial center. A partial deconstruction of the former building created an opening in the building. The project was to close it with a new façade made of prefabricated module that integrate reused products. This study analyses the 509 m² of south façade at R+1 and R+2 levels depicted in Figure 19 and made of 31 prefabricated modules.

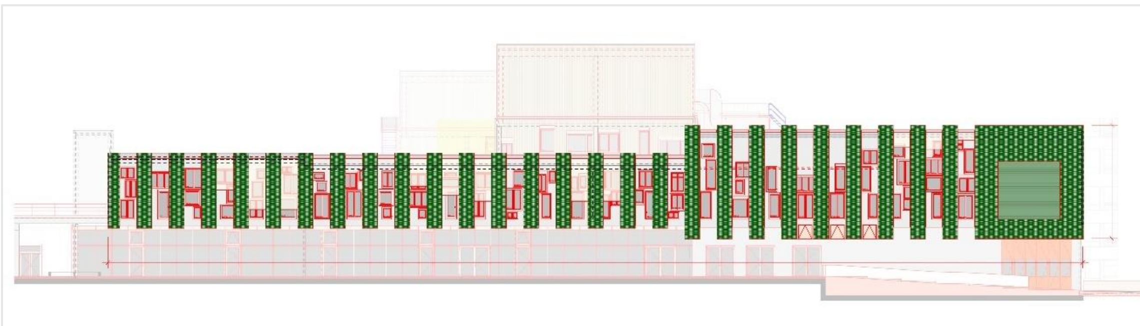


Figure 19: View of the south façade made of prefabricated modules with reused materials

The modules were assembled in a workshop located in Frick (AG) and then installed on site with reused trapezoidal steel sheets collected from the building itself and from an old warehouse nearby. The modules include new and reused elements: glulam wood beams (40% reused), rock wool insulation (100%) and windows (90% reused). They are completed with new products for functional purposes and covering such as plasterboard, Fermacell, mineral coating, and sealing membranes. The glue laminated wood beams are made from reclaimed wood collected near Basel. The windows are manufacturing surplus with defects, salvaged from eight manufacturers, as well as the rock wool insulation. The use of manufacturing surpluses from defects is considered as a reuse practice in this study with the argument of saving products destined for disposal, but it could be considered differently as these are new products.

The Figure 21 illustrates the mass flow of the reused elements. The supply circle for reused components in the Elys project is quite extensive, ranging from the canton of St. Gallen to the canton of Bern. Once the modules have been assembled, they are transported together to the building site, which is 40 km away from the workshop. The loss rate of reused materials resulting from the modification and assembly of the modules is 9%, as indicated in the Table 15, but this figure is calculated with a default loss rate of 10% for reused materials other than windows, as no information on losses was available. In reality, they could be higher due to the manufacturing process and the cutting of the glue laminated beams.

Table 15: Mass of reused materials and weighted average distance of supply for the prefabricated façade in the Elys project

| **Tons of reused materials** | | **Distance of supply (weighted average)** | **Overall reused material loss rate** |
|---|---|---|---|
| In-situ | Ex-situ | | |
| 18 t.<br>35 $kg/m^2_{façade}$ | 14 t.<br>45 $kg/m^2_{façade}$ | 84 km | 9% |


Figure 20 : View of the prefabricated façade of Elys during assembling the workshop (top) and during the construction on site (bottom)

*© Martin Zeller*

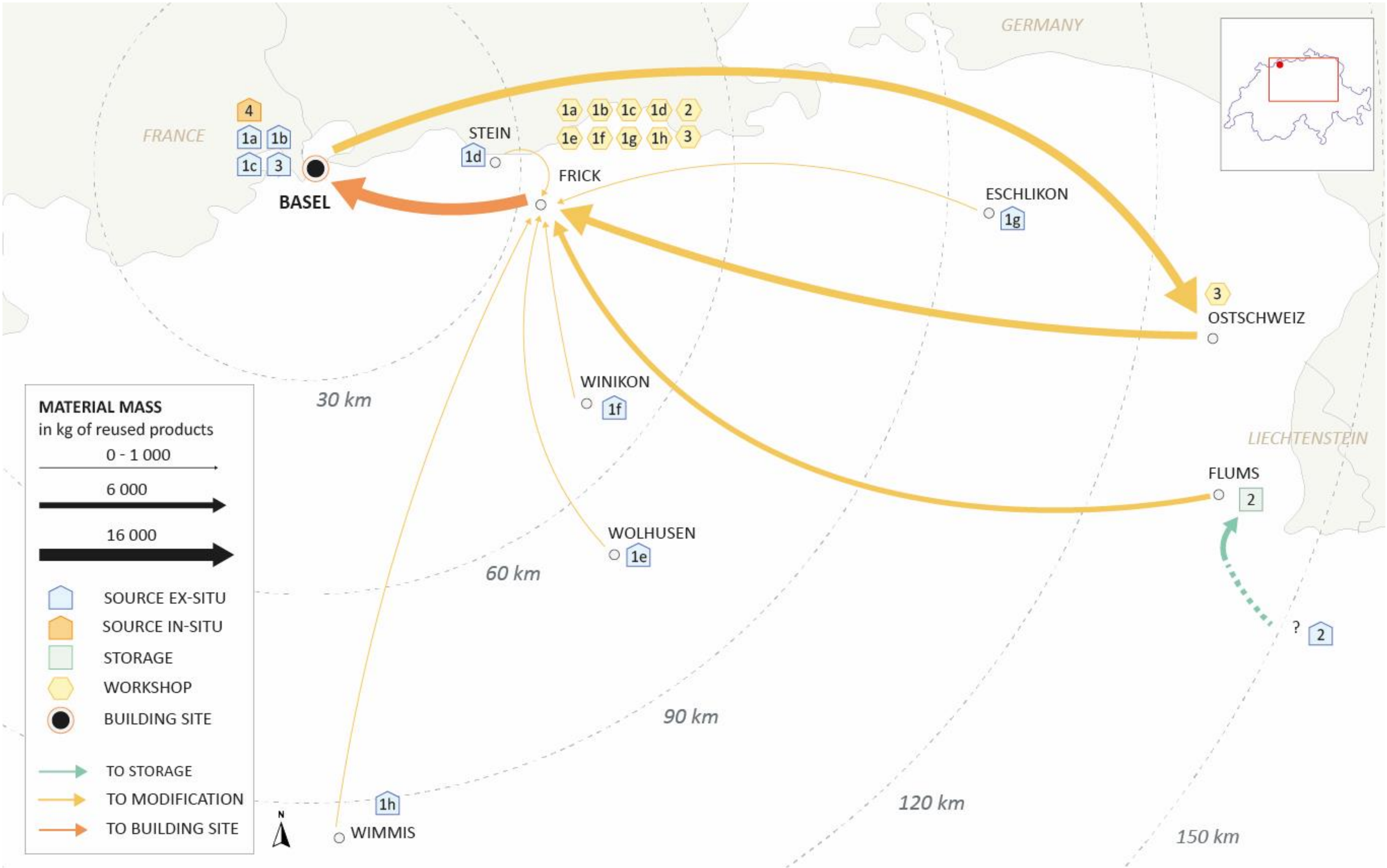



Figure 21: Mass flow map of reused products for the prefabricated façade in the project ELYS

Table 16 : Detail of logistic chains of reused components for the prefabricated façade in the Elys building

| n° | Component | Distance in km as: *Total (to storage / to workshop / to site)* | Mass (tons) | Use | Logistic chain's description |
|---|---|---|---|---|---|
| **1a & 1b** | Windows a & b | 70 (0 / 30 / 40) | 1.1 | Prefabricated façade | Triple glazing windows with wood frames provided by Schwald AG and Schweizer René, assembled on HUSNER site in Frick |
| **1c** | Windows c | 70 (0 / 30 / 40) | 0.3 | Prefabricated façade | Triple glazing windows with PVC frames provided by Kiefer Ego, assembled on HUSNER site in Frick |
| **1d** | Windows d | 45 (0 / 5 / 40) | 0.3 | Prefabricated façade | Triple glazing windows with wood-metal frames provided by Erne Holzbau, assembled on HUSNER site in Frick |
| **1e** | Windows e | 90 (0 / 50 / 40) | 0.2 | Prefabricated façade | Triple glazing windows with wood frames provided by Gawo Gasser, assembled on HUSNER site in Frick |
| **1f** | Windows f | 70 (0 / 30 / 40) | 0.6 | Prefabricated façade | Triple glazing windows with wood frames provided by Biene Fenster, assembled on HUSNER site in Frick |
| **1g** | Windows g | 110 (0 / 70 / 40) | 0.5 | Prefabricated façade | Triple glazing windows with PVC frames provided by Gautschi Fenster, assembled on HUSNER site in Frick |
| **1h** | Windows h | 135 (0 / 95 / 40) | 0.05 | Prefabricated façade | Triple glazing windows with wood frames provided by Wenger Fenster, assembled on HUSNER site in Frick |
| **2** | Rockwool Insulation | 250 (100* / 110 / 40) | 4.0 | Prefabricated façade | 10 years old, collected from different projects as construction surplus, stored by FLUMROC (Reuse Market), assembled on HUSNER site in Frick, remnants reused to fulfil the modules |
| **3** | Wood | 290 (0 / 250 / 40) | 6.6 | Prefabricated façade | 60 years old, sourced from nearby sites in Basel, transformed into glued laminated beams somewhere in Ostschweiz, assembled on HUSNER site in Frick, reused to form the framework of the modules, up to 9m high. |
| **4** | Trapezoidal steel sheet | 0 (0 / 0 / 0) | 18.2 | Prefabricated façade | 40 years years old, dismantled from the building itself, in-situ reused as façade cladding. |

## 3.5 Chauchy: reuse in a transformation of an old barn

Figure 22 : View of the Chauchy building
*https://chauchy.ch/*

| | |
|---|---|
| **Canton** | VD |
| **Owner** | Cooperative |
| **Project type** | Transformation with in-situ and ex-situ reuse |
| **Building type** | Residential |
| **Studied surface area** | 548 m² ERA |
| **Floors and underground** | 4 floors, no underground |
| **Re-use strategy** | Conservation of structure, site-to-site reuse, in-situ reuse |
| **Scope of analysis in Reuse-LCA** | Whole building LCA (construction) |
| **Phase** | Completed in 2024 |

The project Chauchy in Denens (VD) by Coopérative d'architecture C/O is the transformation of an existing old barn dating from XIX$^{th}$ century into a housing cooperative. It comprises 6 apartments ranging from 1.5 to 3 rooms and 120 m² of common spaces (kitchen, laundry and guest rooms). The spaces are designed around the concept of "cluster" which a balance between autonomy with individual apartments, and social interaction and solidarity with common spaces and utilities.

The project gathers all three practices of reuse and totalises 306 tons of reused materials over 10 categories of products:

- Adaptive reuse: the existing stone rubble structure and wooden roof structure have been preserved, representing respectively 205 and 1.3 tons of materials.
- In-situ reuse: the transformation works led to the deconstruction of several components of the original barn. Some of the stone rubbles, which has been dismantled to open up spaces for windows, were reused in gabion walls surrounding the garden. Terracota bricks from former load-bearing interior walls have been reused in new internal partition walls. Former 40 years old window shutters were reconditioned and reused on-site.
- Ex-situ reuse: The wooden beams (24 x 14 cm) formed the floor structure of a building in Geneva dating from 1910 which was to be demolished. The wooden beams were donated by the dismantling company, which saved on disposal costs. They were inspected at the source site by Materiuum (in charge of the reuse inventory) and inspected by the carpenter at the target site to ensure their reliability for structural floors. They were cleaned of nails and staples in Denens, cut to size and laid side by side to form plain floors for the ground floor (130 m$^2$) and the mezzanine on the 2nd floor (25 m$^2$). Sanitary equipment (WCs, washbasins, shower trays, bathtubs) were purchased from Promaison, a social enterprise specialising in the retail sale of used product.

The reuse mass flow map in Figure 24 shows that most of the elements were sourced nearby within a radius of about 40 km, the distance to Geneva for the collection of wooden beams and sanitary equipment. Some storage and reconditioning operations were conducted in towns within 10 km of the site. This results in a very low weighted average supply distance of 3.3 km, as indicated in Table 17.

Table 17: Mass of reused materials installed and weighted average distance of supply in the Chauchy project

| **Mass of reused materials** | | | **Distance of supply (weighted average)** | **Overall reused material loss rate** |
|---|---|---|---|---|
| Preserved / adaptive reuse | In-situ | Ex-situ | | |
| 206 t.<br>376 $kg/m^2_{ERA}$ | 89 t.<br>162 $kg/m^2_{ERA}$ | 11 t.<br>20 $kg/m^2_{ERA}$ | 3.3 km | 22% |

Figure 23 : View of the wooden beams salvaged from a deconstruction at Geneva (top), and them reused as a plain structure of intermediate floors (bottom) in the Chauchy project.

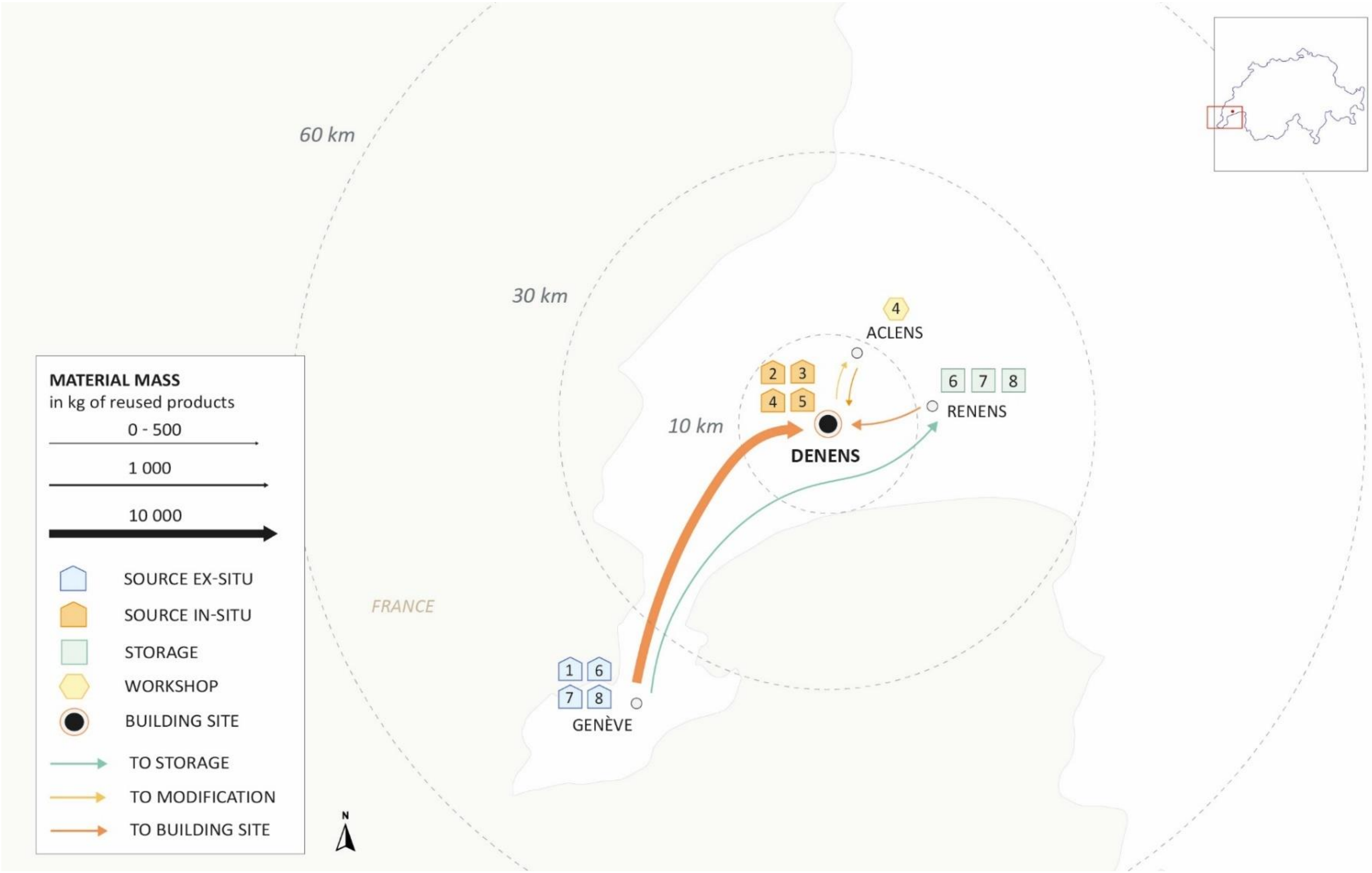



Figure 24: Mass flow map of reused products in the project Chauchy

Table 18 **:** Detail of logistic chains of reused components in the Chauchy building

| n° | Component | Distance in km as: *Total (to storage / to workshop / to site)* | Mass (tons) | Use | Logistic chain's description |
|---|---|---|---|---|---|
| **1** | Wooden beam | 64 (0 / 0 / 64) | 10.3 | Intermediate floors | 120 years old, dismantled from a building in Geneve, supplied by Materiuum, stored 200m from the building site in Denens for 3 months, reused at 1st floor and in the attics |
| **2** | Brick | 0 (0 / 0 / 0) | 1.4 | Interior partition walls | 170 years old, dismantled from the building itself, originally part of load-bearing wall, supplied by project owner, stored 10 months on site |
| **3** | Windows frames | 0 (0 / 0 / 0) | 1.2 | Envelope | 40 years old, concrete frames, dismantled from the building itself |
| **4** | Window shutters | 22 (0 / 11 / 11) | 0.2 | Envelope | 40 years old, dismantled from the building itself, transported to a workshop and painted |
| **5** | Rubble stones | 0 (0 / 0 / 0) | 87 | Exterior surrounding gabion wall | 170 years old, dismantled from the building itself, stored 10 months on site, reuse in gabion walls |
| **6** | WC | 78 (63 / 0 / 15) | 0.3 | Bathrooms | 10 years old, dismantled from a building in Geneve, supplied by Materiuum, stored in a barn owned by the project owners in Renens for 10 months |
| **7** | Sink | 78 (63 / 0 / 15) | 0.2 | Bathrooms | 10 years old, dismantled from a building in Geneve, supplied by Materiuum (reuse market), stored in a barn owned by the project owners in Renens for 10 months |
| **8** | Shower | 78 (63 / 0 / 15) | 0.3 | Bathrooms | 10 years old, dismantled from a building in Geneve, supplied by Materiuum (reuse market), stored in a barn owned by the project owners in Renens for 10 months |

## 3.6 PPN Tower 107: reuse in a building transformation within a district project development

Figure 25 : View of the tower 107 in the PPN project

| | |
|---|---|
| **Canton** | GE |
| **Owner** | Caisse de Pension Etat de Genève |
| **Project type** | Transformation |
| **Building type** | Office |
| **Studied surface area** | 17 floors, 2 underground floors |
| **Floors and underground** | Adaptive reuse of the structure and in-situ reuse |
| **Re-use strategy** | Whole building LCA (construction) |
| **Scope of analysis in Reuse-LCA** | 7’932 $m^2$ of energy reference area (ERA) |
| **Phase** | Completed in 2023 |

The transformation initiative in the PAV (Praille-Acacias-Vernets) Pointe Nord district, called the PPN project, was supervised by the CPEG (Caisse Prévoyance de l'Etat de Genève) and aimed at converting three buildings into administrative space to host around 650 people from various departments of the State of Geneva. This study analyses the transformation of the 17-storey Tower 107, previously owned by the company Firmenich SA and constructed in 1964. The project has been coordinated by the architectural firm Baud & Früh in collaboration with the association Matériuum, which actively promotes reuse practices. The project implemented adaptive reuse by preserving the 60 years old structure made of reinforced concrete that allowed to preserve around 10’000 tons of material. The PPN project enabled dismantled elements to be reused directly in the project or supplied externally for reuse. The Tower 107 transformation included the following element reused in-situ:

- Interior doors: 75 doors collected from the tower 107 itself (3 tons).
- Suspended ceilings: 690 m² of microperforated metal suspended ceilings were reused in-situ, collected from buildings 101 and 102 on the same PPN site (4 tons).

Of the approximately 654 doors deconstructed three buildings of the PPN project, 444 could not be reused in-situ or externally due to various technical constraints. This results in a loss rate of 68% for the entire PPN project, which is used in our study of Tower 107. For the suspended ceilings, the architects indicated a loss rate of 5%. Tower 107 also includes the in-situ recycling of its own façade stone cladding, which was crushed into gravel for use in a terrazzo flooring. The building also features a new 1062 m² BIPV (building-integrated photovoltaic) façade capable of producing 69.2 MWh/year.

Table 19: Mass of reused materials and weighted average distance of supply for in the PPN 107 project

| **Tons of reused materials** | | **Distance of supply (weighted average)** | **Overall reused material loss rate** |
|---|---|---|---|
| Adaptive reuse | In-situ | | |
| 10'000 t.<br>1260 kg/m²$_{ERA}$ | 7 t.<br>0,9 kg/m²$_{ERA}$ | 0 km | 49% |

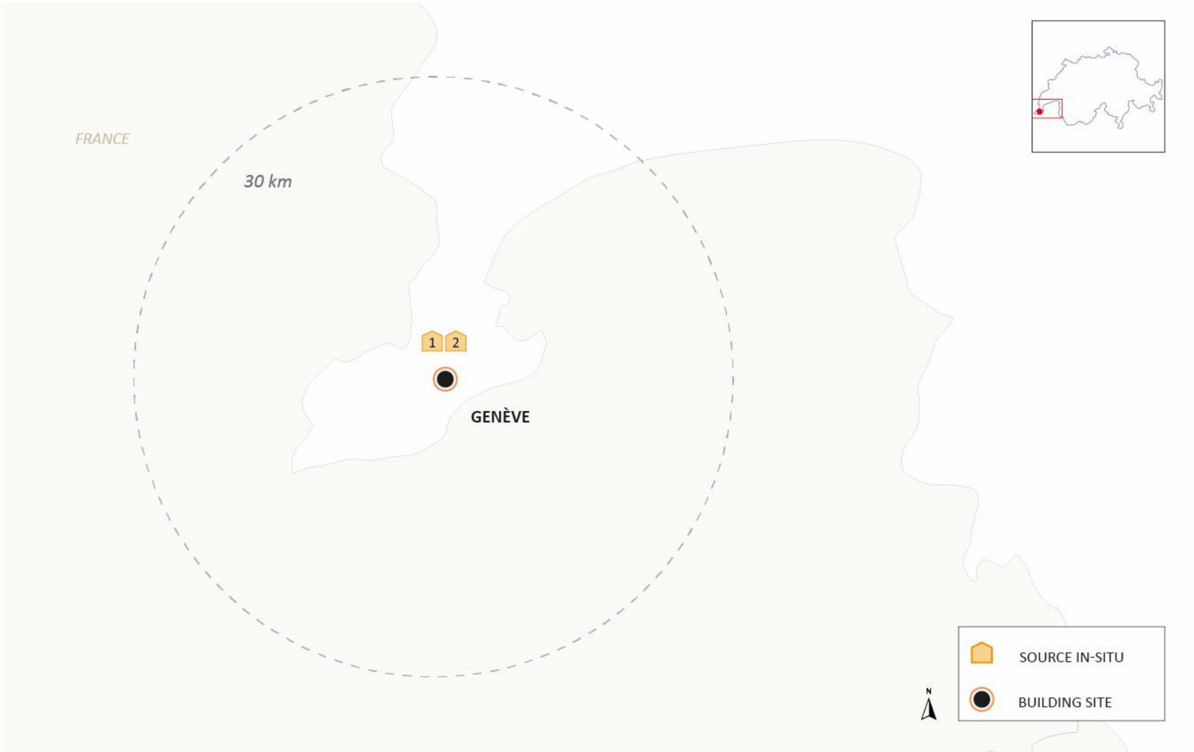



Figure 26**:** Mass flow map of reused products in the project PPN Tower 107

Table 20: Detail of logistic chains of reused components for the PPN Tower 107 project

| **n°** | **Component** | **Mass (tons)** | **Use** | **Logistic chain's description** |
|---|---|---|---|---|
| **1** | Suspended metal ceiling microperforated | 4.0 | Interior | 20 years old, dismantled from the building, stored on site for 18 months, in-situ reused |
| **2** | Interior doors | 3.0 | Interior | 20 years old, dismantled from the building, stored on site for 18 months, in-situ reused |

## 3.7 Fayards: reuse of windows frames in a building energy-related renovation

Figure 27 : View of the Fayard building

| | |
|---|---|
| **Canton** | GE |
| **Owner** | Fondation HBM Jean-Dutoit CAP Prevoyance |
| **Project type** | Renovation with in-situ reuse of window frames |
| **Building type** | Mixed-use (residential, commercial, and recreational) |
| **Studied surface area** | 25,545 m² ERA (95% residential) |
| **Floors and underground** | Five buildings, each with 5 floors, no underground (except for one building) |
| **Re-use strategy** | In-situ reuse of wooden window frames, paired with new glazing |
| **Scope of analysis in Reuse-LCA** | Renovation focusing on energy and GHG balance of windows |
| **Phase** | Phase 32 of SIA |

The renovation project of the Fayard building in Versoix (GE) led by Fondation HBM Jean Dutoit & CAP Prévoyance aims to energy retrofit 5 residential buildings constructed between 1990 and 1995. They represent a total energy reference area (ERA) of 25,545 m² and a total glazing surface of 4,437 m² which correspond to 18.2 tons of windows frame. The project distinguishes itself by the adaptive reuse of the existing window frames (wooden metal) combined with the retrofitting of their glazing and sealing (i.e., integration of new glazing). This strategy reduces for the windows retroffing the new material consumption and waste generation in the energy renovation, minimising GHG emissions due to materials.

Table 21: Mass of reused windows frames in the project (reclamation rate only refers to the windows' frame)

| Reused windows frames | Reclamation rate |
|---|---|
| 18.2 t. | 100% |

## 3.8 MixCity: reuse of concrete slabs from a building deconstruction

Figure 28 : View of the MixCity building during the combined deconstruction and demolition © Julien Pathé 2401

| | |
|---|---|
| **Canton** | VD |
| **Owner** | Arab Bank Switzerland Ldt |
| **Project type** | Deconstruction with concrete reuse. |
| **Building type** | Industrial building |
| **Studied surface area** | 728 m² of salvaged concrete slabs |
| **Floors and underground** | 3 floors + 1 underground floor |
| **Re-use strategy** | Selective dismantling |
| **Scope of analysis in Reuse-LCA** | Dismantling |
| **Phase** | Completed in 2023 |

The MixCity project in Renens (VD) of a new industrial and logistic building in 2025, involved the deconstruction of a pre-existing office building dating from 1980's. Then building has a reinforced concrete frame structure, 3 floors and 1 underground floors, with approximately 3090 $m^2_{ERA}$. The deconstruction project adopted a selective dismantling approach, encouraged by the municipality of Renens and lead by a team composed of Steiner AG (general construction company), 2401 (structural engineering consultancy) and Cand-Landi (demolition and deconstruction company). The project team partnered with students, academics and architects who reused the elements into four construction projects in the Romandie region (RebuiLT, EPFL, HEIA-Fr, Atelier Simplon, MacIver-Ek Chevroulet).

The selective dismantling requires a precise layout plan for placing the temporary shoring beams and for the sawing of the floors. It led to the saving of concrete slabs and columns representing 25% of the building's structure mass. The environmental impacts of the dismantling and supply of concrete elements.in the case study is assessed in Appendix, focusing on "downstream reuse" rather "upstream reuse" like in the other building case studies.

The quantities of concrete per project are given in table 4.

Table 22: Mass of salvaged concrete elements in the MixCity deconstruction project

| Salvaged concrete elements | Reclamation rate |
|---|---|
| 410 t (slab) and 23 t (pillars)<br>728 $m^2_{\text{Concrete slabs including some pillars}}$ | about 25% |

# 4 Results

The results are presented for the 5 building case studies located in Zürich (K.118, Hobelwerk D), Basel (Kosmos) and in Geneva Lake region (Firmenich PPN Tower 107 and Chauchy). For each case study, the material intensity is presented followed by the reuse rate and the adaptive reuse (or preserved rate). It is then followed by the LCA results presented in this report only for the GHG emissions. For the sake of clarity and to remain consistent in this chapter i.e., include only the analyses of whole buildings for demand-side reuse, additional case studies at other scales i.e., at the scale of a building element for demand-side reuse (ELYS case study in Basel city (BS)), at the dismantling site for the offer-side of concrete reuse (MixCity case study in Renens (VD)) as well as an analysis of adaptive reuse of existing windows frame (Fayards case study in Versoix (GE)) are reported in Appendices II, III and IV.

## 4.1 LCA of case studies

### 4.1.1 K.118: transformation and vertical extension

The K.118 building has a material intensity of 797 kg/m² ERA (1,130 tons total), with reused elements comprising approximately 38% of the total mass, including 25% preserved from the existing building and 13% ex-situ reused (Figure 29).

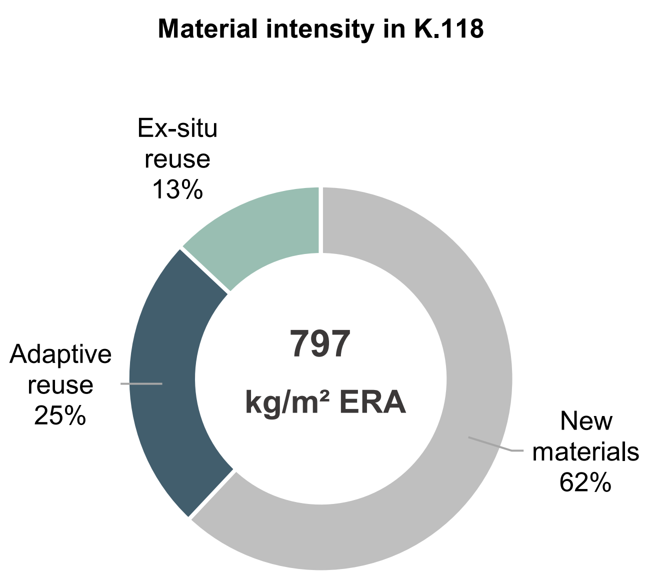



Figure 29: Material intensity and materials origins in the K.118 building

Figure 30 uses a Sankey diagram to depict the material composition of Building K.118, categorizing mass flows by building layer, origin (new/reused), and material families. The mass of components of the water installation (e.g., pipes, sanitary elements), exhaust air system, heat generation, and heat distribution are missing because this information is unavailable in the default KBOB LCA data.

**Structure layer**

- The structure accounts for 50% of the building mass.
- The structure is 36% reused: 21% of the mass is a preserved reinforced concrete structure (adaptive reuse), and 15% is ex-situ reuse of the steel beams used for the structure of the vertical elevation.

**Underground and exterior layer**

- The underground and exterior elements account for 21% of the building mass
- The underground and exterior elements are 34% reused from the preserved reinforced concrete foundation (adaptive reuse).

**Envelope layer**

- The envelope elements account for 15% of the building mass
- The envelope layer is 68% reused, consisting of the original brick and mortars walls that have been preserved, the reused windows, and the trapezoidal steel sheeting that covers the new floors.

The K.118 building contains 10% of bio-based materials (83 kg/m²$_{ERA}$). There are significant reuse rates across material categories: 25% of concrete and 50% of stone-based materials (e.g., bricks) are adaptively repurposed, alongside nearly all structural steel elements. Reclaimed wood and bio-based materials account for a quarter of their total mass. Reuse also extends to lighter, smaller-volume components—including insulation, HVAC systems, sanitary fixtures, PV installations, and furniture—though these account for a smaller share of overall mass.

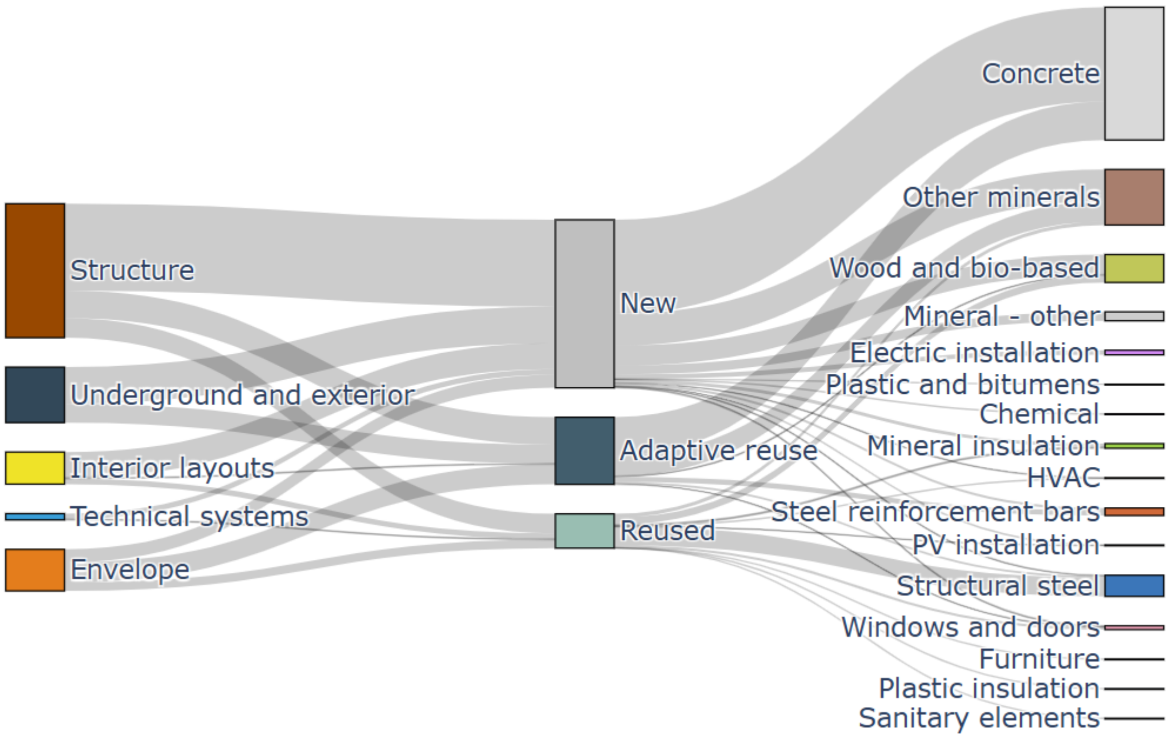



Figure 30: Sankey diagram of the mass flow of building components by building layer, origin and material family, K.118

The Figure 31 presents the life cycle GHG emissions per square meter for both transformed and newly built areas. The SIA 390 target values are shown with blue and red dashes for comparison.

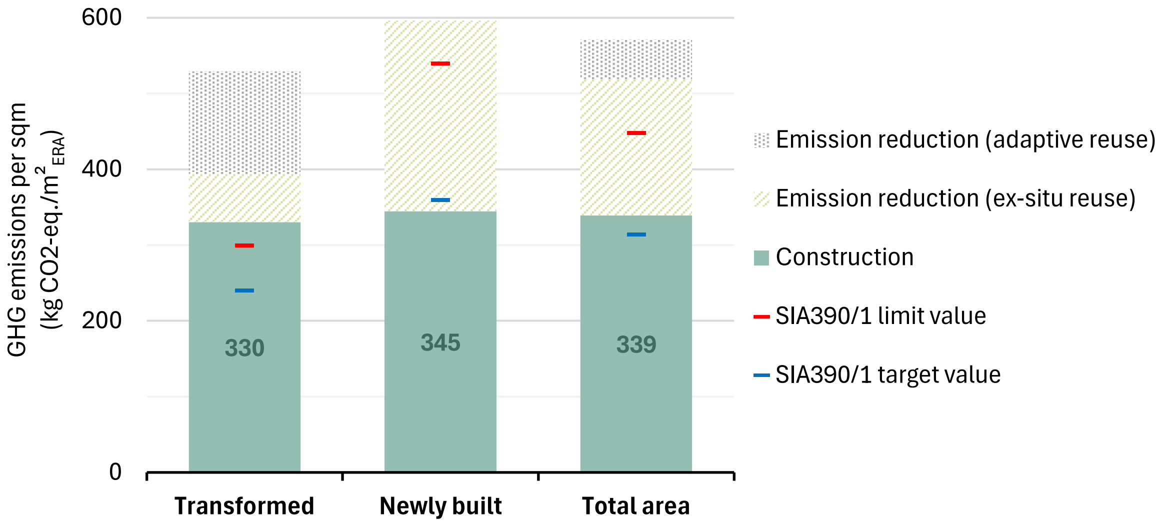



Figure 31: Construction's GHG emissions of one square meter of K118 by type of area and positioned towards SIA 390/1 reference values (transport A4 is excluded)

**Material and impact allocation in K.118**

The K.118 project combines a transformation and an extension, necessitating the use of two distinct functional units in the life cycle assessment (LCA):

- **Transformed area** (38% of ERA): 1 m² of office/workshop space on the ground and first floors.
- **Newly built area** (62% of ERA): 1 m² of office/workshop space on the third to fifth floors.

To allocate new and reused construction materials and activities, three allocation rules were applied:

- **Location-Based Allocation**: Materials with clearly defined locations or specific purposes, such as windows, claddings, or structural elements, are directly assigned to the corresponding area. For example, foundation reinforcements required for the extension are fully allocated to the newly built area.
- **Shared Elements Allocation**: Common components including technical systems (electricity, heat, water, ventilation, and photovoltaic), as well as balconies and exterior stairs, are distributed based on the proportional area shares of the transformed and newly built areas (38%/62%).
- **Default, Proportional**: For elements lacking precise location data, such as interior wall materials, allocation follows the same area-based ratio (38%/62%).

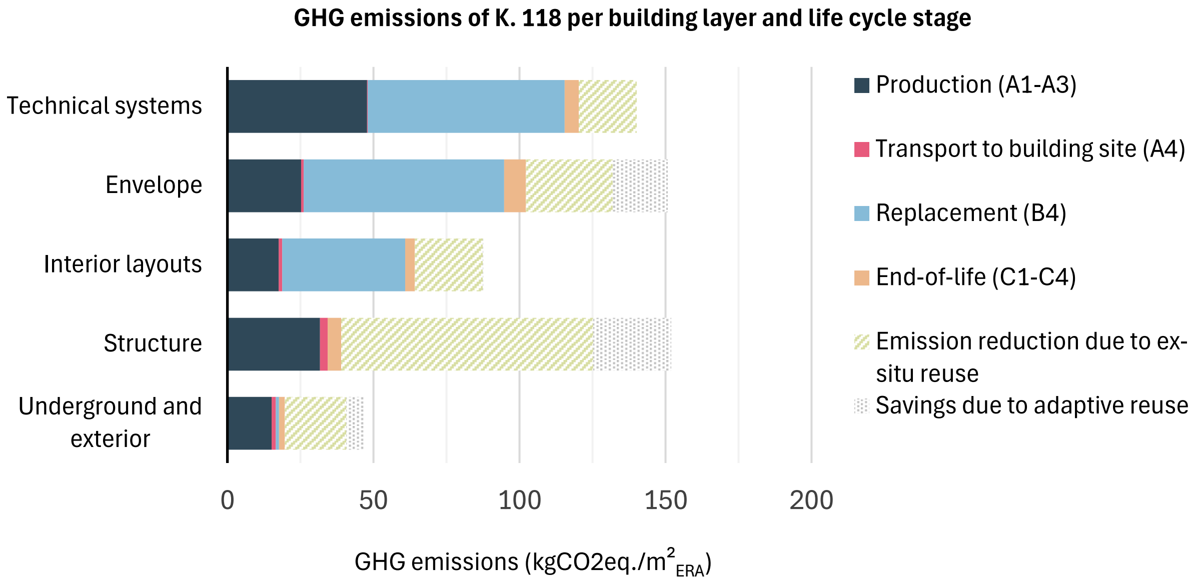



Figure 32: GHG emissions per building layer and life cycle stage, K.118

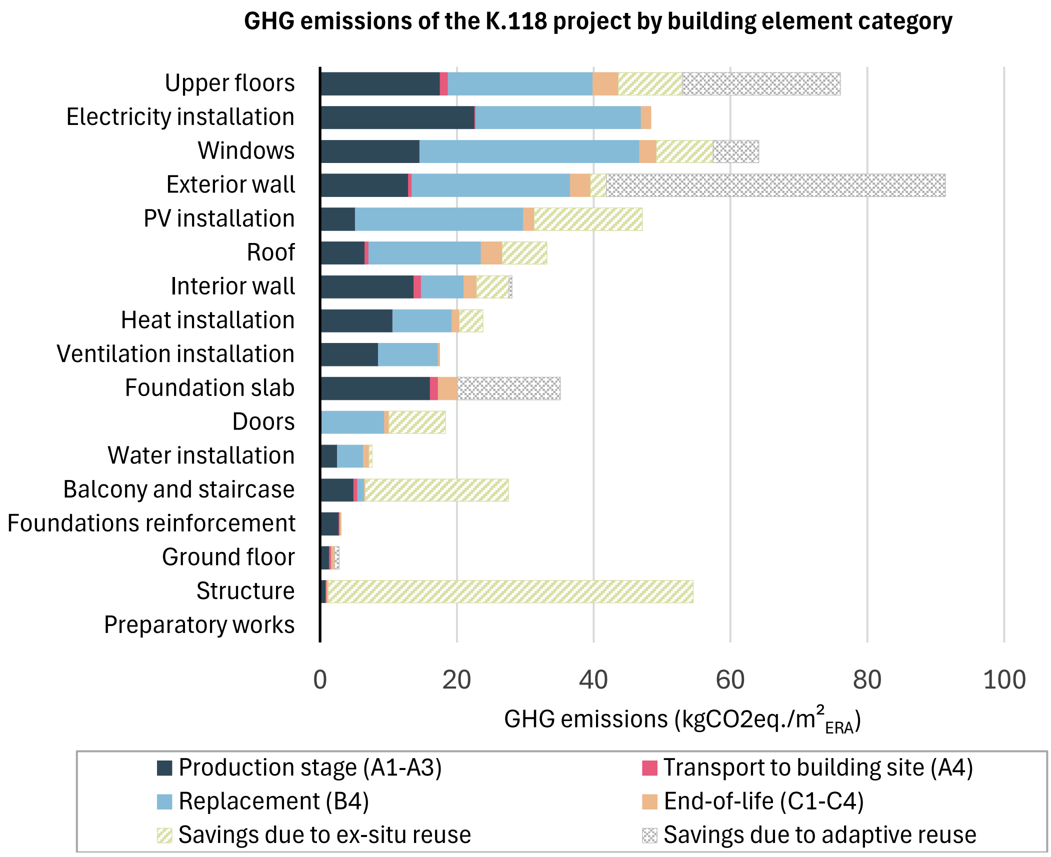



Figure 33: GHG emissions per building element category and life cycle stage, K.118

The project's greenhouse gas (GHG) emissions fall between the SIA 390's base and ambitious targets. Adaptive reuse and ex-situ reuse strategies collectively contributed to a potential saving of 40% in GHG emissions per square meter over the building's life cycle.

**Key Findings from detailed analysis:**

- **Transformed area:** the emissions of 340 kg $CO_2$ eq./m² $_{ERA}$ are slightly above the SIA 390 base target of 300 kg $CO_2$ eq./m² $_{ERA}$ (Figure 31). Despite ex-situ reuse contributing to a 16% reduction in emissions, this result is attributed to the extensive scope of the transformation, which included renewing the foundation slab and technical installations, as well as the future replacement of components with new materials, for example the aluminum windows blinds (Figure 33).

    - Adaptive reuse significantly reduces GHG emissions by 155 kg $CO_2$-eq./m² $_{ERA}$, primarily due to the preservation of existing structural elements, such as brick walls, floors, windows, and foundations.

    - Ex-situ reused elements help reduce the GHG emissions of the transformed area through specific reused components (such as claddings and doors in the ground and first floors), as well as shared reused elements (PV panels, staircases, and balconies).

- **Newly built area:** this area's emissions are below the limit value for new construction and nearly meet the ambitious SIA 390 target. While the newly built area does not directly benefit from adaptive reuse, it achieved a substantial reduction of 247 kg $CO_2$-eq./m² $_{ERA}$ through the ex-situ reuse of steel beams, external claddings and windows.

- **Building layer:** the analysis of GHG emissions across building layers reveals that technical systems are the most emissive category, contributing 125 kg $CO_2$ eq./m² $_{ERA}$. This category includes all the new utilities from electricity, ventilation, water systems, heating, and photovoltaic (PV) installations. The reuse of PV panels, heat emitters, and water systems resulted in a 14% reduction in emissions of these installations. The envelope follows, with emissions of 104 kg $CO_2$ eq./m² $_{ERA}$. Reuse strategies applied to this category achieved 33% reduction in emissions. For interior layouts, the emissions amount to 88 kg $CO_2$ eq./m² $_{ERA}$, with a 27% reduction achieved through reuse practices. The most substantial GHG emission reductions are observed in the structural elements, which emit 44 kg $CO_2$ eq./m² $_{ERA}$. A 75% reduction was achieved through the adaptive reuse of the existing building and the reuse of structural steel beams for the vertical extension. Finally, the underground and exterior layers have a relatively small contribution to the project's total GHG emissions, at 27 kg $CO_2$ eq./m² $_{ERA}$, with a 33% reduction resulting from reuse strategies.

- **Element category and component:** the reused construction products that most significantly reduced the GHG emission of the building compared to new ones are: the load-bearing steel structure for the extension (-86 kg $CO_2$ eq./m²$_{ERA}$), the steel beams in the existing exterior wall (-19 kg $CO_2$ eq./m²$_{ERA}$), the steel external staircase (-17 kg $CO_2$ eq./m²$_{ERA}$), the PV panels (-16 kg $CO_2$ eq./m²$_{ERA}$), the existing brick and concrete walls (-11 kg $CO_2$ eq./m²$_{ERA}$ and -10 kg $CO_2$ eq./m²$_{ERA}$ respectively) and the trapezoidal steel sheets (-8 kg $CO_2$ eq./m²$_{ERA}$).

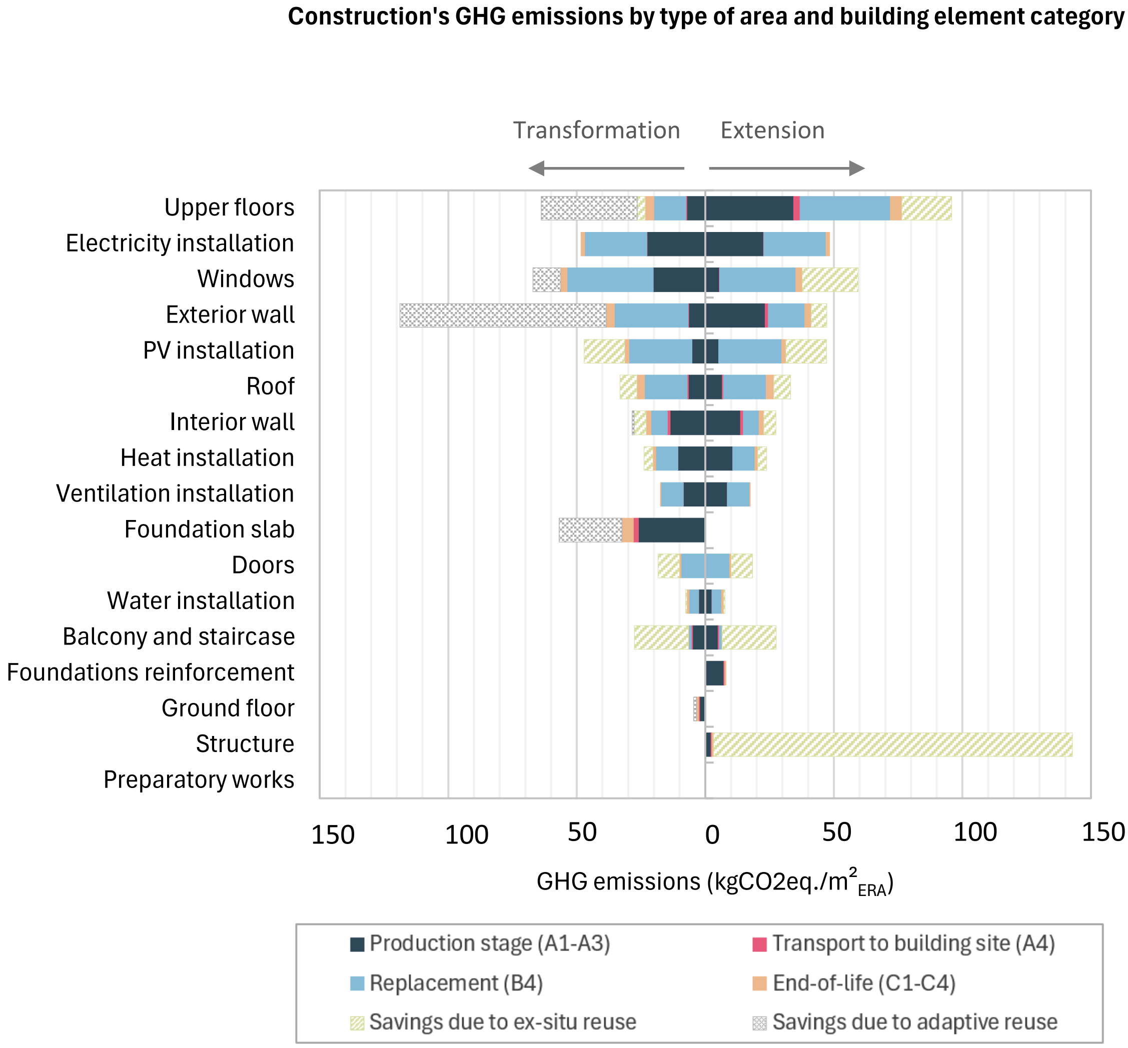



Figure 34: K118 construction's GHG emissions per m² by type of area (left : transformed existing area, right: elevation new area), and by element category

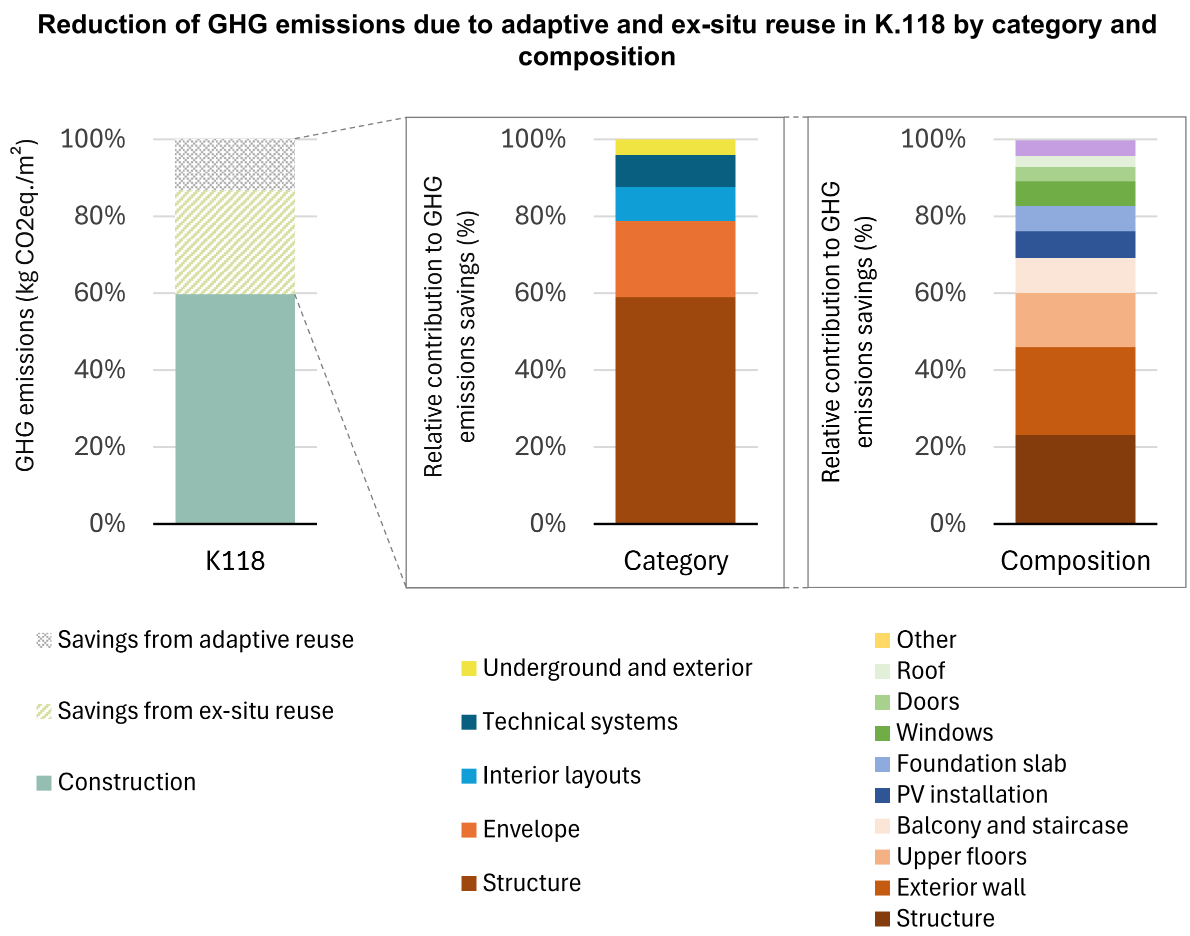



Figure 35: K118 construction's GHG emissions and savings due to reuse per m² (left), relative contribution to GHG emissions savings due to reuse from different building categories and components type (middle and right)

### 4.1.2 Hobelwerk Haus D: new construction

As shown in the Figure 36, the Hobelwerk Haus D building has a material intensity of 758 kg/m$^2_{ERA}$ (1'714 tons total). The reused elements are sourced ex-situ and account for 2% of the building mass.

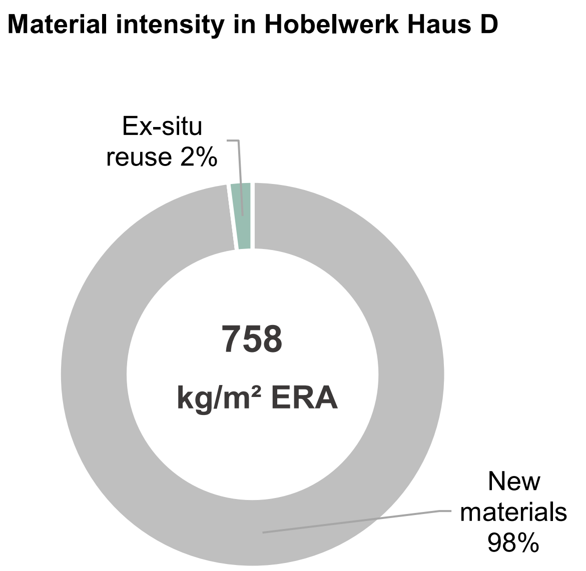



Figure 36: Material intensity and materials origins in the Hobelwerk Haus D building

Figure 37 uses a Sankey diagram to depict the material composition of Building K.118, categorizing mass flows by building layer, origin (new/reused), and material families. The mass of water installation components (e.g., pipes, sanitary elements) is missing, the information being unavailable in the default KBOB LCA data.

**Structure layer**
- 22% of the total building mass.
- The only reused component is steel balcony grating accounting for 0,2% of the structure.

**Underground and exterior layer**
- 32% of the total building mass
- Reuse represents 0,8% of this category (granite plates finishes of exterior surroundings).

**Envelope layer**
- 14% of the total building mass
- The envelope layer is 5% reused, consisting of wood cladding for balconies, windows and shutters.

**Interior layouts**
- 32% of the total building mass, driven primarily by anhydrite floor screeds.
- The reuse contributes to 2,4% of this category (ceramic tiles and doors).

The Haus D project contains a fair share of bio-based materials of 30% (217 kg/m$^2_{ERA}$). Reused materials represent just 1.8% of the building's total mass. Within this limited reuse, mineral-based materials (e.g. stone, ceramic) account for 40% of the mass reused. Wood and bio-based elements (24%) and windows/doors (27%) follow as key contributors. Smaller contributions come from furniture (6%), steel components (1.4%), and sanitary fixtures (1.6%). The reused materials are primarily allocated to the balconies (25% of reused materials), Interior wall finishes (20%), as exterior surrounding finishes (14%), and doors (13%).

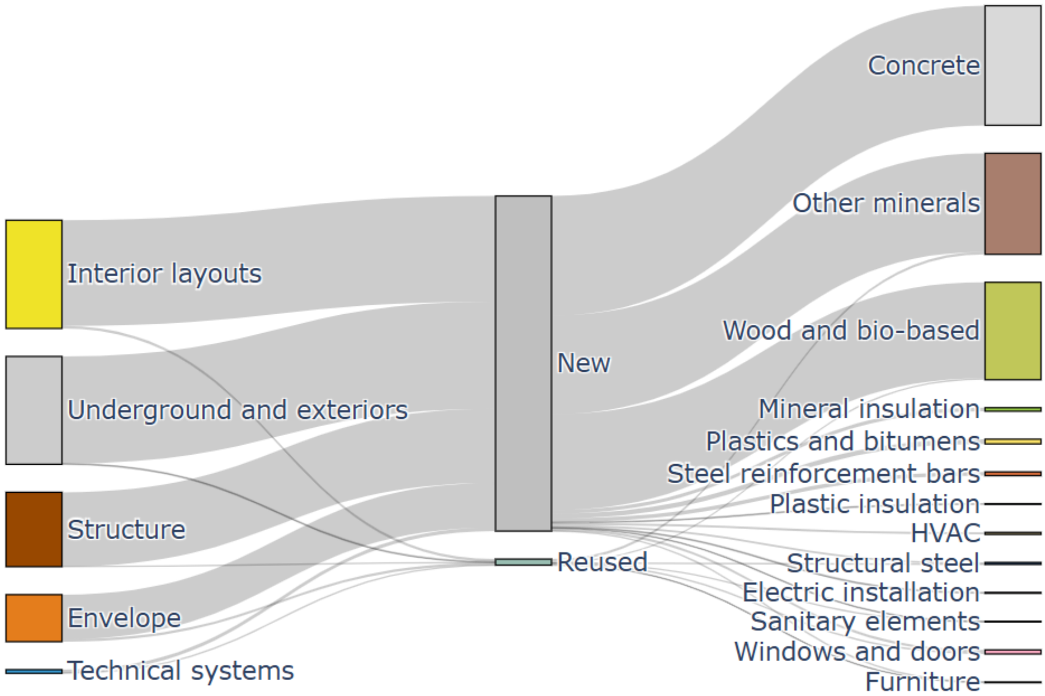



Figure 37: Sankey diagram of the mass flow of building components by building layer, origin and material family, Hobelwerk Haus D

Figure 38 compares the lifecycle embodied greenhouse gas (GHG) emissions per square meter for Haus D and a variant constructed exclusively with new components. Emissions are categorised by life cycle stage, and the SIA 390 limit and target values are depicted as red and blue dashed lines, respectively. The project's embodied emission of **436 kg $CO_2$ eq./m²$_{ERA}$** or **7,3 kg $CO_2$ eq./(m²$_{ERA}$.an)** situates between the SIA 390's limit and target values. The life cycle stages contributing primarily to the total emissions are the initial production (45%) and the future replacements (40%). The reuse strategy reduced the total emissions by 4% compared to the variant "only new" (reduction of 17 kg $CO_2$ eq./m²$_{ERA}$), with all savings in the initial production stage (modules A1-A3).

**Key Findings from detailed analyses:**

- **Building layer:** An analysis of GHG emissions by building layer (Figure 39) reveals interior layouts as the most emissive category, contributing 149 kg $CO_2$ eq./m²$_{ERA}$ due to interior and partition walls, finishes and their anhydrite screeds for floors support. Reuse strategies reduced this layer's life cycle emissions by 3% (5 kg $CO_2$ eq./m²$_{ERA}$). The envelope layer follows with 122 kg $CO_2$ eq./m² $_{ERA}$, where reuse achieved the highest reduction (7%, or 9 kg $CO_2$ eq./m²$_{ERA}$). Technical systems, responsible for 84 kg $CO_2$ eq./m²$_{ERA}$, saw minimal effect from reuse (1% emissions reduction, 0.5 kg $CO_2$ eq./m²$_{ERA}$). Structural elements, based on a wood framework, emitted only 47 kg $CO_2$ eq./m² $_{ERA}$ and achieved a 3% reduction (1.7 kg $CO_2$ eq./m²$_{ERA}$) through reuse. Lastly, the underground and exterior layers contributed the least to total emissions (35 kg $CO_2$ eq./m² $_{ERA}$), with 1% reduction resulting from reuse strategies (0.4 kg $CO_2$ eq./m²$_{ERA}$).

- **Element category and component:** an analysis by components category (Figure 40) identifies reused construction elements with the greatest contributions to GHG reductions compared to new equivalents. Key drivers include the 62 salvaged windows (-3.3 kg $CO_2$ eq./m²$_{ERA}$), the 98 shutters (-4.1 kg $CO_2$ eq./m²ERA), the 80 interior doors (-2.4 kg $CO_2$ eq./m²ERA), the ipé wood balcony cladding (-2.1 kg $CO_2$ eq./m²ERA), the ceramic tiles for interior walls finish (-2 kg $CO_2$ eq./m²ERA), and the trapezoidal aluminum cladding panels (-1.1 kg $CO_2$ eq./m²ERA). Notably, salvaged windows and shutters account for 45% of the GHG emission reductions due to reuse in Hobelwerk Haus D.

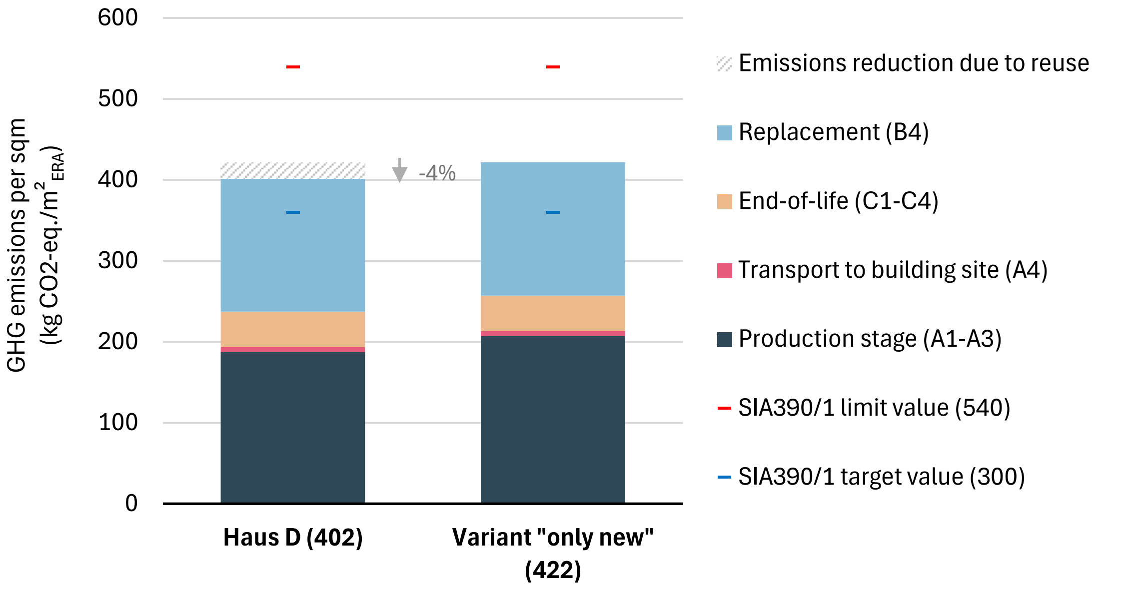



Figure 38: Construction's life cycle GHG emissions of Hobelwerk Haus D compared to an equivalent variant with only new construction materials and the SIA 390 limit and target values

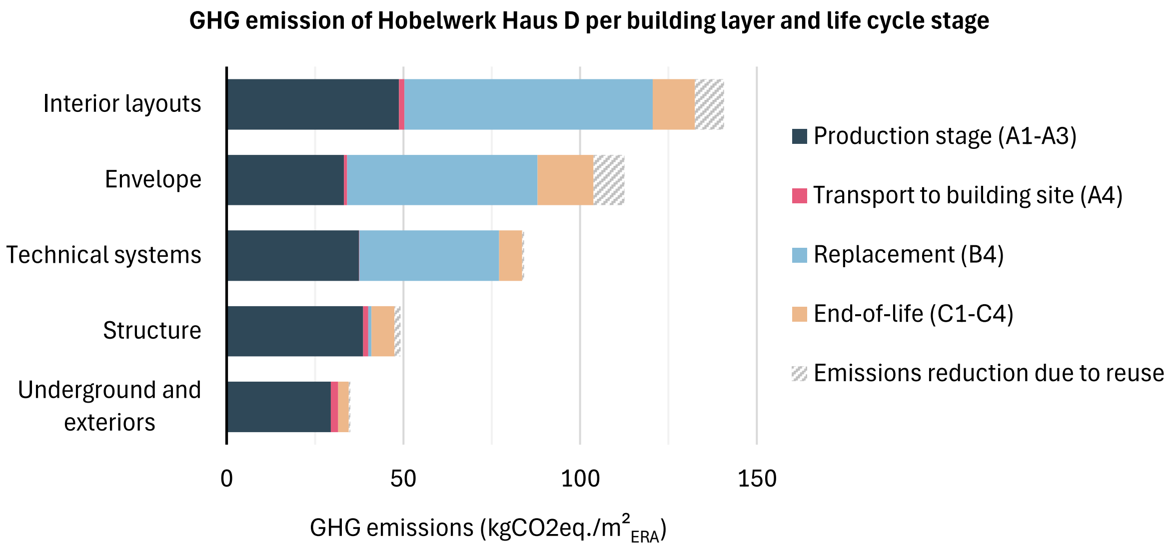


Figure 39: GHG emission per building layer and life cycle stage, Hobelwerk Haus D

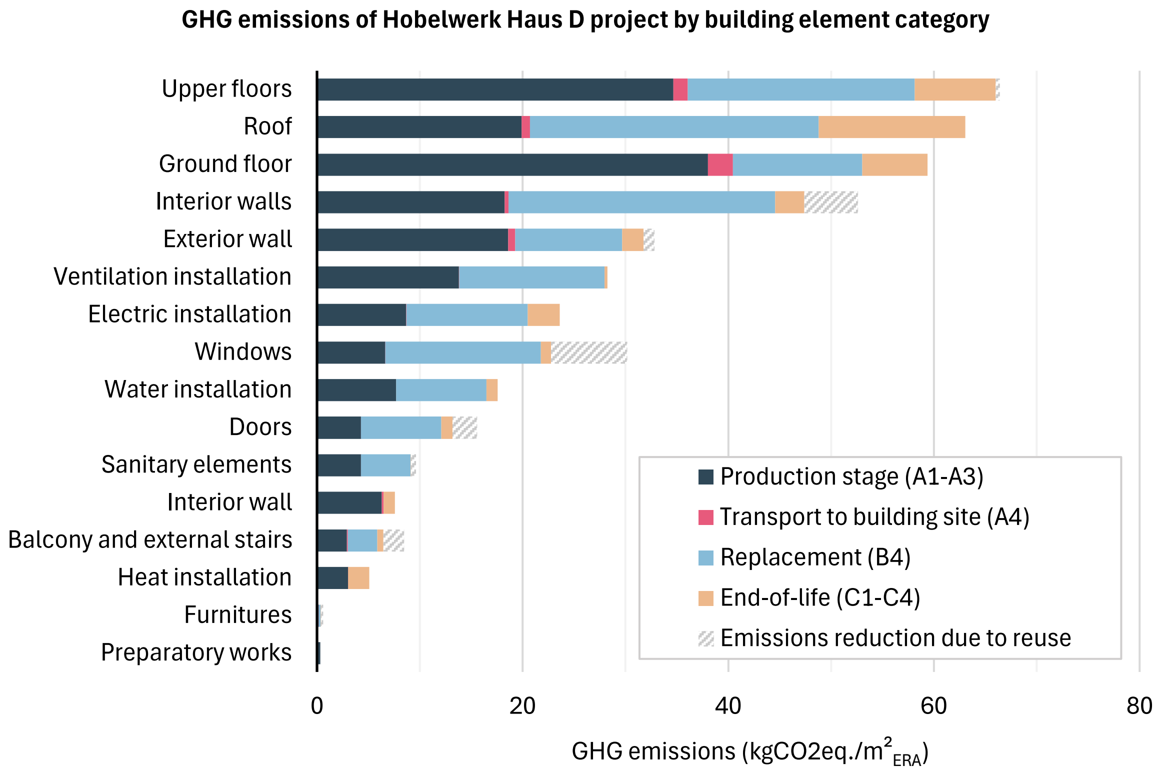



Figure 40: GHG emission per building component category and life cycle stage, Hobelwerk Haus D

### 4.1.3 Kosmos: new construction

As shown in the Figure 41, the Kosmos building has a material intensity of 581 kg/m$^2_{ERA}$ (420 tons total). The reused elements are sourced ex-situ and account for 13% of the building mass.

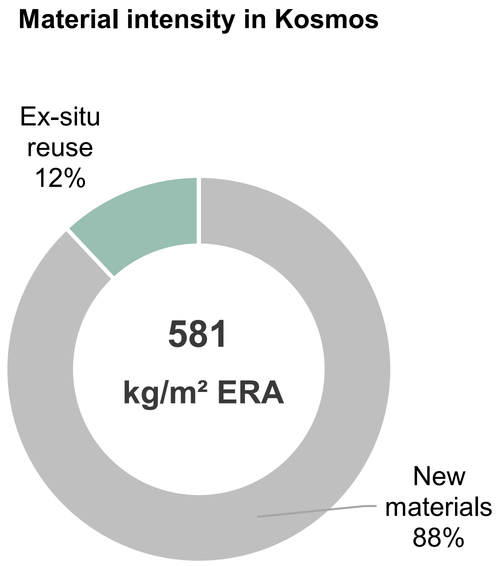



Figure 41: Material intensity and materials origins in the Kosmos building

Figure 42 uses a Sankey diagram to depict the material composition of building K.118, categorising mass flows by building layer, origin (new/reused), and material families. Notably, the mass of water installation components (e.g., pipes, sanitary elements) due to missing information in the KBOB LCA dataset.

**Underground and exterior**

- 57% of the total building mass, including the external steel structure of “Faraday cage”, balconies and stairs
- Contains no reused construction products.

**Structure**

- 24% of the total building mass, comprises reinforced concrete, construction wood, and steel parapet for balconies.
- Contains no reused construction products.

**Envelope**

- 9% of the total building mass
- 66% of its material mass is sourced from reuse, related to the reclaimed electric pylons of the “Faraday cladding” for balconies, the flat roof stone plates, and the exterior cladding made of HPL panels.

**Interior layouts**

- 6% of the total building mass.
- The reuse contributes to 27% of this category’s mass (e.g., OSB/MDF panels, ceramic tiles).

The Kosmos project contains a fair share of bio-based materials of 19% (111 kg/m$^2_{ERA}$) but also an important amount of steel due to the balconies and external staircases (25%, 145 kg/m$^2_{ERA}$). Reused materials represent 12% of the building’s total mass. Most of the reused mass is related to the electric pylons for the “Faraday cladding” (41%). Stone and ceramic plates account for 31% of the mass reused, followed by wood and bio-based elements (25%).

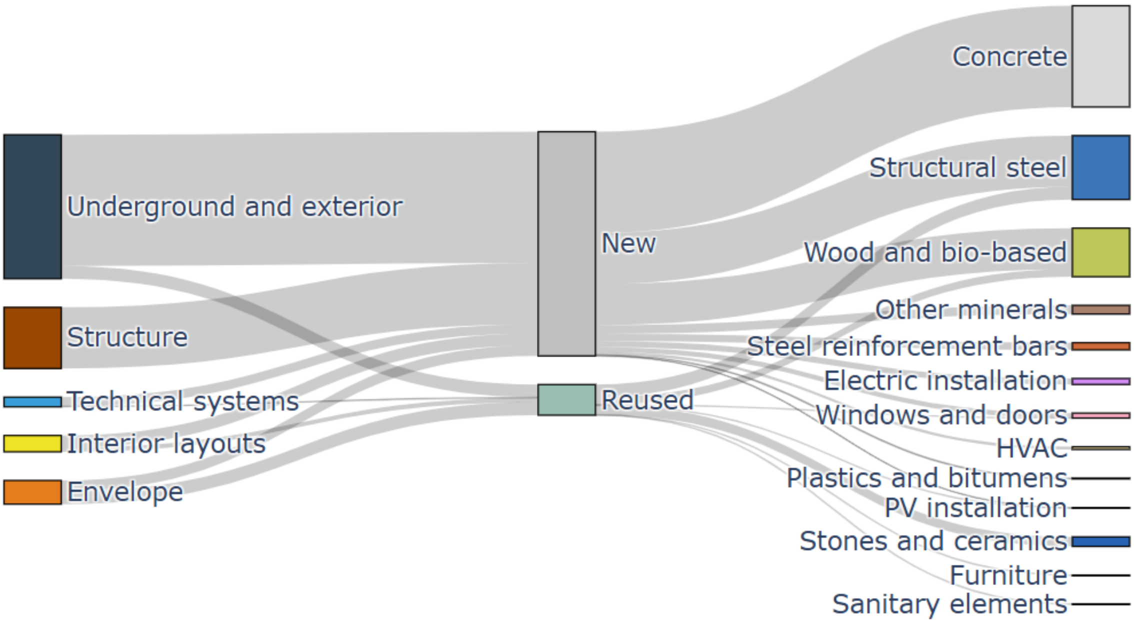



Figure 42: Sankey diagram of the mass flow of building components per category and material, Kosmos

Figure 43 compares the lifecycle embodied greenhouse gas (GHG) emissions per square meter for Haus D and a variant constructed exclusively with new components. Emissions are categorised by life cycle stage, and the SIA 390 limit and target values are depicted as red and blue dashed lines, respectively.

The project's life cycle embodied emission of **529 kg $CO_2$ eq./m²ERA** (or **8.8 kg $CO_2$ eq./(m²ERA.an)**) falls just below the SIA 390 limit value of 540 kg $CO_2$ eq./m²ERA. The initial production stage (Modules A1-A3) dominates emissions, accounting for 63%, followed by future replacements (29%). The reuse strategy reduced total emissions by 9% compared to an all-new construction variant, saving 51 kg $CO_2$ eq./m²ERA. Notably, 99.6% of these savings occurred in the initial production stage (Modules A1-A3), while transport saw minimal impacts (0.4%), underscoring reuse's negligible effect on lowering transport-related emissions in this case study.

- **Building layer:** An analysis of GHG emissions by building layer (Figure 44) reveals the structure layer the most emissive category with 164 kg $CO_2$ eq./m² ERA, almost exclusively related to the initial construction (96%) of the high emission from the steel elements but without any replacements under the 60 years of the building. The envelope layer follows with 161 kg $CO_2$ eq./m²ERA. It includes the windows, the steel parapet on the balconies, or the reuse process of the HPL panels and electric pylons. Reuse strategies reduced this layer's life cycle emissions by 19% (39 kg $CO_2$ eq./m²ERA). The Technical systems are responsible for 123 kg $CO_2$ eq./m²ERA. The reuse of 30 m² of PV panels and 11 sanitary elements helped reduce this layer's emissions by 3% (4 kg $CO_2$ eq./m²ERA). The underground and exteriors layer emits 46 kg $CO_2$ eq./m²ERA, mostly at initial construction. Lastly, the interior layouts layer contributed the least with 33 kg $CO_2$ eq./m² ERA. Reuse allowed to reduce the emissions of this layer by 18% reduction or 7.1 kg $CO_2$ eq./m²ERA.

- **Element category and component:** the Figure 45 shows that the most contributing elements of the building and a major design hotspot are the external balconies and staircases made of steel with 155 kg $CO_2$ eq./m²$_{ERA}$ (or 2.6 kg $CO_2$ eq./m²$_{ERA}$/a). The exterior wall follows as the second-largest contributor at 78 kg $CO_2$ eq./m²$_{ERA}$. It is also the element with the most significant emissions reduction, achieved through the reuse of HPL cladding panels (23% reduction or 23 kg $CO_2$ eq./m²$_{ERA}$), which are also the wall's GHG emission first contributors. The electric pylons repurposed into the balconies cladding present emissions reductions of 63% compared to using new steel poles, but this latter scenario is not realistic as the balconies cladding exist solely because of the opportunity of reusing pylons. One could also argue that the building would emit even less GHG emissions without including the steel pylons cladding into the construction. The reuse of ceramic tiles and wood panels in the interior walls reduced these elements GHG emissions by 34% (5.8 kg $CO_2$ eq./m²$_{ERA}$). The salvaged PV panels reduced the GHG emissions of the PV installation by 9% (2.9 kg $CO_2$ eq./m²$_{ERA}$). This relatively low reduction is explained by the fact that the reused PV panels represent one third of the total installed power, (accounting for their degraded performance due to ageing) and additional new components are needed in a PV installation's life cycle (e.g., inverter, mounting structure, electric installation, and replacement panels after 30 years).

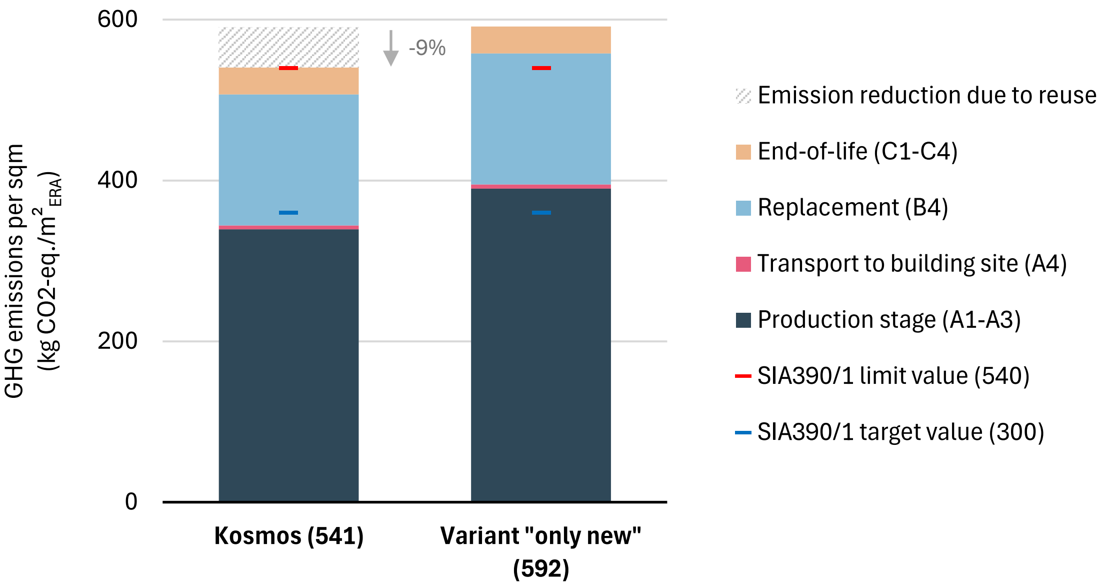



Figure 43: Construction's life cycle GHG emissions of Kosmos compared to an equivalent variant with only new construction materials and the SIA 390 limit and target values

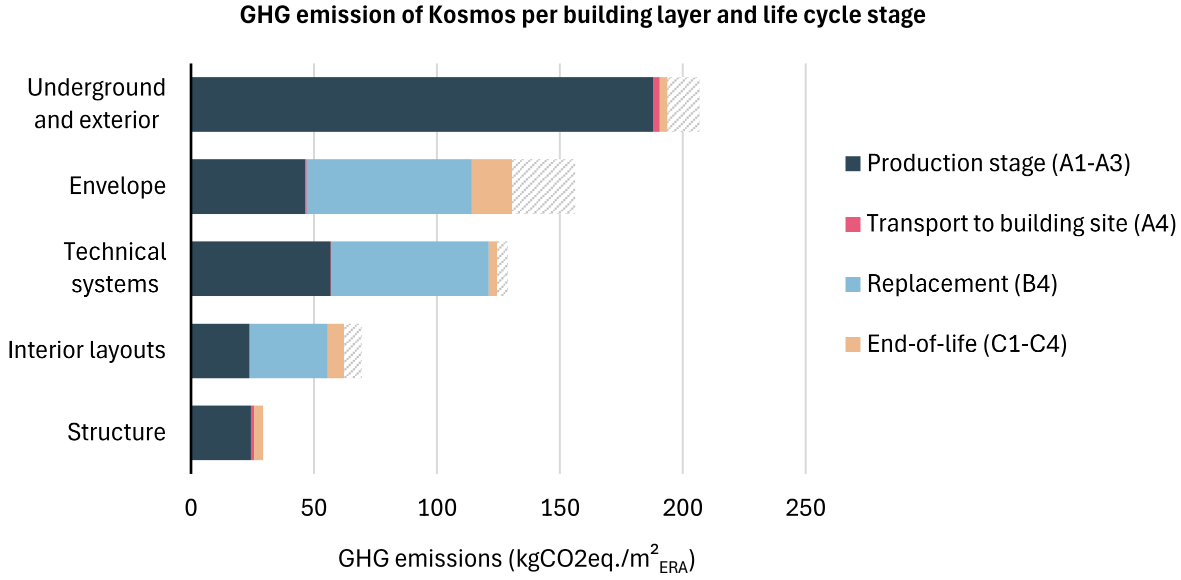



Figure 44: GHG emission per building layer and life cycle stage, Kosmos

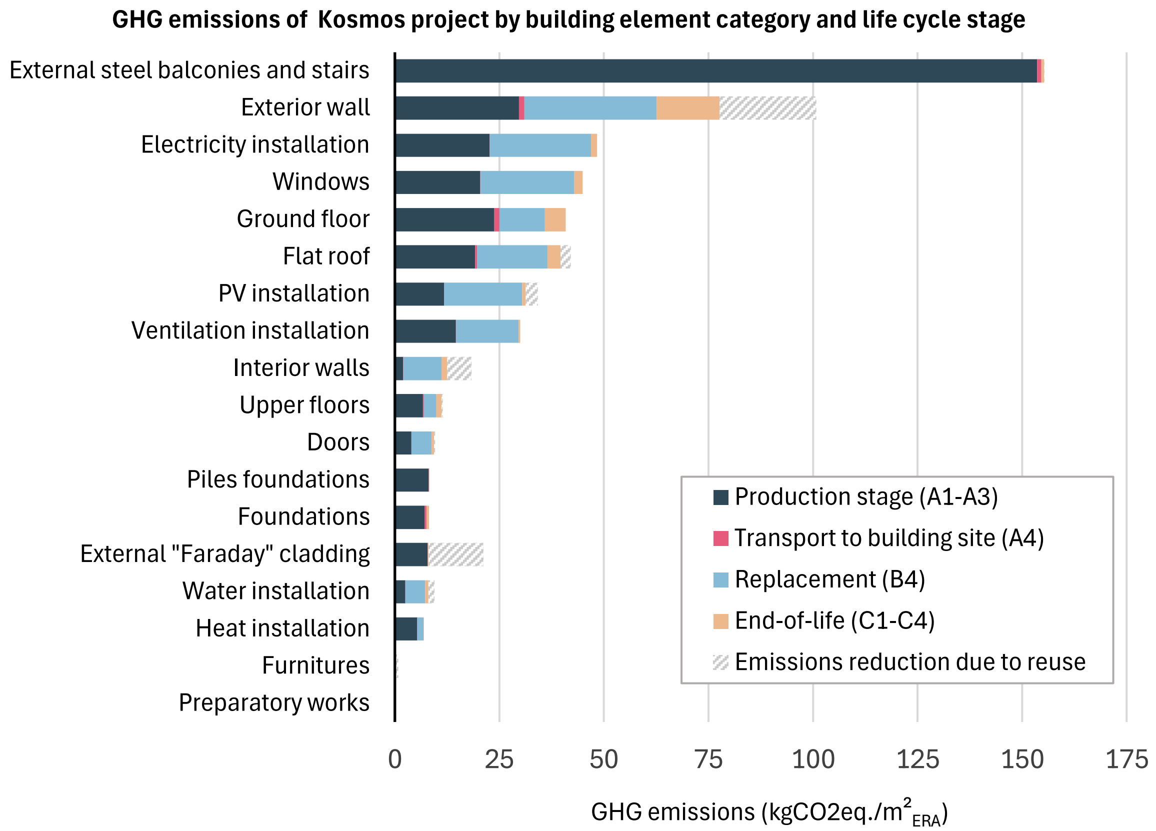



Figure 45: GHG emissions per building element category and life cycle stage, Kosmos

### 4.1.4 Firmenich PPN Tower 107: transformation

The building includes 130 kWp of building integrated photovoltaic (BIPV) installation. The photovoltaic self-consumption rate is assumed to be 70%, derived from typical values for office buildings. Within the project, the newly installed windows incorporate electrochromic glazing. As no LCA data exists for this glass type in the KBOB LCA database, the LCA of glazing were estimated using proxy data from the available glazing, which clearly underestimate its true environmental impacts[4] due to unaccounted manufacturing characteristics.

The Firmenich tower has a material intensity of about 10'931 tons and 1390 $kg/m^2_{ERA}$. Figure 46 shows that, as a transformation, the adaptive reuse account for 91% of the mass of the project. The in-situ is marginal (0.1% of the total mass), and the new materials represent 8.9% of the total mass.

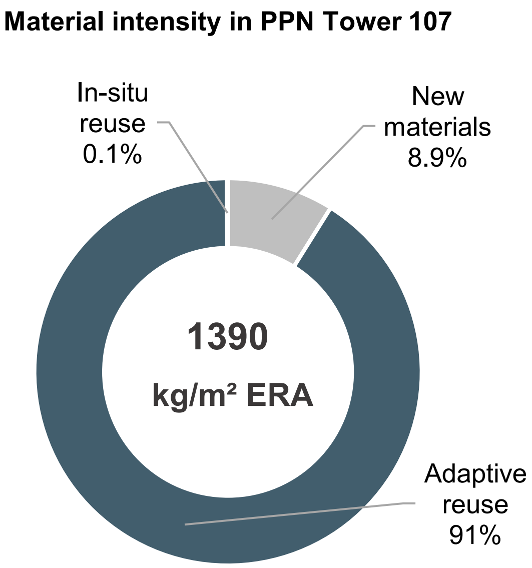



Figure 46: Material intensity and materials origins in the PPN Tower 107 building

Figure 47 uses a Sankey diagram to depict the material composition of the building PPN Tour 107, categorising mass flows by building layer, origin (new/reused), and material families. Notably, the mass of water installation components (e.g., pipes, sanitary elements) due to missing information in the KBOB LCA dataset.

**Structure layer**

- 63% of the total building mass is the reinforced concrete structure.
- 98% of the structural elements are adaptively reused, the remaining is additional new concrete.

**Underground and exterior layer**

- 22% of the total building mass.
- Essentially adaptively reused.

**Envelope layer**

[4] The GHG emissions per kg of KBOB glazing are about 2.3 on average for all glazing, double or triple (with a range from 2.0 to 2.7 kgCO2e per kg). For example, this value is obtained by dividing the GHG emissions of 48.5 kgCO2e for e.g., the KBOB data ID 05.010 "Double vitrage, verre ESG, U<1.1 W/m2K" by 20.8 kg the mass of this double glazing. An intercomparison with the displayed EPD data on the Sage-Glass electrochromic glazing as available in the French EPD database since February 2025 show a GHG emissions of 156 kgCO2e for 37.5 of glazing which means a GHG intensity of 4.2 kgCO2e per kg which means twice more GHG emissions as the KBOB proxy data. As the EPD accounts for different assumptions and notable the use of Guarantees of Origin for the electricity use for the glazing production, it is likely that the KBOB data if recalculated be even higher than this GHG emissions value.

- 3% of the total building mass
- 10% is adaptively reused

**Interior layouts**

- 10% of the total building mass.
- 72% is adaptively reused, and 0,6% is in-situ reused.

The building is predominantly composed of reinforced concrete, constituting 85% of its total mass, whereas bio-based and metal materials each account for minimal proportions (0.5%).

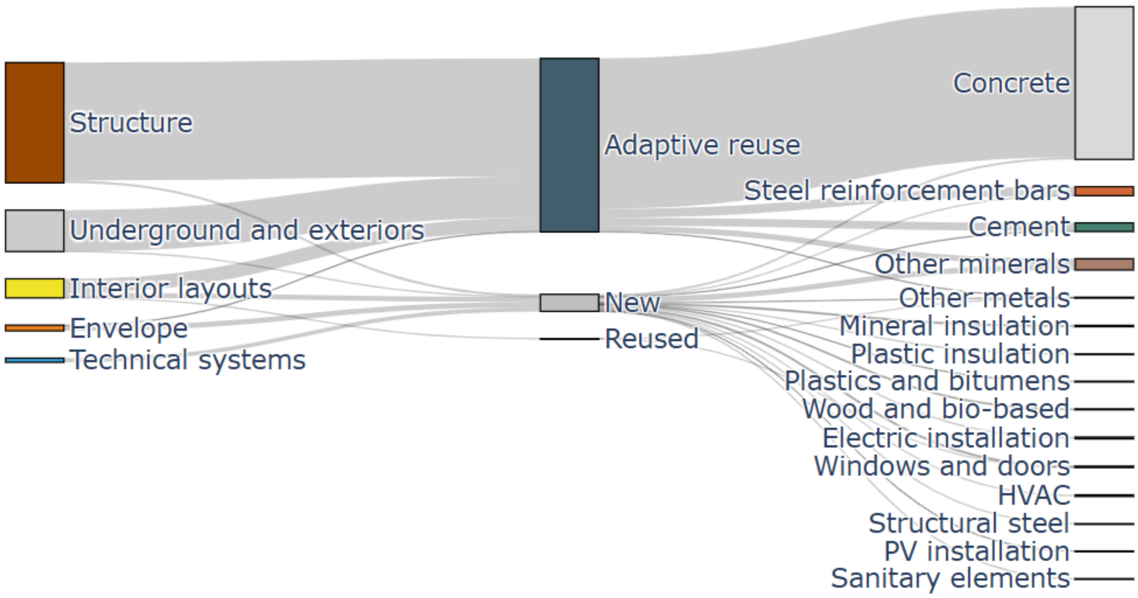



Figure 47: Sankey diagram of the mass flow of building components per category and material, Tour 107

Figure 48 compares the life cycle embodied greenhouse gas (GHG) emissions per square meter for the transformation of the PPN Tour 107 and a variant of an equivalent entirely new construction. Emissions are categorised by life cycle stage, with the SIA 390 limit and target values for a transformation project illustrated as red and blue dashed lines, respectively. The project's embodied emission of **347 kg $CO_2$ eq./m²$_{ERA}$** or 5.8 kg $CO_2$ eq./m²$_{ERA}$/a is **15% higher than the SIA 390's limit value**. Highest contributions to total emissions arise from future replacement (48%) followed by the initial manufacturing stage (43%). Implementation of reuse strategies reduced total emissions by 32% (174 kg CO2-eq/m²$_{ERA}$) relative to the all-new construction variant, with all the reduction occurring in module A1-A3. Notably, 99% of this reduction is attributed to the adaptive reuse of the structural framework, while in-situ reuse of interior doors and suspended ceilings have a negligible influence on overall emissions.

**Key Findings from detailed analyses:**

- **Building layer:** An analysis of GHG emissions by building layer (Figure 49) reveals the technical systems as the most emissive category, contributing 160 kg $CO_2$ eq./m²$_{ERA}$. This is explained by the integral renewal of sanitary, ventilation, electrical, and heating installations, alongside the integration of a new photovoltaic façade system, with no reuse strategies implemented in this layer. The interior layouts have the second-highest emissions

(101 kg $CO_2$-eq./m² ERA), where adaptive reuse of interior walls achieved a 15% (18 kg $CO_2$ eq./m²ERA), and in-situ reuse of doors and suspended ceilings contributed a marginal 2% reduction (2 kg $CO_2$ eq./m²ERA). Emissions from the envelope layer (80 kg $CO_2$ eq./m²ERA) was not concerned by reuse. In contrast, the structural and underground layers, with emissions of 14 kg $CO_2$ eq./m²ERA and 4 kg $CO_2$ eq./m²ERA respectively, are both directly concerned by adaptive reuse, achieving a 90% reduction in both their potential emissions as new.

- **Element category and component:** an analysis by component category (Figure 50) identifies the first contributors to the life cycle GHG emissions of the transformation as the new electrical and ventilation installations (48 and 41 kg $CO_2$ eq./m²ERA, respectively), and the windows, that incorporate aluminum frames with elevated embodied carbon (41 kg $CO_2$ eq./m²ERA). Adaptive reuse strategies achieve reductions of 40–50% in emissions for interior walls, exterior walls, floors, and staircases. In-situ reuse of doors diminishes emissions for the interior door category by 1 kg $CO_2$ eq./m²ERA, less than 10% of the doors' actual initial emissions due to the limited proportion of reused doors. Similarly, the in-situ reuse of suspended ceilings shows a marginal reduction of 1.2 kg $CO_2$ eq./m²ERA.

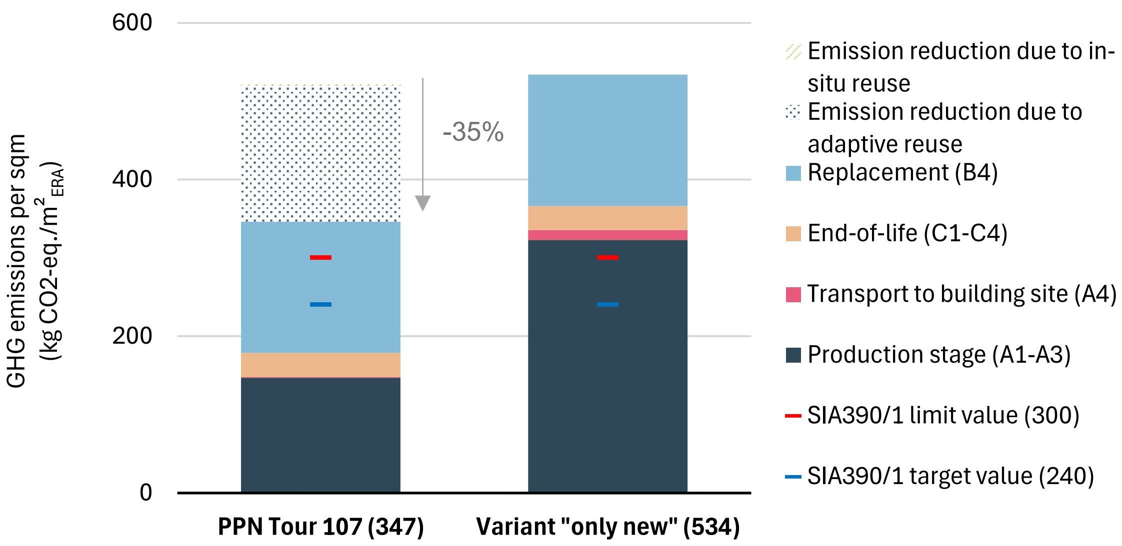



Figure 48: Construction's life cycle GHG emissions of PPN Tour 107 compared to an equivalent variant with only new construction materials and the SIA 390 limit and target values

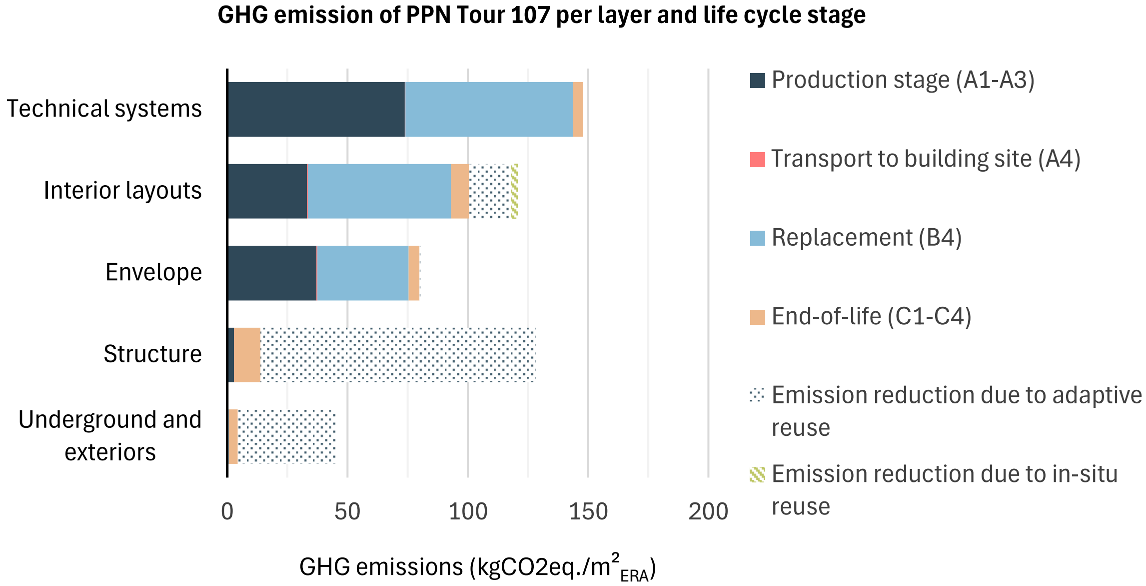



Figure 49: GHG emission per building layer and life cycle stage, PPN Tour 107

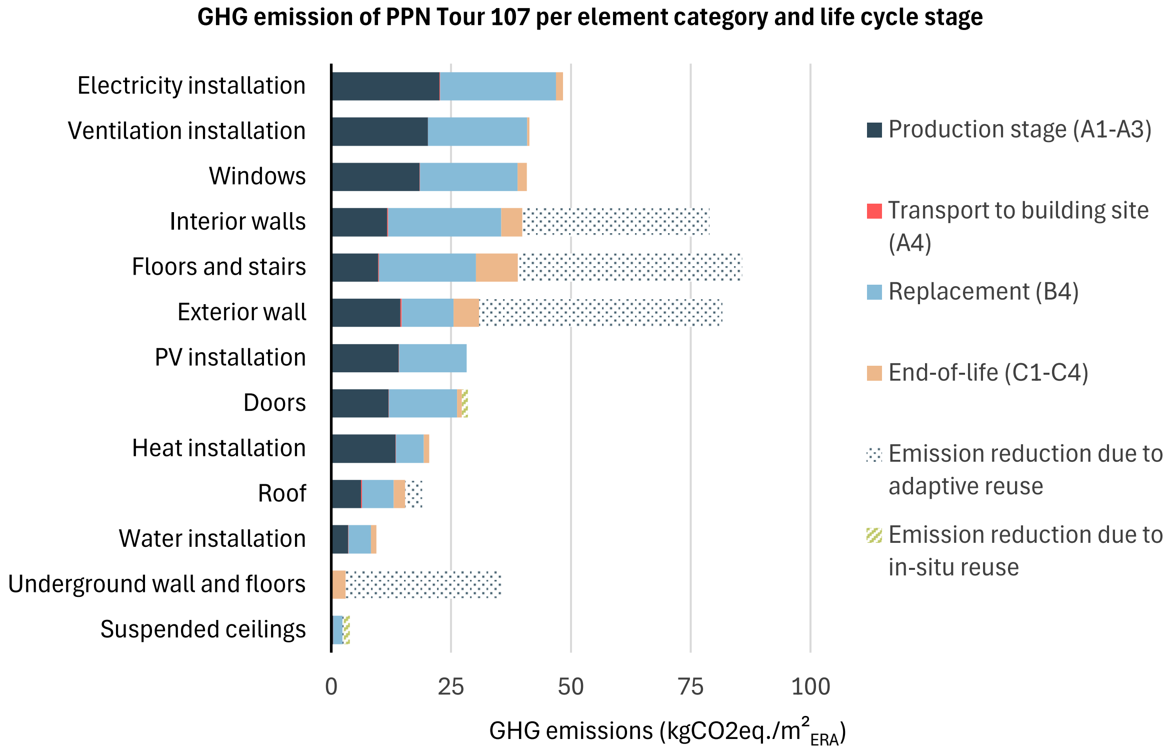



Figure 50: GHG emission per element category and life cycle stage, PPN Tour 107

### 4.1.5 Chauchy: transformation

The photovoltaic self-consumption rate is about 30% and allows allocating the same share of the PV systems embodied emissions to the building. The length of the geothermal probes is estimated by applying a ratio of 75% to the energy reference area of the building based on a professional documentation source[5].

As shown in the Figure 51, the Chauchy building has a material intensity of 1305 kg/m$^2_{ERA}$ (715 tons total). The reused elements, preserved from the existing building (23%, adaptive and in-situ) and sourced ex-situ (3%), account for approximately 25% of the total building mass.

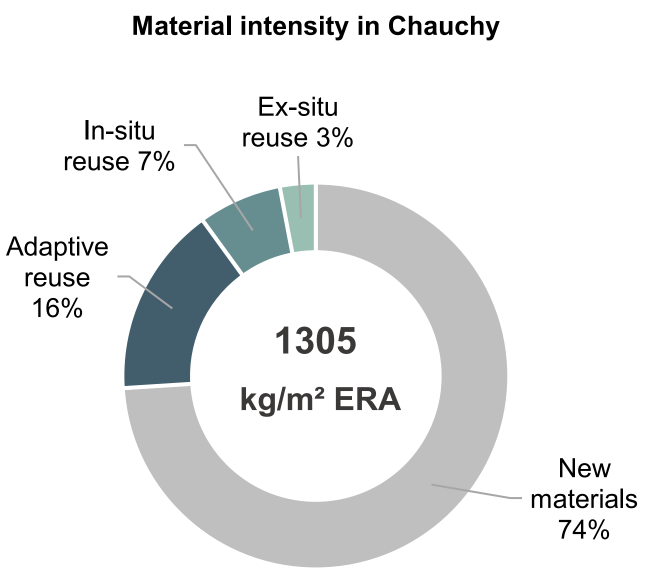



Figure 51: Material intensity and materials origins in the Chauchy building

The Sankey diagram in the Figure 52 illustrates the material mass distribution across building layers (envelope, structure, interior layout, technical systems, underground and exterior), categorized by origin (new or reused), and by material family.

**Structure layer**

- Constitutes 54% of the total building mass.
- Of which 56% derived from reused materials: 53% corresponds to the preserved stone structure (adaptive reuse), while 3% originate from ex-situ reuse wood beams sourced from Geneva.

**Underground and exterior layer**

- Account for 39% of the total mass.
- Of which 32% is sourced from in-situ repurposing of stones originally part of the superstructure, now integrated onto underground perimeter wall.

**Envelope**

- Comprises 4% of total mass
- Of which 4% originates from in-situ reuse windows shutters.

**Interior layouts**

- Represents 2% of the total mass
- This layer has 10% in-situ reused elements from the bricks repurposed from a load-bearing wall to non-load bearing partition wall.

Material composition analysis reveals that the building comprises 45% natural minerals, predominantly existing structural stone, 38% newly cast concrete or cement-based materials, 8% processed mineral

[5] https://www.geotherm.ch/fr/telechargements.html?file=files/geotherm/pdf/chantiers_sondes_geothermiques.pdf&cid=10280

materials (e.g., plaster, bricks), and 6% bio-based materials, including timber, cork, cellulose and other derivatives.

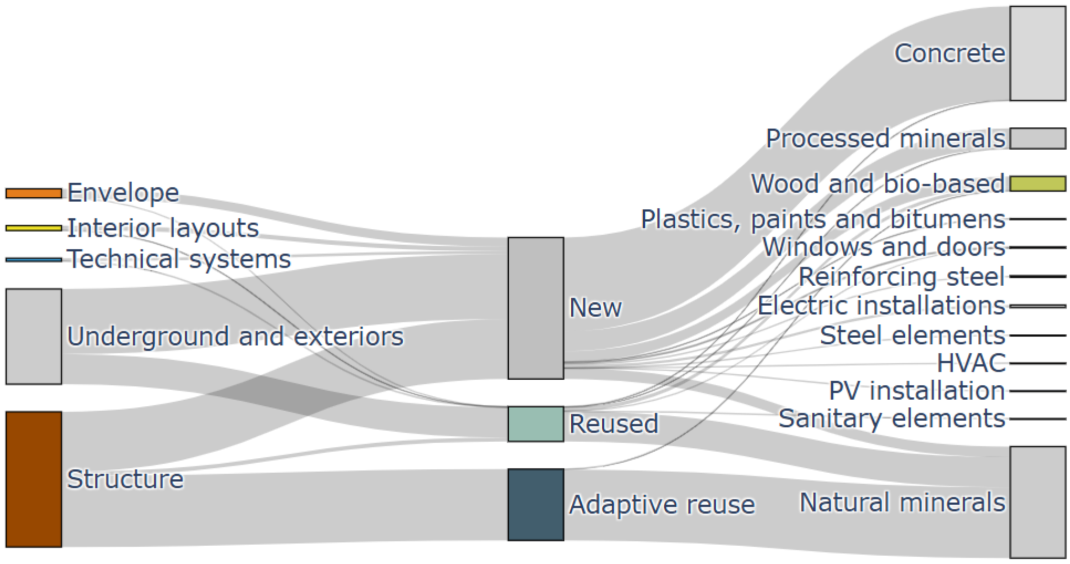



Figure 52: Sankey diagram of the mass flow of building components by building layer, origin and material family, Chauchy

Figure 53 compares the lifecycle embodied greenhouse gas (GHG) emissions per square meter for Chauchy and a variant constructed exclusively with new components. Emissions are categorised by life cycle stage, and the SIA 390 limit and target values for transformation project are depicted as red and blue dashed lines, respectively. The project's embodied GHG emissions of **344 kg $CO_2$ eq./m²$_{ERA}$** or **5.7 kg $CO_2$-eq./(m²$_{ERA}$.an)** is 17% above the SIA 390's limit value for transformation. On the other hand, it is close to the SIA 390/1 target value for new construction of 360 kg $CO_2$ eq./m²$_{ERA}$. This could also be considered due to the level of building elements' renewal in the Chauchy project: new upper floors structures, new roofing, new technical installations for electricity, water and heating.

The life cycle stages contributing primarily to the total emissions are the initial production (56%) and the future replacements (32%). The reuse strategy reduced the total emissions by 7% compared to the variant "only new" (reduction of 27 kg $CO_2$ eq./m²$_{ERA}$).

**Key Findings from detailed analyses:**

- **Building layer:** An analysis of GHG emissions by building layer (Figure 54) identifies technical systems as the most emissions-intensive category, contributing 132 kg $CO_2$ eq./m²$_{ERA}$. This is attributed to the comprehensive renewal of ventilation, water, and electrical installations, integration of a new PV system, and the installation of heating distribution components and geothermal probes. The reuse of sanitary equipment within this layer achieved a modest emission reduction of 3.5 kg $CO_2$ eq./m²$_{ERA}$ (1% of the total emissions). The structure layer, with emissions of 69 kg $CO_2$ eq./m² $_{ERA}$, exhibited the most significant reduction across all layers. Adaptive reuse of the existing stone structure reduced emissions by 11 kg $CO_2$-eq./m²$_{ERA}$ (13% reduction for the layer), while the reuse of wood beams in the upper floor structure contributed an additional 2.5 kg $CO_2$-eq./m²$_{ERA}$ reduction (3.5% of the layer's total). The underground and exterior layers benefited from the in-situ repurposing of stones into perimeter walls, resulting in a reduction of 3.9 kg $CO_2$-eq./m²ERA, corresponding to a 7% decrease in emissions for this category.

- **Element category and component:** an analysis by components category (Figure 55) identifies the heat installation system—comprising heat distribution infrastructure, a heat pump, and geothermal probes—as the most emissions-intensive category, contributing 36 kg $CO_2$-eq./m²ERA. The PV installation represent the second largest contributor to building life cycle emissions at 33 kg $CO_2$ eq./m²ERA, despite a 30% allocation factor applied to account for self-consumption. The exterior wall components account for 30 kg $CO_2$-eq./m²ERA. The adaptive reuse of existing stone wall reduces the emissions of this component by 25%. However, this reduction must be contextualised by the fact that natural stone constitutes 80% of the exterior wall's total mass. The limited emissions reduction arises from the inherently low embodied carbon of natural stone, which exhibits a cradle-to-grave impact of 0.04 kg $CO_2$-eq./kg—approximately half that of conventional concrete (0.10 kg $CO_2$-eq./kg). The reuse strategy achieved a reduction in GHG emissions across multiple components categories: a decrease of 4 kg $CO_2$ eq./m²ERA in water installations (via reused sanitary equipment), an equivalent reduction of 4 kg $CO_2$ eq./m²ERA in the ground floor (through the reuse of stone elements), a reduction of 2 kg $CO_2$ eq./m²ERA in interior walls and intermediate floors (attributable to retained bricks and wood beams), and a reduction of 0.5 kg $CO_2$ eq./m²ERA in windows (with the reused shutters).

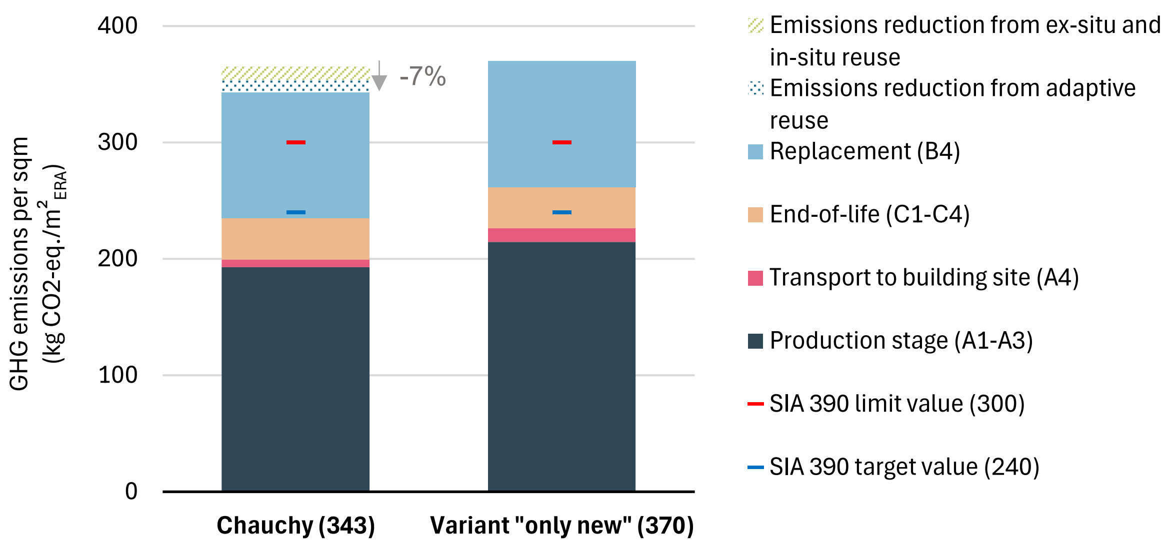



Figure 53: Construction's life cycle GHG emissions of Chauchy compared to an equivalent variant with only new construction materials and the SIA 390 limit and target values

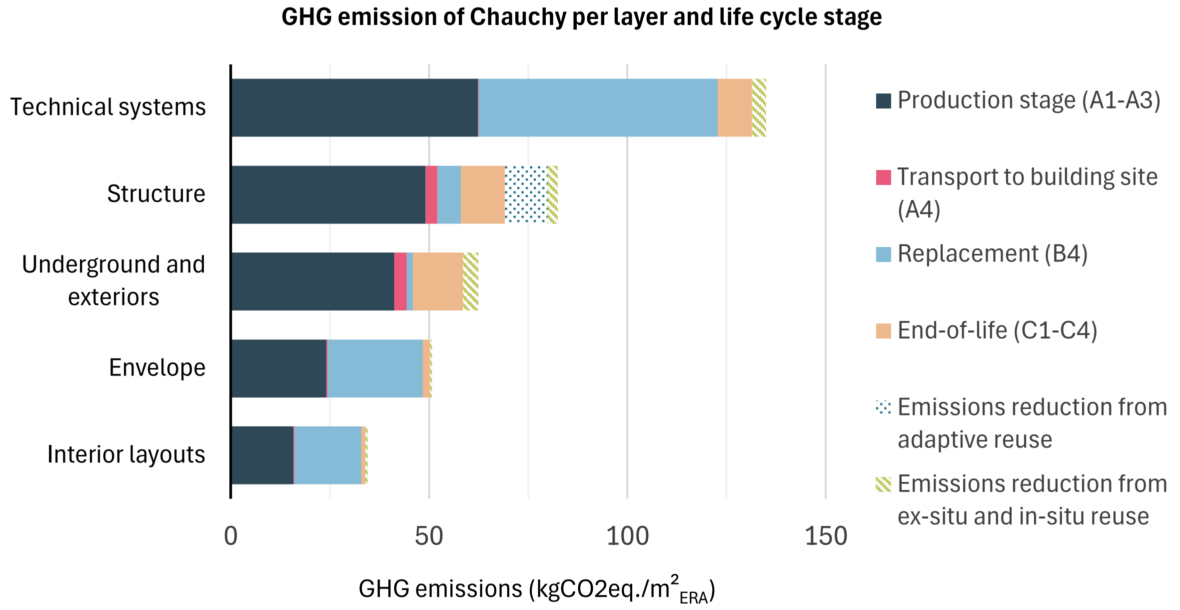



Figure 54: GHG emission per building layer and life cycle stage, Chauchy

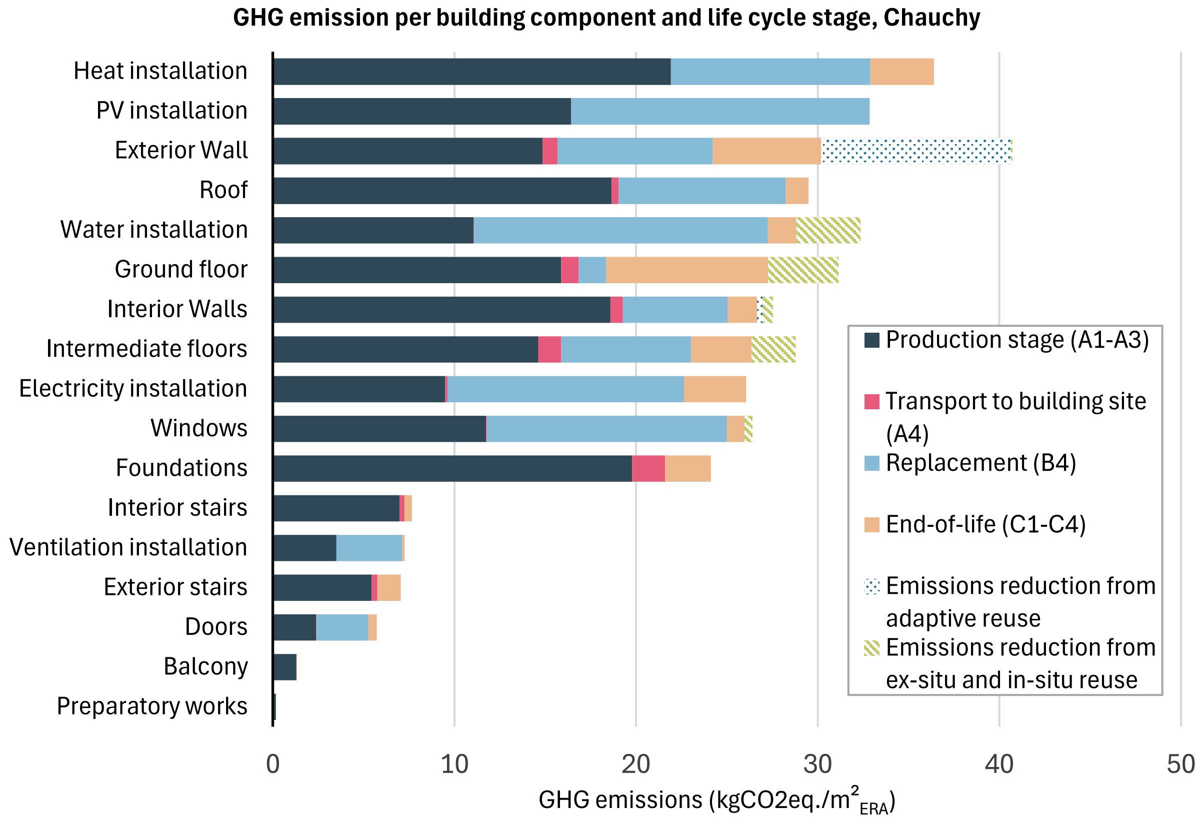



Figure 55: GHG emission per building components category and life cycle stage, Chauchy

## 4.2 Inter-comparison of the case studies

### 4.2.1 Material intensity and material inflows

Figure 56 illustrates material mass inflows (new, reused) and preserved material stock across case studies, while the numbers given in Table 23. Over the five case studies, adaptive reuse preserved 10’421 tons of materials, with new and reused inflows being 3’583 tons and 301 tons, respectively.

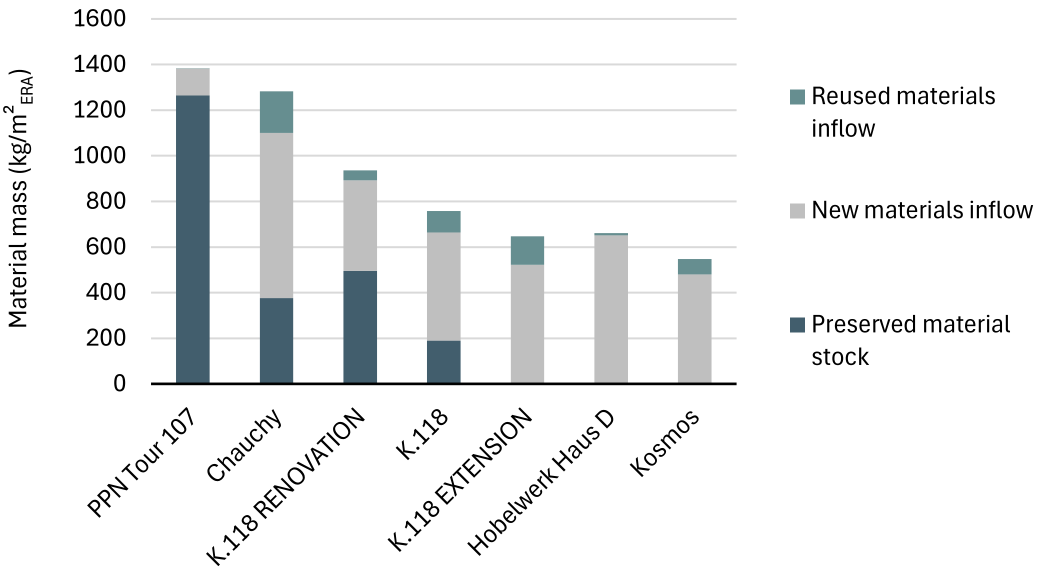



Figure 56: Material mass inflow per origin of new or reused, and preserved material stock through adaptive reuse for each case study

Table 23: Area and quantities of materials in each case studies, and total values

| | Unit | PPN Tour 107 | Chauchy | *K.118 RENOVATION* | K.118 | *K.118 EXTENSION* | Hobelwerk Haus D | Kosmos | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| Energy reference area | $m^2$ ERA | 7’862 | 548 | *541* | 1’416 | *875* | 2’261 | 724 | **12’811** |
| Preserved materials | tons | 9’946 | 206 | *269* | 269 | *0* | 0 | 0 | **10’421** |
| New materials inflow | tons | 686 | 396 | *215* | 671 | *456* | 1’483 | 347 | **3’583** |
| Reused materials inflow | tons | 7 | 100 | *23* | 133 | *110* | 11 | 50 | **301** |

### 4.2.2 Reuse rate and preserved rate

Figure 57 shows the preserved and reuse rates for each case study calculated according to the methodology in section 2.1. The average preserved rate over the transformation case studies is about 60% and the average reuse rate over all the case studies is 15%.

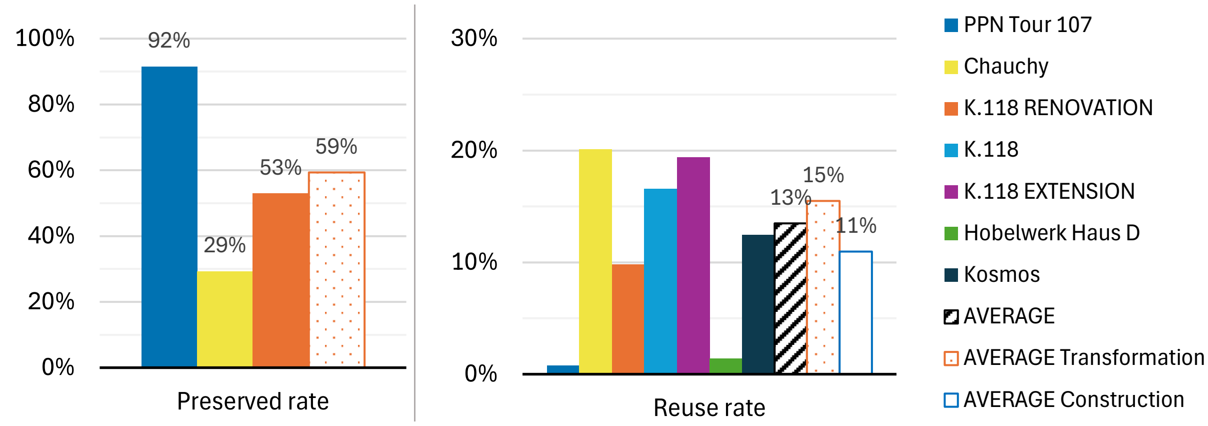



Figure 57: Preserved rate (left) and reuse rate (right) in each case study, with average values

Figure 58 reveals the reuse rates by building layer. The envelope components achieved the highest average (20%), followed by interior layouts (14%) and underground/exteriors (13%). The lowest reuse rates are 8% for both the structural elements and technical systems. The highest reuse rate is reached in the envelope layer of Kosmos (55%) with reused HPL and mineral cladding elements. It reaches 35% in the envelope layer of the vertical extension of K.118 with many reused wood elements, rockwool insulation and windows.

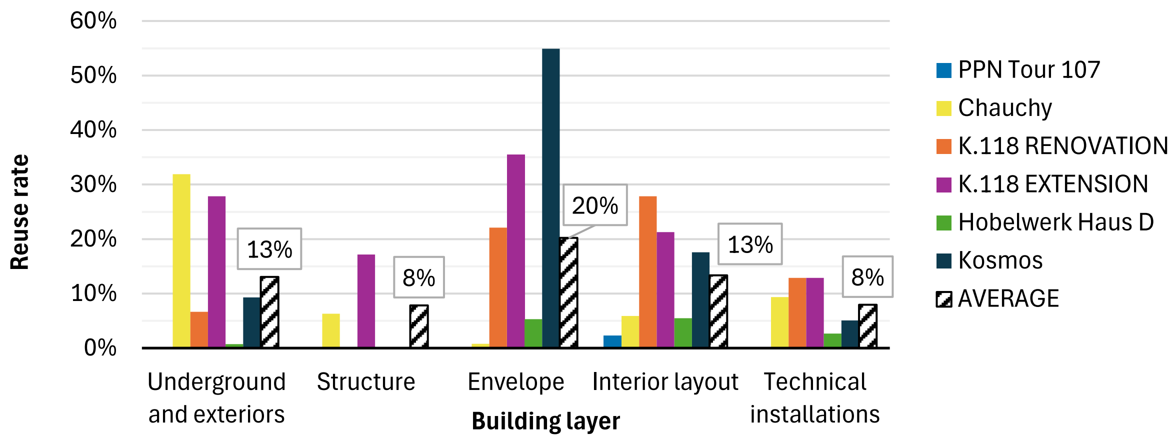



Figure 58: Reuse rate per layer in each building case study and average reuse rate

### 4.2.3 Life cycle GHG emissions at building scale

Figure 59 shows the embodied GHG emissions per life cycle stage for each case study, with emissions reduction from reuse, average values and the SIA 390/1 indicative values. Transformation case studies (left of the graph) averaged 342 kg $CO_2$ eq./m²$_{ERA}$, all exceeding the SIA 390/1 base indicative value for transformation (300 kg $CO_2$ eq./m²$_{ERA}$) despite adaptive reuse reducing emissions up to 174 kg $CO_2$ eq./m²$_{ERA}$ (PPN Tour 107). The new constructions averaged 431 kg $CO_2$ eq./m²$_{ERA}$, better than the SIA 390/1 base indicative value of 540 kg $CO_2$ eq./m²ERA. In terms of life cycle GHG emission reduction:

- On average over the transformation projects:
  - Preservation reduced emissions by 22%, but it varies from 33% in case of reinforced concrete structure (PPN Tour 107) to 3% in case of an existing low carbon structure like natural stone (Chauchy).
  - In-situ/ex-situ reuse reduced emissions by 6%
- On average over the new construction projects: reuse reduced emissions by 20%.

It is interesting to compare K.118 Extension and Chauchy which have similarly the highest reuse rates (20% and 17% respectively). On the one hand, Chauchy presents the lowest effect of reuse on decarbonation (-11 kg $CO_2$ eq./m²ERA). On the other hand, ex-situ reuse has important decarbonation effect in the case of the extension of K.118, through the reuse of steel structures and windows (potential reduction of 252 kg $CO_2$ eq./m²ERA). K.118 Extension hence meets the SIA 390/1 ambitious value of 360 kg $CO_2$ eq./m²ERA.

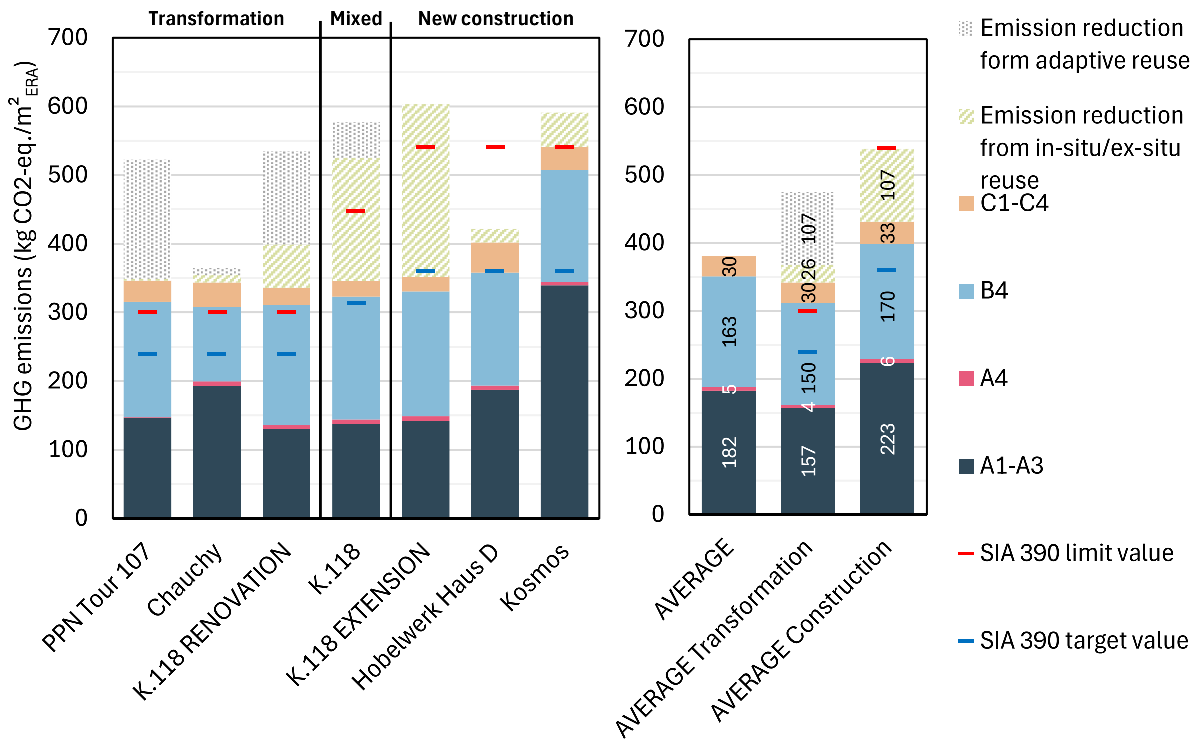



Figure 59: Life cycle embodied GHG emissions per life cycle stage and emission reductions from type of reuse, for each case study and with average values

The whole building LCA are comparatively presented in Figure 60 showing the GHG emissions across the building case studies, highlighting emission reductions achieved through adaptive reuse (in transformation projects) and in-situ/ex-situ reuse. The highest emissions reduction due to reuse is found in the K.118 project, especially in the structure layer, explained by the extensive reuse of steel components for the vertical extension (-86 kg $CO_2$ eq./m²ERA). Other substantial emission reduction due to reuse is in the envelope layers of K.118 and Kosmos with respectively -26 and -30 kg $CO_2$ eq./m²ERA. Apart from these cases, emission reductions exhibit relatively balanced distribution both in absolute terms and across building layers, with average reductions of -1 to -9 kg $CO_2$ eq./m²$_{ERA}$ (average reduction of -4 kg $CO_2$ eq./m²$_{ERA}$).

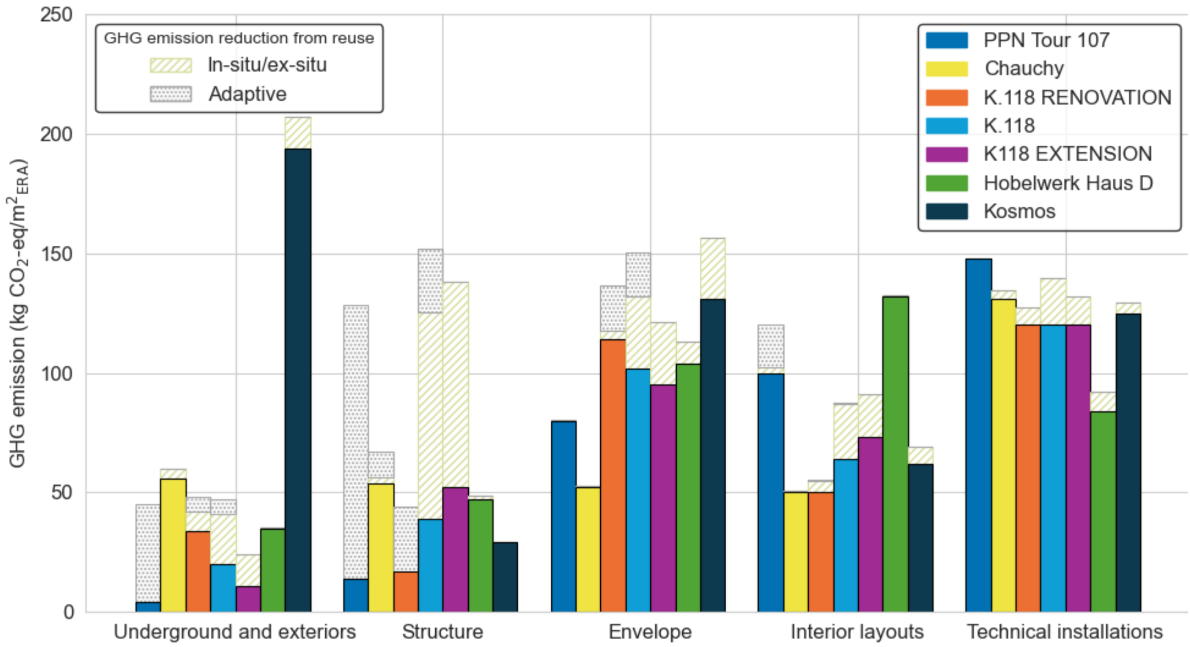



Figure 60: Life cycle GHG emissions and GHG emissions reduction from reuse for each case study and building layer

### 4.2.4 Building design and/or transformation strategies towards decarbonisation

Figure 61 illustrates the life cycle GHG emissions categorised and ranked by building layer. The figure integrates annotations about the design parameters that explain the building's position in terms of impacts. The design characteristics of the case studies are summarised in the Table 24 to help the interpretation of the Figure 61. Reuse is one of multiple interdependent design levers across distinct building layers that can participate to decrease a construction GHG emissions. This section examines the role of the reuse strategies within the broader scope of design choices, constraints, and decarbonisation strategies characterising the case studies.

In the **underground and exteriors** layer, Kosmos's external steel assembly of balconies and stairs skewed the results as it alone represents 150 kg $CO_2$ eq./m²$_{ERA}$, far from the average value of 50 kg $CO_2$ eq./m²$_{ERA}$ average in this layer.

The **structure** layer presents a low average impact (36 kg $CO_2$ eq./m²$_{ERA}$) and a narrow spread (17-52 kg $CO_2$-eq./m²$_{ERA}$). These low values are related to structures either mainly made of glue laminated timber (Kosmos, Hobelwerk Haus D), preserved (Chauchy, PPN Tour 107, K.118 Renovation), or made of reused steel (K.118 Extension).

The building **envelope** layer has average emissions of 97 kg $CO_2$ eq./m²$_{ERA}$ and a high variability (52-131 kg $CO_2$-eq./m²$_{ERA}$). The case studies reflect different design choices in terms of window-to-wall ratio (WWR), metal frame windows, insulation and cladding. The highest envelope's emissions is related to Kosmos (131 kg $CO_2$ eq./m²$_{ERA}$) which has a high WWR of 40%, aluminum triple glazing windows, rockwool insulation and reused HPL panels cladding (45 kg $CO_2$ eq./m²$_{cladding}$). It contrasts with the lower value from Chauchy (52 kg $CO_2$ eq./m²$_{ERA}$) which has a lower WWR of 27%, wood frame windows, biobased insulation, mineral plaster cladding (8 kg $CO_2$ eq./m²$_{cladding}$). The high GHG emissions of

Kosmos's reused HPL panels is explained by the new replacement stage (module B4), HPL materials having high emissions at production and elimination.

The **interior layout** layer has an average GHG emission of 76 kg $CO_2$ eq./m²ERA with a high variability (50-132 kg $CO_2$ eq./m²ERA), correlated to material choices and density. Kosmos has the lowest emission due to a wide space configuration with minimal partition walls. In the other hand, Hobelwerk has the highest emission to due dense acoustic/thermal insulation and support screed in floors, interior walls and ground floors.

The **technical installations** layer has the highest average GHG emissions with 121 kg $CO_2$ eq./m²ERA and a variability between 84 kg $CO_2$ eq./m²ERA and 148 kg $CO_2$-eq./m²ERA. Based on the KBOB LCA data per square meter, office-specific installations have higher GHG emissions than residential-specific. Hence, the variability in GHG emissions is explained mainly by the type of building and the number of photovoltaic panels installed. The highest emissions are associated to the office tower PPN Tour 107 which has an important quantity of PV panels (0.14 m² panels/m²ERA). In the other hand, Hobelwerk Haus D is a residential building with no photovoltaic installed on roof and has the lowest emissions of this layer.

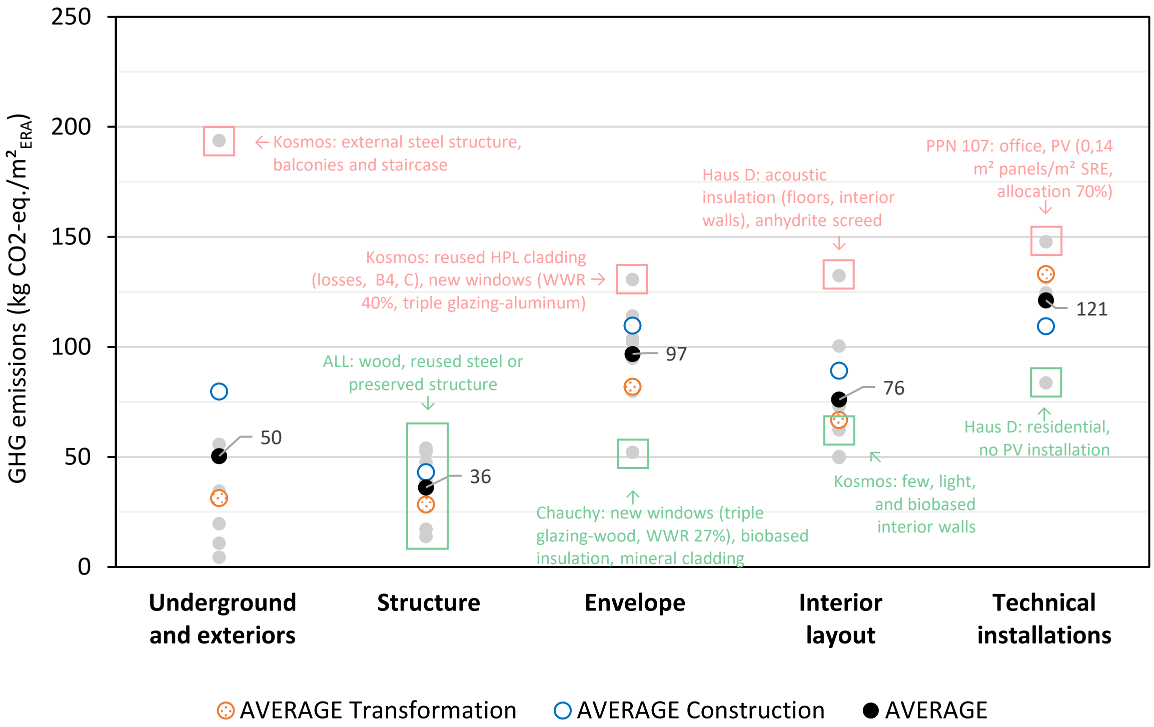



Figure 61: Life cycle GHG emissions of each case study (grey dots) and average values (black and coloured dots) per building layer. Annotations are added to underline the design parameters that explain the higher emissions (red text) and lower emissions (green text) in each category.

Table 24: Design characteristics of the case studies

| | PPN Tour 107 | Chauchy | K.118 | Hobelwerk Haus D | Kosmos |
|---|---|---|---|---|---|
| **Underground and exteriors** | Reinforced concrete frame (preserved) | - Reinforced concrete<br>- XPS insulation 8cm | - Reinforced concrete (preserved and new) | - Reinforced concrete (new) | - Reinforced concrete (new)<br>- External steel structure for balconies and staircase (mostly new) |
| **Structure** | Reinforced concrete frame (preserved) | - Stone walls (preserved)<br>- Timber floors (reuse and new) | - Existing wall: Clay brick (preserved)<br>- Extension: Steel structure (reused) | - Glulam beams (66%)<br>- Reinforced concrete (28%)<br>- Wood timber (6%) | - Glulam beams (53%)<br>- Wood timber (27%)<br>- Reinforced concrete (20%) |
| **Envelope** | - Windows: triple glazing aluminium frame<br>- Window blinds *(in reality electrochrom windows were used and not modelled because of lack of data)* | - Terra cotta tiles roofing<br>- Windows: triple glazing wood frame, Window-to-wall ratio of 27%<br>- Biobased insulation<br>- Mineral cladding<br>- Reused wooden window shutters | **Existing wall**<br>- Cellulose insulation<br>- Preserved windows<br>- New windows, triple glazing wood frame, 90 m²<br>**Extension**<br>- Prefabricated wood frame façade<br>- Straw insulation<br>- Rockwool insulation (reused)<br>- Reused windows<br>- Reused trapezoidal metal cladding<br>-Window blinds | - Reused trapezoidal aluminum cladding<br>- Glass wool wall insulation 24 cm<br>- EPS roof insulation 20 cm<br>- Windows: triple glazing wood/metal frame, Window-to-wall ratio of 19%<br>- Reused aluminum window shutters | - Reused HPL panels cladding (highest emissions due to new replacement)<br>- Windows: triple glazing wood-metal frame, Window-to-wall ratio of 40%<br>- Rockwool insulation 16 cm |
| **Interior layout** | - Suspended ceilings (reused)<br>- Terrazzo flooring (in-situ recycling) | - Clay brick walls<br>- Fiber-reinforced gypsum board<br>- Plasterboards | - Sand lime brick and concrete partition walls<br>- Reused OSB panels<br>- Reused stone tiles | - Polyurethane insulation 12 cm and EPS insulation 3 cm<br>- Cement and anhydrite plaster flooring | - Glulam frame<br>- OSB and plaster panels<br>- Rockwool insulation |
| **Technical installations** | - Ceiling heating plates<br>- New building integrated PV installation, 130 kWp, 0,14 $m^2_{panels}/m^2_{SRE}$, self-consumption rate of 70% (office)<br>- Renewal of electricity, heating, ventilation and water distributions, and sanitary equipment | - Geothermal heat pump and probes<br>- New PV roof installation 30 kWp, 0,30 $m^2_{panels}/m^2_{SRE}$ auto-consumption rate of 30% (residential)<br>- Renewal of electricity, heating, ventilation and water distributions<br>- Reused sanitary equipment | - Reused radiators<br>- Reused sanitary equipment<br>- Reused PV panels completed with new components, 18,7 kWp (instead of 20 kWp due to ageing), 0,12 $m^2_{panels}/m^2_{SRE}$, auto-consumption rate of 70% (office)<br>- Electricity, heating, ventilation and water distributions | - Heated floor system connected to district heating<br>- Electricity, heating, ventilation and water distributions<br>- Reused sanitary equipment<br>- No PV installation | - Radiators and district heating<br>- Reused sanitary equipment<br>- Electricity, heating, ventilation and water distributions<br>- PV installation 10,9 kWp (31% reused / 69% new), 0,09 $m^2_{panels}/m^2_{SRE}$, auto-consumption rate of 70% (office) |

### 4.2.5 Upfront GHG emissions of new and reused material inflows

This analysis exclusively focuses on manufacturing and transport phases emissions, excluding considerations of future replacements, end-of-life scenarios, and adaptive reuse potential. Notably, emission reductions are calculated against new material equivalents.

The Figure 62 provides a comparison of the GHG emissions intensity of the building materials (kg $CO_2$-eq./kg) according to actual reused material inflows, new material inflows, and the theoretical emissions of new equivalent materials replaced by the reused materials.

The significant variability in emission intensities range of emissions across case studies (from 0.16 to 1.19 kg $CO_2$-eq./kg) reflect different proportions of low-carbon materials in each design and the nature of the project. On average the weighted GHG emissions are:

- New materials: 0.510 kg $CO_2$-eq./kg.
- Reused materials: 0.130 kg $CO_2$-eq./kg. A production GHG emission reduction over A1-A4 of 75% compared to the new materials inflow.
- New equivalents replaced by reuse: 1.40 kg $CO_2$-eq./kg. This value reflects the fact that in most case studies, the reuse strategy is oriented towards materials with relatively high embodied GHG emissions such as steel beams, energy intensive wood panels, windows, photovoltaic panels or sanitary elements. The manufacturing GHG emissions reduction from reuse compared to the new equivalent is 91%, higher than the emissions reduction with the average mix of new materials inflow (75%).

Chauchy emerges as an exception, where the reused materials are mainly low-carbon (such as natural stone, wood beams or wooden shutters) and would still have low emissions if they were newly produced.

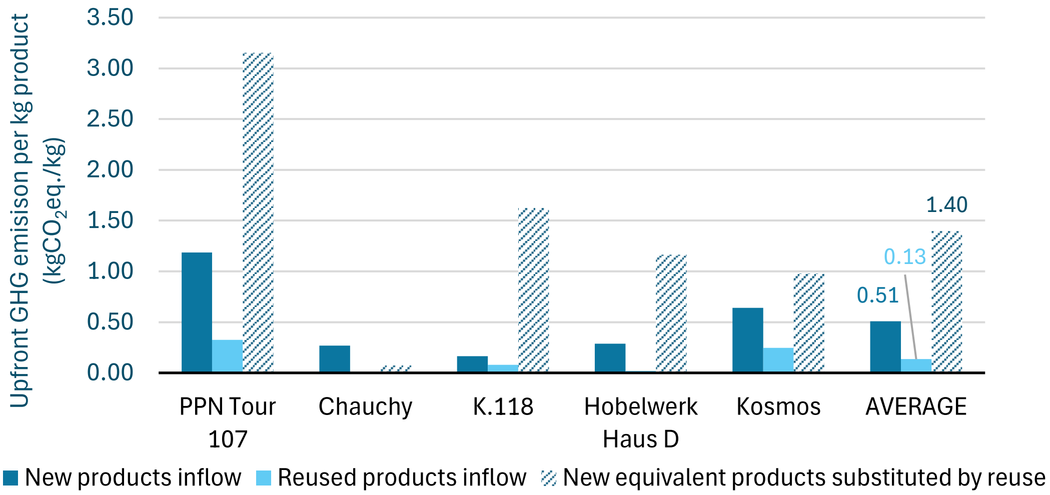



Figure 62: Upfront GHG emissions of new and reused inflows, and from the new equivalents that were substituted by reuse, per case study

The origins of GHG emissions within the reuse logistic chains averaged per case study vary considerably as shown in Figure 63:

- The highest impacts in PPN Tour 107 (0.327 kg $CO_2$-eq./kg of reused product) are mostly related to prolonged storage of 1.5 years in building hall (78% of the impact).
- The second more emissive case, Kosmos, is notably concerned by the elimination of HPL panels offcuts during preparation (50% of impacts), and steel pylons modifications (29%).

- These projects contrast with Chauchy's negligible emissions from its in-situ reuse strategy with few modifications (0.004 kg $CO_2$-eq./kg). This is explained by heavy stone elements that are reused in-situ with no modifications.

An insight into the transport of reused components is revealed from these data. The highest contribution of transport phases is 50% of the logistic emissions found in the K.118 project. Even with a long average distance of supply of 116 km (see section 3.1), the reuse elements had 50% less emissions than the new elements effectively used in the project (0.079 and 0.164 kg $CO_2$-eq./kg resp. according to Figure 62).

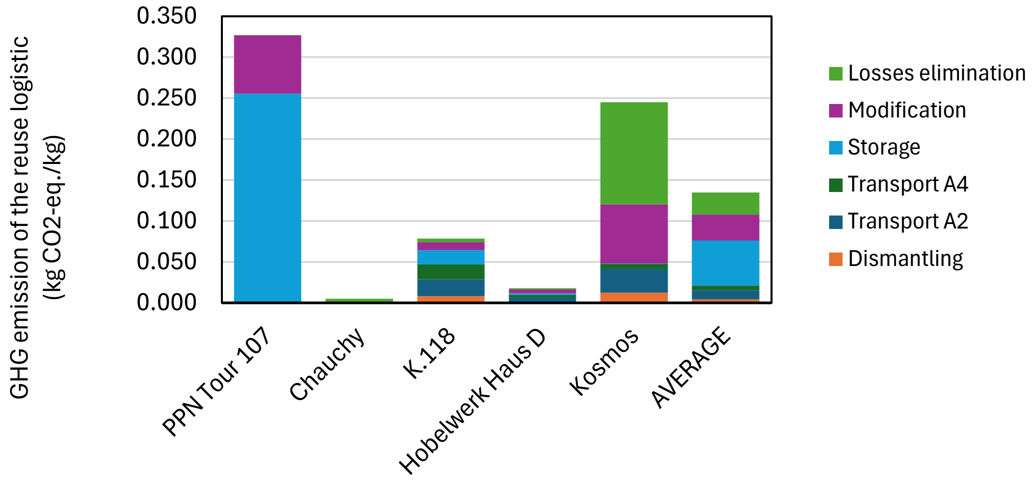



Figure 63: Upfront GHG emission of the average reuse logistic per case study and logistic step

Reuse logistic emissions on the Figure 63 are broken down by transport, reuse activities (includes dismantling, storage, modification), and elimination of modification's losses. The main results are:

- Window shutters: Painting operation for the refurbishment contributed 75% of the reuse emissions in Hobelwerk Haus D.
- Metal beams: In Kosmos, the steel pylons' preparation operations (cutting and surface treatment) accounted for 64% of reuse emissions. In K.118, the dismantling operation (modelled with a default LCA data of deconstruction using diesel-powered equipment) accounted for 40% of reuse emissions.
- Support and accessibility fixtures: the reused staircase in K.118 has 82% of reuse emissions associated with storage (3 years storage in a building hall).
- Insulation: In K.118 the prolonged storage of insulation materials over 2 to 2.5 years accounted for 35% to 82% of emissions depending on the material type and other reuse operations' burdens. Polyurethane insulation demonstrated additional impacts from default hypothesis of 10% material losses contributing 47% of reuse emissions.

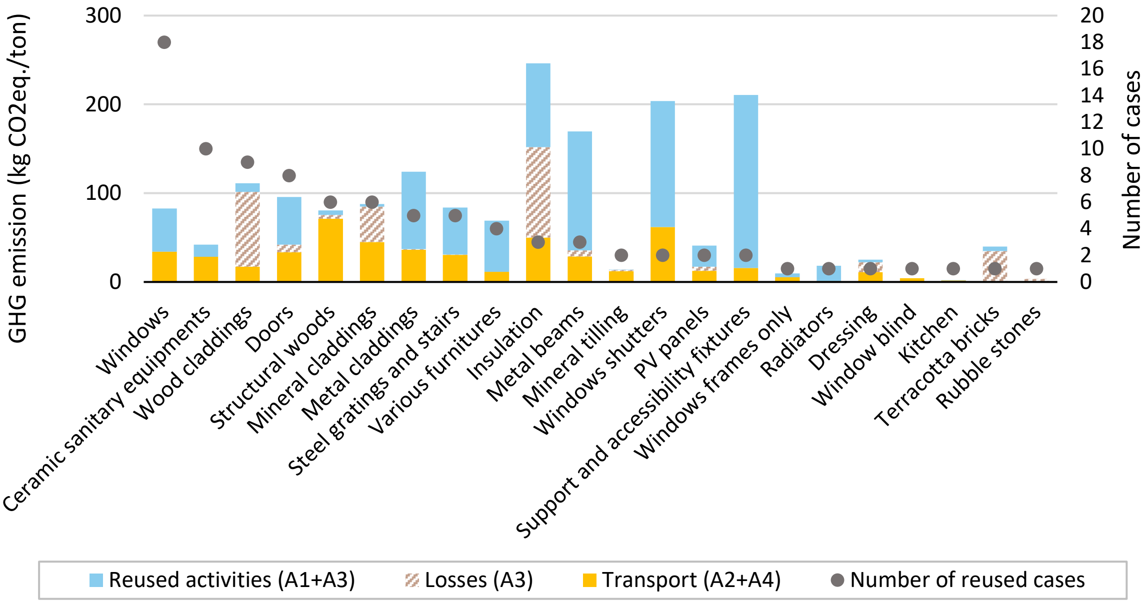



Figure 64: GHG emissions of reuse logistic chains, averaged per component category

As described in Table 25, the average supply distance of reused components is 87 km. While transport (A2–A4) averages 57% of A1-A4 emissions, this drops to 24% when isolating on-site supply (A4).

Table 25: Transport role in products GHG emissions (modules A1 to A4) of reused components in average

| Metric | Value |
|---|---|
| Average transport distance (A2-A4) | 87 km |
| Average total transport (A2-A4) contribution to reuse logistic GHG emissions | 57% |
| Average transport to site (A4) contribution to reuse logistic GHG emissions | 24% |

# 5 Case studies insights and discussions

This section builds upon the previous whole building case studies results and inter-comparison to draw some discussions and interpretation of the results.

## 5.1 Synergies and limitations of reuse within broader design and decarbonisation strategies

The design analysis by building layer reveals that, even with relatively high reuse rates, material reuse in construction remains a complementary strategy within broader design choices that influence a building decarbonisation. While certain applications—such as the reuse of heavy and carbon intensive structural elements in the K.118 steel extension—demonstrate clear efficiency, most reuse strategies must be complemented with careful low carbon design principles to maximize the overall GHG emissions reduction. These include the adoption of lightweight and low-carbon materials, optimized building form and material quantities, careful dimensioning, strategic window-to-wall ratios, efficient technical installations, and sufficiency-based design.

A second insight from the case studies is the different levels of GHG emissions optimisation of building layers. As low-carbon, preservation and reuse strategies reduce the emissions of the structure, the main contributors to the life cycle GHG emissions shift towards the technical installations, the interior layouts, and the envelope. This reinforces the need for comprehensive GHG emissions optimization looking at all building layers. Consequently, subsequent optimisation efforts must focus on these layers, requiring close collaboration between architects and specialised engineers. Along with this optimisation of all building layers, the designers should rely on disaggregated LCA data allowing such optimisation which is not yet the case especially for the technical systems where a lot of average default values are used per $m^2$ of ERA.

## 5.2 Reduction of building's upfront GHG emissions due to reuse

This section examines the relationship between mass-based reuse rates and upfront GHG emissions reductions (modules A1-A4) across the building case studies. The analysis focuses exclusively on production and transport phases emissions, excluding considerations of future replacements and end-of-life as well as adaptive reuse potentials. Notably, emissions reductions are calculated against new material equivalents, maintaining identical end-of-life impacts regardless of whether components are new or reused.

Figure 65 shows that the reuse rate alone relates to upfront (A1–A4) emission reductions with different trends. On average, the reuse rate is about 13% while it leads to 26% GHG emissions reduction in the buildings sample. Yet, these average values hide different trends. For example, despite having similar reuse rates around 20%-mass, there is a ten-fold difference between K.118 and Chauchy in terms of GHG emissions reduction (63% and 6% of upfront GHG emission reduction respectively). This large difference is explained by the mix of materials that constitutes the reuse products inflow in each project:

- K.118 reused mostly high-carbon materials such as steel beams, steel sheets, windows, etc.
- Chauchy reused mostly low-carbon materials such as stones and wood beams.

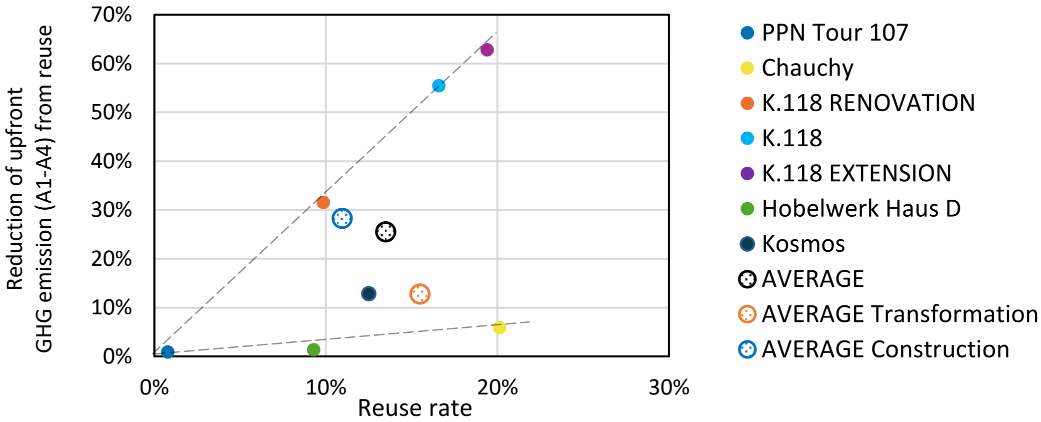



Figure 65: Reuse rate and the reduction of upfront GHG emissions for each case study, with average values

## 5.3 Activities contributing to the life cycle GHG emissions of reused products

Three primary factors influencing emissions profiles can be drawn from the previous observations:

- Material processing requirements: Notably surface treatments and diesel-powered operations.
- Prolonged storage in a dedicated building: The construction's burdens are allocated according to space and time (m².year) of the storage activity.
- Material characteristics: The density and volume of the products influence the scale of the dismantling, processing, handling and storage operations. In another hand, is also affects the results of comparison of reused products' emissions either expressed per kg or another unit.
- Material composition: The material composition will affect the waste treatment impacts related to losses occurring during preparation operations. This aspect depends on the national waste management infrastructures modelled in the KBOB LCA data.

Particularly noteworthy are the possible compounded effects such as:

- For heavy materials like structural steel, diesel-powered deconstruction combines with preparation requirements to produce substantial emission burdens. In the other hand, it must be put in context by the high emissions reduction compared to the manufacturing of new steel.
- For low density products, the need of space combined with prolonged storage in a building hall can produce substantial emissions.

The findings underscore the necessity of case-specific evaluation when assessing the carbon benefits of reuse strategies, as emissions drivers considerably vary across material types and reuse processes.

## 5.4 Reduction of life cycle GHG emissions from reuse at the component level

Building on project-scale LCA results, evaluates reuse performance at the component level, assessing life cycle GHG emissions (i.e., modules A1-A4 and C1-C4 only, without future replacements) of logistic chains and the potential reduction relatively to new equivalent materials.

Reuse outperformed new equivalents in 91 of 92 cases, achieving in average ≥70% life cycle GHG emissions reduction. This result is consistent with the SIA 390/1 informative appendix that proposes to account as a default value for a reused product of 20% of the new equivalent's GHG emissions at pre-project phase. Figure 67 shows that the average emissions reduction is the highest for the technical system components (95%), and the lowest for the structural components (69%). However, variability in emission reductions exists within building layers and underscores the need for component specific analysis.

The analysis per building component category on Figure 66 reveals that structural wood components exhibit the lowest GHG emissions reductions (30% average) and greatest variability among all categories. This is due to the low-carbon of this material associated with reuse impact due to the transport that can limit the benefits. For example, one reused element in this category—structural wood in the K.118 project - even exceeds its new equivalent's emissions due to a 230 km sourcing distance.

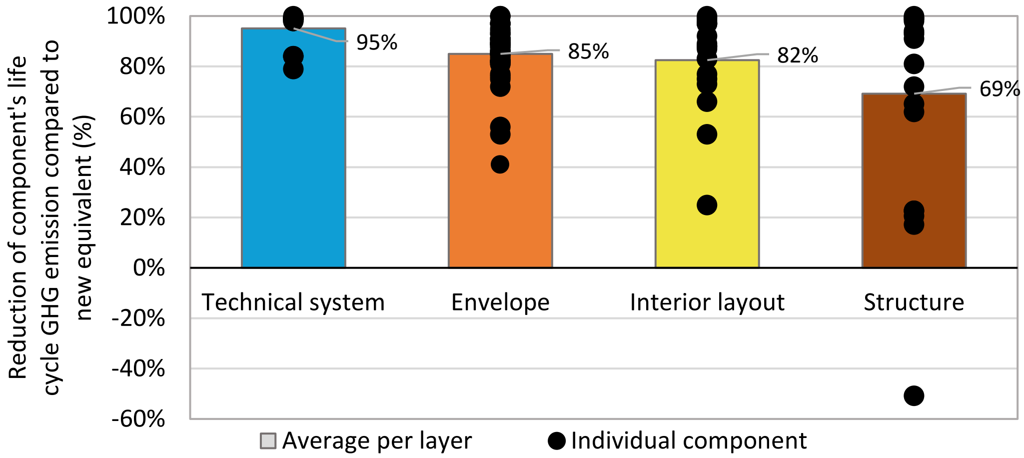



Figure 66: Reduction of life cycle's GHG emission (A1-A4 & C1-C4) of reused components compared to new equivalent material per building layer

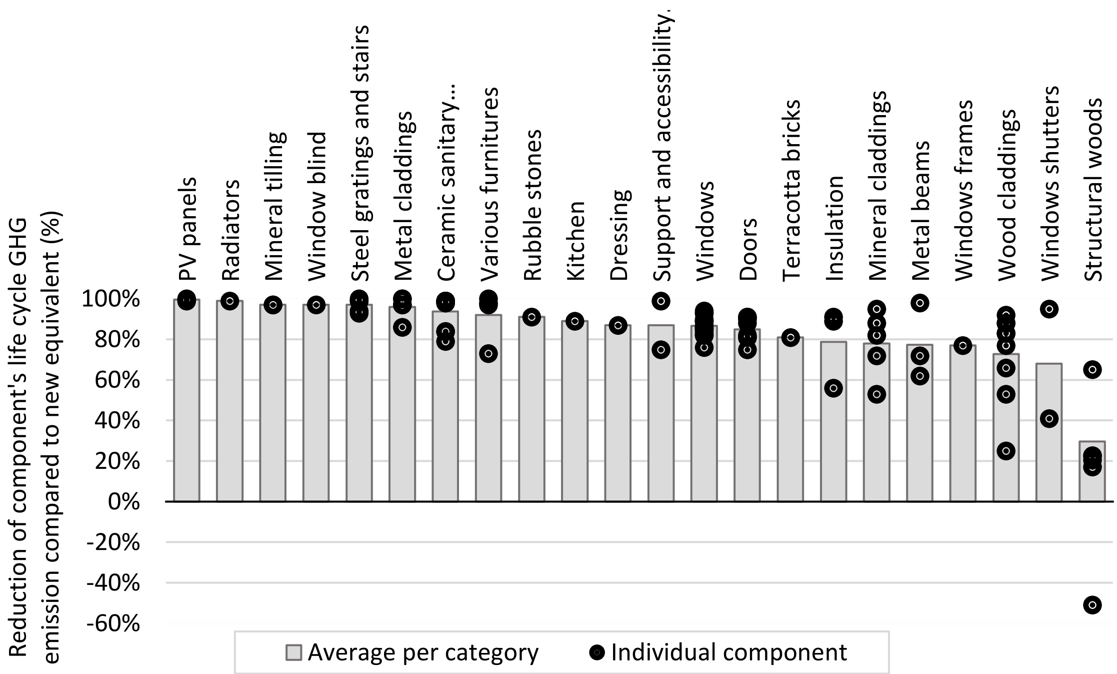



Figure 67: Reduction of life cycle's GHG emission (A1-A4 & C1-C4) of reused components compared to new equivalent material per component category

## 5.5 Transport distance limits for reuse efficiency

To assess whether transportation emissions may cancel the reuse benefits, a maximum allowable distance was calculated according to formula described in methodology section 2.3.6. This metric expressed as kilometre defines the farthest a reused element can travel while maintaining emissions parity with its new equivalent.

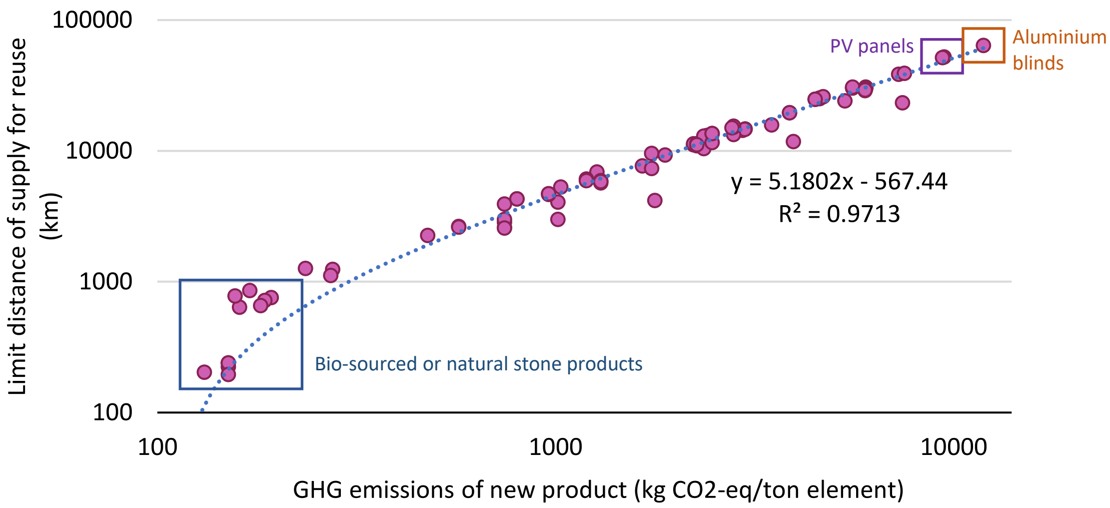



Figure 68: Limit distance per reused component

As demonstrated in Figure 68, reused elements replacing high-carbon new equivalents (e.g., aluminium blinds, PV panels) allow longer transport distances exceeding 10’000 km while retaining carbon benefits. Conversely, low-carbon materials like structural wood or natural stone require local sourcing (<100 km) to ensure a carbon reduction compared to new elements.

These findings must yet be put into perspective:

- Logistics mode limitations: In these results a road transport is assumed. For highest distances (>10’000 km), alternate modes of freight, e.g., by air or ship, with distinct emissions factors would apply.
- Vehicle-specific emissions variability: Calculations used a 16-32t. lorry (0,181 kg $CO_2$/tkm). Real-world factors range widely depending on the size of truck: from 0,117 kg $CO_2$/tkm for a 32-40 t. lorry, to 1,75 kg $CO_2$/tkm for a van.
- Load factor and empty return: KBOB’s LCA data assume European average load factors. Optimised project-specific logistics (e.g., Chauchy’s consolidated delivery of sanitary equipment into one van) can reduce emissions but are not accounted for in this study[6].

Low-carbon material: even if low-carbon products show less “carbon benefits” or more impacts than new equivalents if supplied over long distances, they still contribute to project-scale decarbonisation, as exemplified by Chauchy and K.118 case studies, as their embodied carbon remains lower than energy or carbon-intensive materials.

[6] The use of mobitool (web link: mobitool) as recommended by the KBOB would allow to specific the load factor in the lorry and for heavy materials, this could significantly decrease the GHG emissions as per tons x kilometer, the usual unit used to assess transport related impacts in LCA, the diesel consumption drops due to the fact that the lorry is fully loaded unlike the generic transport data that assume an average load factor of about 25 to 30%.

## 5.6 Positioning and limitations of the study

The average reuse rate in the 5 demand-side reuse new building case studies was found to be 13% in mass. This leads to an average GHG emissions reduction of 20% for the upfront emissions (A1-A4) compared to a design with only new equivalent materials. The weighted average of the GHG emissions of all reused components was found to be 0.13 $kgCO_2e/kg$. The findings of this study can be compared to a recent study conducted in the FCRBE Interreg project in Europe on 32 buildings with reuse strategies [47]. The authors also found diverse reuse practices according to the building layer depending on the specific context of the project. A relatively close and consistent weighted average of the GHG emissions of all reused components was recorded with about 0.12 $kgCO_2e/kg$, a similar value as found in this study for the Swiss context. A same limitation exists, in the European study, with the definition of the GHG emissions reduction due to reuse. Originally, the choice of the equivalent new material remains a simple metric to motivate building owners and decision makers to favour reuse over new materials. In future works, such metrics should shift towards a functional equivalent approach that may be or may not be the same new material. As discussed in some of the case studies, a functional equivalency approach for both the new and reuse component, provides a more accurate assessment than a simple material equivalency.

In this study, even if buildings differ in project's type (new or transformation), typology, form factor, material intensity and materials used, they allow to get a clearer picture of reuse tendency on a specific building sample gathering some of the "best practices" at a certain time of building design and transformation. On the one side, the potential of reuse to mitigate building's GHG emissions exists but on the other side, it cannot alone solve the whole decarbonisation issue of the upfront GHG emissions in new and renovated buildings. "Demand-side" case studies will always rely on a limited stock of reclaimed components extracted from the "offer-side" of the building stock. Even in a "cutting-edge" project of a selective deconstruction of a concrete structure (cf. the analysis in Appendix III of this report), a relatively low reclamation rate with about 25% of the concrete structure saved for next reuse cases was found.

Interestingly, a "top-down" study on the reuse potential in Swiss buildings also funded by the SFOE found a rather lower reuse potential in the stock comparatively to the advanced pilot buildings analysed in this project. The authors took the Baden (AG) building stock as a representative city. By 2050, they estimated that only 10'780 tons $CO_2e$ can be saved due to reuse compared to the current GHG emissions of the built stock estimated at 187'463 tons $CO_2e$, which means that the reuse potential by 2050 represents "only" 6% of the current construction GHG emissions of the stock. The authors conclude that due to the increase of new constructions compared to the current level of building deconstruction, there is not enough materials to source for these new constructions even if it is assumed 100% of recovery rate in the deconstructed buildings.

This "bottom-up" study (Reuse-LCA) and the parallel "top-down" study jointly recall that in-situ or ex-situ reuse remain an interesting measure to decarbonize building, but it should be used in connection with other low-carbon measures due to its lack of scalability for the whole building stock. First, the best measure to decarbonize a building project is to maintain and preserve the existing materials. This stresses the relevance of the adaptive reuse (i.e., maximize the preserved rate) as exemplify for the PPN Tower 107 in this study. If a building must be built or transformed, additional measures should be coupled to reuse with design-related ones (form factor, window wall ratio etc.) and material choices and building layer optimisation (for structural, non-structural materials and technical systems) as investigated in the SFOE Net zero GHG emissions in buildings project conducted in parallel of this study [48]. So, even if a design team wants to maximise reuse and circular strategies, many other measures must be combined due to the limited number of reused components in mass but also to minimise for all building layers the GHG emissions according to the new ambitious SIA 390/1 limit values.

Finally, the current version of the Swiss LCA database for construction currently hinder a reliable assessment of best practices for all building layers. On the one side, insufficient data and ratio often based on m² ERA (energy reference area) prevents precise and representative evaluation of technical installations' emissions. This issue is well known and repeatedly highlighted in other research projects, but a robust and practically applicable solution is still lacking. On the other side, the main building materials are represented, and project-specific optimisation remains possible. These gaps highlight the need for more tailored LCA data to support advanced decarbonization strategies, where LCA data would be organized by building layer (structure, envelope, interior fittings, and technical systems), and at the right level of details matching the action leavers of each building planner (e.g., civil engineer, building physicist, architect, HVAC engineer…), each one being in the end "responsible" of a part of the GHG emissions optimization of the building.

# 6 Conclusions and perspectives

This study analysed 8 case studies including 6 demand-side reuse on whole buildings and external façade, one adaptive reuse of windows frame and one offer-side case study of a concrete structure deconstruction for reuse. The study reports on demand-side reuse that reusing building components decreases on average the GHG emissions. For all case studies and components, only one situation was not beneficial, at the component scale. It was, in the specific case of a structural wood, a biobased material with a high transport distance. However, this negative aspect does not increase much the GHG emissions for the corresponding building layer. For the rest, all reuse components lead to GHG savings when compared to their equivalent new materials. In terms of new equivalent materials and at the component scale, it is about -90% of savings in terms of GHG emissions. When considering a mix of reused components integrated in a sample of different new and existing building types, the savings decrease a bit up to -75%. These savings show that the reused components were mostly carbon intensive in the case studies. As expected, the adaptive reuse which preserves the existing elements in a building is the most powerful type of reuse. It does not need any logistics like the ex-situ reuse and for the structural elements, it displays the highest savings. The analysed case studies also revealed differences by building layers with much less reuse in the technical installations compared to the other layers. It remains open to check whether these findings are also valid for other buildings as the ones analysed in this project were selected due to a willingness to be circular and low carbon[7].

This study's results align well with the state-of-the-art such as in Pfäffli, 2020 [29], despites different calculation hypotheses about the replacement and end-of-life scenarios (see section 2.3.4). The emission reduction of a reused component as a metric (often wrongly called "avoided emissions"), should serve solely as a supplementary information used to support decision making, demonstrating reuse relevance through comparative LCA against equivalent new materials While offering initial insight into potential savings, this metric exhibits significant bias and limitations when functional equivalency is not accounted for and overcome the type of material of a reused component. Indeed, without reuse, the choice for a new functional equivalent component would not have necessarily been the same type of material. This is particularly relevant given that reused elements in the studied projects predominantly comprised GHG-intensive materials (see Figure 62 in section 4.2.5). This recalls that the reuse of elements in practice may currently prioritise availability considerations over a sound and rationale sizing or functionality. Ideally, both should be accounted for to not oversize or use inefficiently the reuse materials.

At the building scale, reuse contributes to a range of low carbon measures that will help the building sector achieve the net zero goals by 2050. In total, up to 20% of GHG emissions could be saved on average in the building case studies (new constructions) compared to the equivalent new variants. The significance of adaptive reuse for the structure and the window frames was also shown as very relevant. However, the reuse of building components remains one of the activable measures in a building project. Many other measures can be and should be combined as depicted in the different analyses to lower the GHG emissions.

The accounting of reuse in building LCA and the results of the Reuse-LCA case studies question the current LCA data used by the new SIA 390/1. It emphasizes the need to improve the LCA data granularity and representativeness for some building layers in a view of correctly assessing decarbonization measures at the level of influence of each building planers.

Several observations go into this direction:

- The SIA 390/1 standard applies a 20% impact value of the new equivalent for reused components in the early design phase (pre-study and pre-project phases according to SIA 390/1 art. B.2.1.7). In the planning phase, the values need to be determined more precisely but data and calculation tools are lacking. The different data of reuse activities collected through the

[7] Most of these building projects were documented in the SIA magazine Tracès showcasing their low carbon and reuse strategies.

investigated case studies and the developed methodology in Reuse-LCA should be consolidated in a calculation tool.

- Default values for technical installations in the Swiss LCA database are simple to handle and help planners in early design phase. However, they do not allow to account for optimised design solutions of HVAC distribution systems or sanitary installations. Each actor of a building project (civil engineer, building physicist, architect, HVAC engineer, etc.) should have access to the right data to calculate and minimise the impacts of their corresponding building layer (structure, envelope, interior fittings, technical installations).
- Transport was found influential in the impacts of reused components. However, the impact values of transport available in the Swiss LCA database are calculated based on an average load factor of trucks. A more tailored assessment is fundamental to better reflect the load factor of the lorry according to the density of construction products and specific logistics. This applies for reused products but also for the LCA of new construction materials sensitive to this parameter.

Additional issues were raised about the replacement scenario in the SIA 390/1 standard for reused products in general, and for new and reused products in the case of renovation projects.

- In this study, a conventional scenario was used with reused products being replaced by new equivalent products at the end of their service lives. By doing so, the benefit of reuse is only accounted for in the upfront emissions of a building as the future replacement emissions do not decrease compared to the equivalent new material. In the SIA 390/1, the use of “amortised value” per year for each material/layer implicitly considers a replacement by the same reused product in the future.
- Similarly, in renovation projects, only the added materials are accounted for in the upfront and future replacement emissions. So, the more complete the renovation, the more replacement emissions it will have as more materials are integrated in the analysis. Conversely, non-renovated elements in existing buildings are excluded from LCA calculations, even though they will require maintenance and replacement in the next years. This means that the LCA results of renovation projects become too sensitive to the LCA perimeter definition (which can be highly variable from a project to another) and hypothetical future replacements.

This also questions in return the lifetime of a reused element vs. the equivalent new. Future works should be conducted to better differentiate design strategies by avoiding impacts’ shifting. With this concluding remark, it recalls that beyond clear ambitions on GHG emissions target values in the new SIA 390/1 standard (2025), there are still a lot of implicit assumptions on LCA data and calculation rules that should clarified and that the practitioners should be aware of when assessing from a LCA point of view circular and decarbonization strategies.

# 7 Outlook and next steps

Following this study, data consolidation will be done and extended to other project cases in canton GE mainly in the framework of the SFOE Mat-Loop project cofounded by the Industrial Services of Geneva and their eco21 unit dedicated to the circular economy. In terms of LCA data and reuse logistic chains, the aim will be to consolidate LCA calculations by component and to have an LCA calculation tool for re-use that will enable the LCA of a re-used component to be calculated on the basis of the indicators in the KBOB 2009/1:2022 recommendation, while also taking into account the GHG emissions saved by reuse, with where necessary adjustments on the functional equivalent for key and relevant components (PV, windows, concrete structural slabs, etc.). As transport was found influential in the impacts of all components in general, a more tailored assessment is needed to better reflect the load factor of the lorry to the type of component and to the specific reuse logistics. The use of adjusted transport data should be integrated in the work of the parallel SFOE project Mat-Loop.

Outside the SFOE projects, the calculated GHG emissions of reuse and the potential emissions reduction will be used and completed by other cases for operational guides to reuse per building product family together with relevant stakeholders (civil engineer, HVAC engineer, building physicist…) in Romandie in partnership with the Industrial Services of Geneva and in the framework of the new legal aspects on embodied carbon for buildings set by the canton of Geneva.

# 8 Publications

*Scientific paper co-written between ETH Zürich and HEIG-VD :*

Xiong S., Frossard M., Lasvaux S., Zea Escamilla E., Habert G. 2024. Environmental savings from concrete reuse: examining the limitations and optimal practices for cutting thresholds of concrete building components for reuse, *Environ. Res.: Infrastruct. Sustain.* **4** 035016: https://iopscience.iop.org/article/10.1088/2634-4505/ad7a22/pdf

*Website containing the case studies and serving to disseminate the SFOE Reuse-LCA project.*

Lien pour accéder au site internet regroupant les analyses sur les 5 projets pilotes

Les études de cas ont fait l'objet d'une publication sur un site internet dédié afin de communiquer sur la méthodologie, les flux de composants réemployés et des résultats obtenus.

Objective and methodology | Case Studies : Building | Case Studies : Component | About

## Primeo Energie Kosmos

**Description**

Type of project: New construction
Type of building: Education and training
Construction materials: Concrete, steel and wood
Building energy reference area (ERA): 723.9 m²
Floors: 3
Location: Münchestein (BL), CH
Project phase: Completed in late 2022
Official webpage

**BUILDING Key Performance Indicators**

| Material Intensity | Life cycle GHG emissions (construction) | Stored biogenic carbon |
|---|---|---|
| 533 kg/m² | 541 kg $CO_2$-eq./m² | 18 kg C/m² |

**REUSE BUILDING Key Performance Indicators**

| Emissions reduction due to reuse | Share of Ex-situ/In-situ | Share of adaptive reuse | Ex-situ reuse supply distance |
|---|---|---|---|
| 65 kg $CO_2$-eq./m² | 13 % of total mass | 0 % of total mass | 77 km (weighted average) |

Figure 69: Screenshot of a part of the webpage for one of the building case studies analysed in the Reuse-LCA project

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# 10 Appendix I: LCA data choices for reuse activities

To address data gaps in the KBOB database for reuse-related activities (e.g., storage, conditioning or element modification), additional LCA datasets were developed using the following procedure:

- **Exporting existing UVEK data:** Activities or products already modelled in the UVEK background database were integrated directly, ensuring compatibility with KBOB standards.
- **For activities not covered by UVEK:** If an activity or product is not modelled in UVEK, the foreground information (such as energy consumption or material inventory) is collected in different ways:
    - Project-specific primary data were prioritized when available (e.g., energy use during modification).
    - Existing datasets from external sources (ecoinvent, French EPD) were adapted into UVEK inventories. Sources have been cross-referenced to ensure representative average values for material/energy inputs.

The new datasets are described in the tables below, specifying their LCA impacts, origin, assumptions (e.g., default transport distances), and applications across case studies.

Table 26: Assumptions for dismantling and modification activities based on energy consumption

| Operation | Description parameter and values | LCA modelling | Source | Case studies |
|---|---|---|---|---|
| Electric cordless drill | Electric cordless drill of 598 W<br>**Duration of use expressed in minutes.**<br>• Panels (wood cladding, photovoltaic): 2 min/m²<br>• Sanitary equipment, aluminium grating: 2 min/item<br>• Doors: 5 min/item<br>• Kitchen: 30 min/item | **LCA dataset**<br>Electricity consumption: *KBOB, id 45.020, consumption mix CH*<br>**Exclusions**<br>• Production and disposal of cordless drill<br>• Disposal of screw waste | Hobelwerk Haus D, Kosmos | Hobelwerk Haus D, Kosmos, |
| Circular saw | Electric circular saw of 5000 W<br>**Duration of use expressed in minutes.**<br>• Metal sheet: 0,32 min/m²<br>• Wood panel: 5 min/m²<br>• Windows: 1 min/item<br>• Wood structure, stone slabs: 10 min/m² | **LCA dataset**<br>Electricity consumption: *KBOB, id 45.020, consumption mix CH*<br>**Exclusions**<br>• Production and disposal of circular saw<br>• Disposal of screw waste | Hobelwerk Haus D, K.118 | Hobelwerk Haus D, K.118 |
| Various dismantling | Electric machine of 1000 W<br>**Duration of use expressed in minutes.**<br>Wood panels, windows, doors, structural wood, claddings, sanitary equipments, window shutters: 10 min/m² | **LCA dataset**<br>Electricity consumption: *KBOB, id 45.020, consumption mix CH*<br>**Exclusions**<br>• Production and disposal of the machine<br>• Disposal of screw waste | K.118 | K.118, Chauchy |

Table 27: LCA datasets for various reuse-related activities

| Product or activity | Functional unit (FU) | Ecological scarcity (UBP/FU) | GHGe (kg CO2-eq./FU) | NRE (kWh/FU) | Source and assumptions | Case studies |
|---|---|---|---|---|---|---|
| Dismantling, default | kg | 9,55 | 0,0067 | 0,025 | UVEK 2021: *deconstruction, average/CH U* | Kosmos |
| Storage, building hall | m². year | 7'140 | 2,97 | 9,99 | UVEK: *Building, hall/CH/I U*<br>50-year lifetime, 1500 m², 7 m height, 70% steel/30% wood<br>Assumption of 3,5 $m^3$/m² of occupied space | Kosmos |
| Storage, exterior field | m². year | 630 | 0 | 0 | UVEK: *Occupation, industrial area* (elementary flow) | Kosmos |
| Natural wood oiling | m² | 3'839 | 0,150 | 0,367 | Ecoinvent 3.9 adapted into UVEK: *cottonseed oil, refined, to generic market for vegetable oil, refined, GLO*<br>0,455 L/m² according to a commercial reference | Kosmos |
| Preparing and assembling steel structure (Kosmos) | kg | 314 | 0,174 | 0,856 | For 20,8 tons prepared:<br>Sawing (1,2 min/cut, 1,75 kW, 52 cuts)<br>+ Drilling (0,60 min/hole, 3,4 kW, 170 holes)<br>+ Screws (steel, 16mmx60mm, x300)<br>+ UVEK: *surface treatment, outer door, natural, at plant/CH U* (942 m²) | Kosmos |
| Painting aluminium shutters | m² | 4'131 | 1,85 | 12,9 | Based on a commercial reference (Metaltop)<br>UVEK: *Acrylic dispersion, 65% in H2O, at plant/RER U* (33%)<br>+ UVEK: *Alkyd paint, white, 60% in solvent, at plant/RER U* (66%)<br>0,671 kg paint/m² | Kosmos |
| Painting wooden shutters | m² | 6'117 | 15,1 | 3,29 | Quantity of paint based on a total of 5 kg used in the project for the 6,7 m² of shutters, decomposition between the type of paint based on UVEK datasets. 4 kg "UVEK: Long oil alkyd resin, 70% in white spirit" and 1 kg "UVEK: Alkyd paint, 60% in solvent | Chauchy |

| | | | | | | |
|---|---|---|---|---|---|---|
| Steel welding | m | 379 | 0,153 | 0,474 | UVEK: *Welding, arc, steel/RER U* | K.118 |
| Preparing salvaged wood parquet flooring | m² | 33 | 0,009 | 0,028 | Cleaning and disposal of nails scraps | K.118 |
| Preparing salvaged windows | m² | 6'784 | 24,6 | 2,34 | Cleaning and replacement of joints according to UVEK inventory | K.118, Chauchy |
| Preparing salvaged photovoltaic panels | m² | 43 | 0,174 | 0,011 | Cleaning, tests and handling | K.118 |
| Preparing steel structure (K.118) | m | 4790 | 8.76 | 2.73 | Includes holes drilling, bolts, and surface treatment from project's information | K. 118 |
| Painting interior doors | m² | 7'720 | 4,15 | 19,1 | UVEK: *surface treatment, inner door, opaquely painted, at plant/CH U*<br><br>1st protective layer 813g/m²; paint layer 584g/m². | K.118 |
| Preparing interior door | piece | 23'328 | 9,32 | 48,9 | Painting and reconditioning (new door threshold) | PPN Tour 107 |

Table 28: LCA datasets for various products

| Product or activity | Functional unit (FU) | Ecological scarcity (UBP/FU) | | GHGe (kg CO2-eq./FU) | | NRE (kWh/FU) | | Source and assumptions | Case studies |
|---|---|---|---|---|---|---|---|---|---|
| | | Production | End-of-life | Production | End-of-life | Production | End-of-life | | |
| Ceramic washbasin | piece | 138'000 | 2'060 | 70,40 | 0,404 | 334 | 2,46 | 30 kg/piece | Kosmos, Hobelwerk, K.118 |
| Ceramic WC | piece | 198'000 | 2'930 | 103 | 0,585 | 509 | 3,53 | 42 kg/piece | Kosmos, Hobelwerk |
| Ceramic shower | piece | 256'000 | 3'740 | 131,00 | 0,734 | 618 | 4,48 | 55 kg/piece | Hobelwerk |
| Suspended ceramic WC | piece | 130'361 | | 95,3 | | 408 | | SFOE's project SYGREN 30 kg/piece | PPN Tour 107 |
| Office Washbasin | piece | 221'975 | | 74,0 | | 340 | | SFOE's project SYGREN 30,4 kg/piece | PPN Tour 107 |
| Urinal | piece | 92'417 | | 63,7 | | 300 | | SFOE's project SYGREN 42 kg/piece | PPN Tour 107 |
| Steel radiator | kg | 8'690 | 497 | 4,69 | 0,006 | 15 | 0,020 | UVEK: *multicolumn radiator/CH U* | Kosmos, Hobelwerk, K.118 |
| Wooden window shutters | m² | 62'700 | 1'298 | 33,50 | 0,800 | 113 | 1,77 | 23 kg/m² | Chauchy |
| Aluminium window shutters | m² | 191'787 | 3'013 | 99,34 | 2,63 | 419 | 1,02 | 14 kg/m² | Hobelwerk |
| Chalkboard | m² | 18'200 | 537 | 12,50 | 0,130 | 42,5 | 0,819 | 10 kg/m² | Hobelwerk |
| Substrate for green roof | kg | 435 | 28,4 | 0,342 | 0,013 | 0,239 | 0,079 | 500 kg/m³ | K.118 |

# 11 Appendix II: demand-site reuse at the scale of a prefabricated reuse façade (ELYS)

The ELYS prefabricated façade has a U-value (excluding windows from the wall) of 0,23 W/m2·K with a total thickness of 56 cm, comprising 30 cm of reused rockwool insulation and 6 cm wood fiber panel. Degraded thermal performance attributable to the age of the rockwool insulation layer was accounted for in the analysis. The functional equivalence of the variant using exclusively new materials was defined with a new rockwool insulation (thermal conductivity: 0,034 W/m·K) and an adjustment of the insulation and wood lathing thicknesses to 21 cm, preserving a U-value of 0,23 W/m2·K.

The window-to-wall ratio is 29% on the ELYS south façade (19% for the glazing only).

The ELYS facade has a material intensity of about 67'517 kg and 107 $kg/m^2_{facade}$. Figure 70 gives the detail of the material intensity and production origin materials for the ELYS facade. 58% of the facade's mass consists of reused elements, sourced ex-situ (24%, including manufacturing surplus origin of 5%) and in-situ (34%).

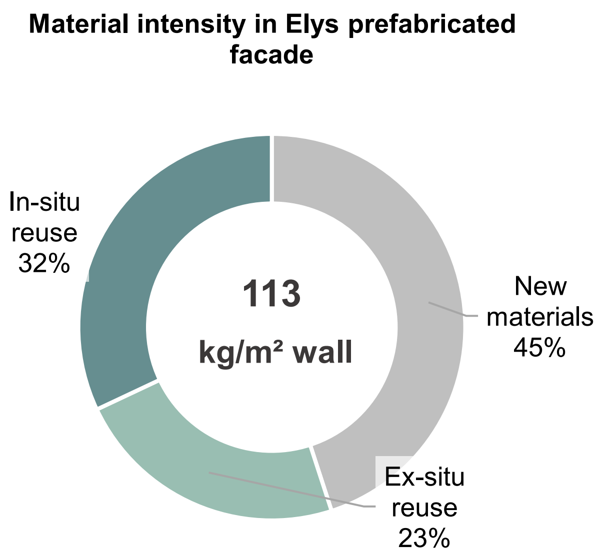


Figure 70: Material intensity and materials origins in the Elys prefabricated south façade

Figure 71 uses a Sankey diagram to depict the material composition the Elys prefabricated façade, categorising mass flows by building layer, origin (new/reused), and material families. The analysis reveals that 88% of the façade's components pertain to the envelope layer, with the remaining 12% attributed to the interior layout due to the Fermacell interior finishes. Steel constitutes one-third of the façade's total mass, entirely derived from reused trapezoidal sheeting. Wood and bio-based materials account for 30% of the mass, with 21% of these materials sourced through reuse. Mineral-based components, including plaster, Fermacell panels, and rockwool insulation, represent 29% of the façade's mass, of which 13% originates from reused sources.

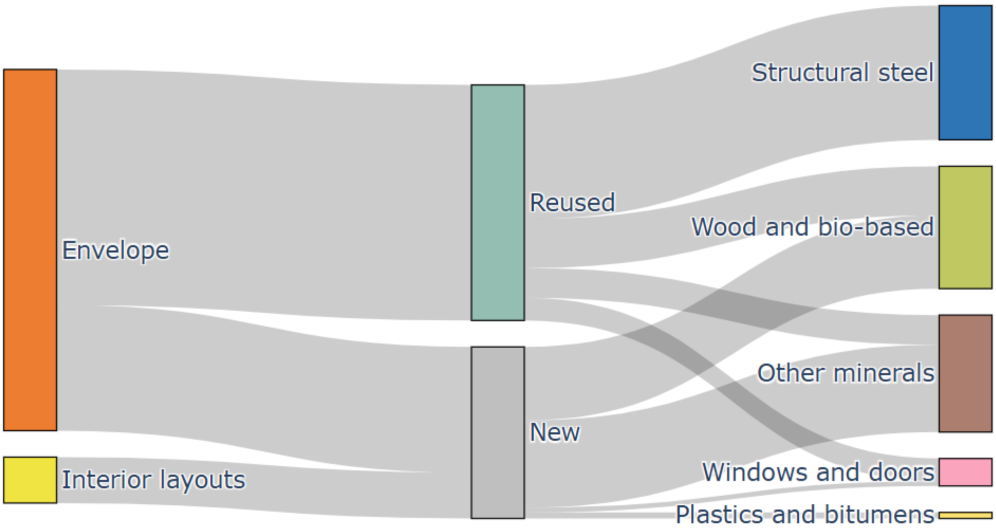


Figure 71: Sankey diagram of the mass flow of building components per category and material, Elys prefabricated south façade

Figure 72 compares the lifecycle embodied greenhouse gas (GHG) emissions per square meter of the prefabricated ELYS south façade and an equivalent variant constructed exclusively with new components. The façade element including the windows, has a life cycle embodied emission of 130 kg $CO_2$ eq./$m^2_{Façade}$. The reuse strategy reduced total emissions by 48% compared to an all-new construction variant, saving 118 kg $CO_2$ eq./$m^2_{Façade}$. Hence, the embodied emissions are primarily related to future replacements (75%), the initial emission from production stage being minimized by reuse practice.

Figure 73 illustrates the distribution of greenhouse gas (GHG) emissions across wall components and life cycle stages. Initial emissions are absent for the reused metal sheet cladding; however, it constitutes the primary contribution to façade emissions, driven by its future replacement after 40 years—a scenario incorporated through Module B4. Reuse of the metal sheets achieves a 66% reduction in emissions relative to new equivalents. Windows, with 79% of their materials sourced from reuse, yield a 33% decrease in their life cycle emissions (13 kg $CO_2$-eq./$m^2_{Façade}$). Similarly, reused rockwool insulation (53% of total insulation mass) reduces associated GHG emissions by 20%. In contrast, the reuse of 40% of wood components results in a more modest 6% mitigation of emissions compared to new materials.

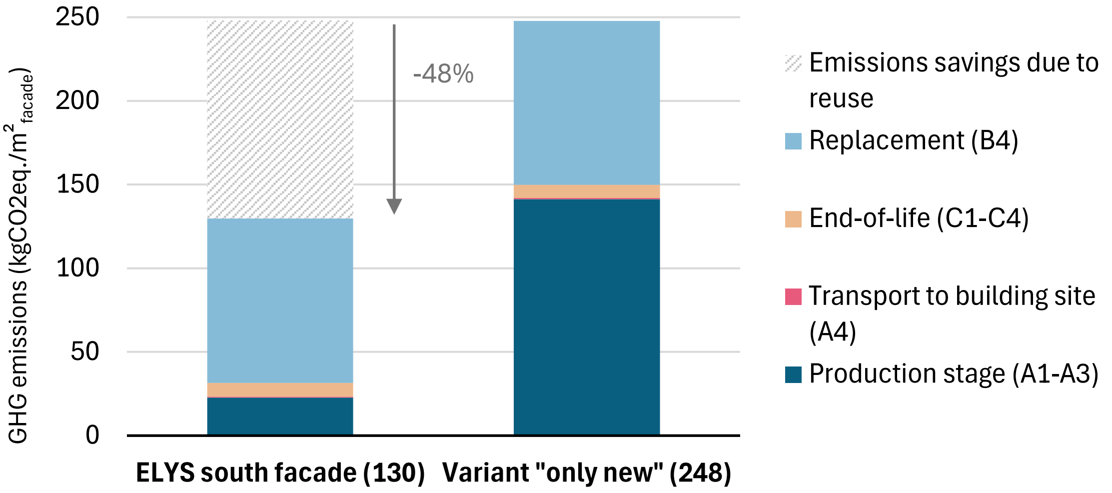


Figure 72: GHG emissions of the project and its variant "only new" over life cycle stage, ELYS prefabricated façade

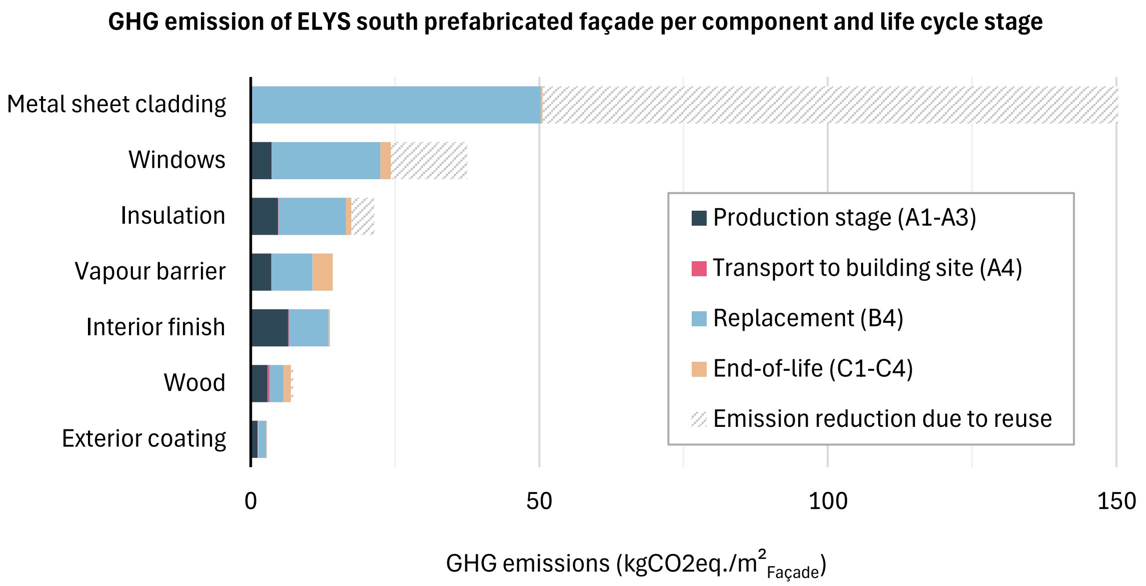


Figure 73: GHG emission per component and life cycle stage, ELYS prefabricated façade

# 12 Appendix III: offer-side reuse of a building's structural frame dismantling (MixCity) for concrete reuse (in french)

## 12.1 Introduction

Cette étude de cas répond à trois objectifs principaux :

1) Evaluer les émissions de gaz à effet de serre (GES) associées aux opérations de déconstruction sélective des éléments en béton ;

2) Identifier les paramètres influençant ces émissions pour le béton réemployé en sortie de chantier ;

3) Analyser la réduction potentielle d'émission de GES du béton de réemploi par rapport à un béton neuf, en fonction de la distance d'approvisionnement vers le nouvel usage.

La recherche a été structurée en deux volets complémentaires :

- Modélisation des émissions de GES

Coordonné par Shuyan Xiong, doctorant à l'ETH Zürich, ce volet a permis de développer un modèle mathématique pour quantifier les émissions de GES générées par la déconstruction sélective du béton en vue de son réemploi. Le modèle intègre divers facteurs tels que le transport, l'énergie nécessaire à la découpe, les mix énergétiques, et les variations de performance des équipements de découpe. Cette approche permet d'évaluer des scénarios de déconstruction dépassant le cadre spécifique du cas étudié à Renens (VD). Cette étude collaborative entre l'ETH Zürich et la HEIG-VD a été publiée dans la Revue *Environmental Research: Infrastructure and Sustainability* en Septembre 2024 en accès ouvert [41].

- Ecobilan contextualisé de la déconstruction du bâtiment MixCity de Renens (VD)

Piloté par la HEIG-VD, ce second volet repose sur une analyse détaillée du chantier de déconstruction de Renens (VD). Il intègre les données réelles de logistique, les plans de calepinage des découpes structurelles et les spécificités opérationnelles du site, afin d'estimer avec précision les émissions de GES du béton réemployé. Ce volet est présenté dans la suite.

## 12.2 Présentation du cas d'étude

Contrairement aux autres études de cas du projet Reuse-LCA, qui examinent des stratégies de réemploi du point de vue de la « demande », le cas étudié dans cette annexe présente le réemploi sous l'angle de l'« offre », ou du « bâtiment donneur ». En 2023, une opération de déconstruction sélective a été menée sur un bâtiment à Renens (VD), marquant la première initiative en Suisse à cette échelle pour la récupération d'éléments d'une structure en béton[8]. Ce bâtiment a dû être déconstruit pour permettre la construction d'un nouveau complexe multifonctionnel lié au projet « MixCity », prévu pour 2025, l'ancienne structure n'étant pas adaptée aux nouveaux usages envisagés. Le bâtiment donneur, de forme rectangulaire, mesurait 40 mètres de long sur 35 mètres de large et comprenait quatre niveaux, dont un sous-sol, pour une surface totale de 3'090 m². La structure porteuse est presque exclusivement en béton armé. La Figure 74 présente des photographies du bâtiment avant et pendant sa déconstruction.

[8] https://2401.ch/deconstruction-et-reemploi-structurel-a-renens/

Figure 74: Photographies du bâtiment en cours de démolition avec une partie démolie et une autre préservée pour le réemploi des éléments en béton armé (photographie : Julien Pathé, 2401)

Les dalles de sol et les poteaux ont été découpés puis intégrés dans quatre nouveaux projets : un boulodrome, un mur de soutènement sur le même site, la structure d'un pavillon low-tech (projet RebuiLT de l'EPFL)[9], et un abri à vélo (projet ConcReTe de la HEIA-FR). Chaque projet a impliqué des stratégies distinctes de réemploi des dalles et poteaux en béton, nécessitant également des plans de calepinage spécifiques pour assurer une déconstruction appropriée à ces nouvelles applications.

Trois de ces projets de réutilisation sont illustrés en Figure 76, bien que les spécificités de ces réutilisations ne soient pas incluses dans la présente étude. En l'absence de tels projets valorisant les dalles de béton réutilisables, celles-ci auraient été recyclées en granulats concassés.

Le taux de récupération de la structure en béton existante est de 25%. Ce flux est illustré par la flèche rouge inférieure sur l'illustration en Figure 75. Cela représente 585.5 m² de dalles et 69.4 m² de colonnes porteuses. Le reste, 75% de la structure, a été démolie et traité comme déchets valorisés de manière standard, par concassage et séparation du béton et des armatures.

Les dalles sont de 25 cm d'épaisseur au sous-sol et au rez-de-chaussée, et de 22 cm d'épaisseur au 1er et 2ème étage. Elles sont supposées armées à hauteur de 2% avec un acier de type III A selon la SIA 162[10] et une résistance $\sigma = 43\ MPa$ suite à la réalisation d'essais à la compression.

[9] https://rebuilt.cargo.site/
[10] Rapport d'étude de faisabilité de la démolition de dalles de précontraintes

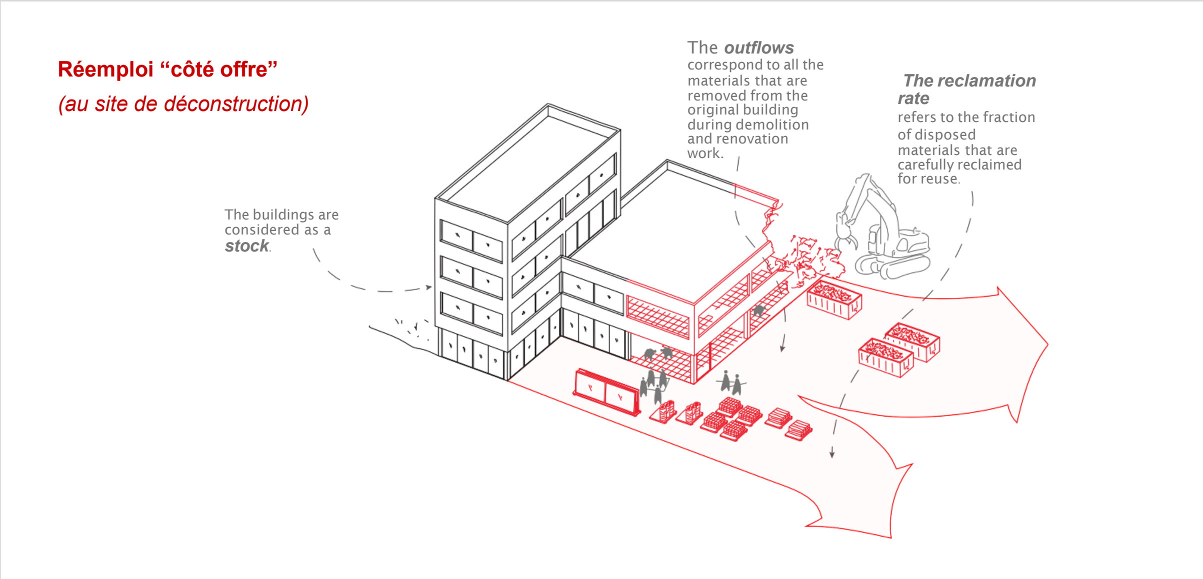


Figure 75: Représentation graphique d’un chantier de déconstruction avec le bâtiment considéré comme un stock de composants, les flux sortants des matériaux et le taux de récupération d’éléments pour du réemploi (graphique reproduit sur la base de Chaussebel et al 2023 [37])

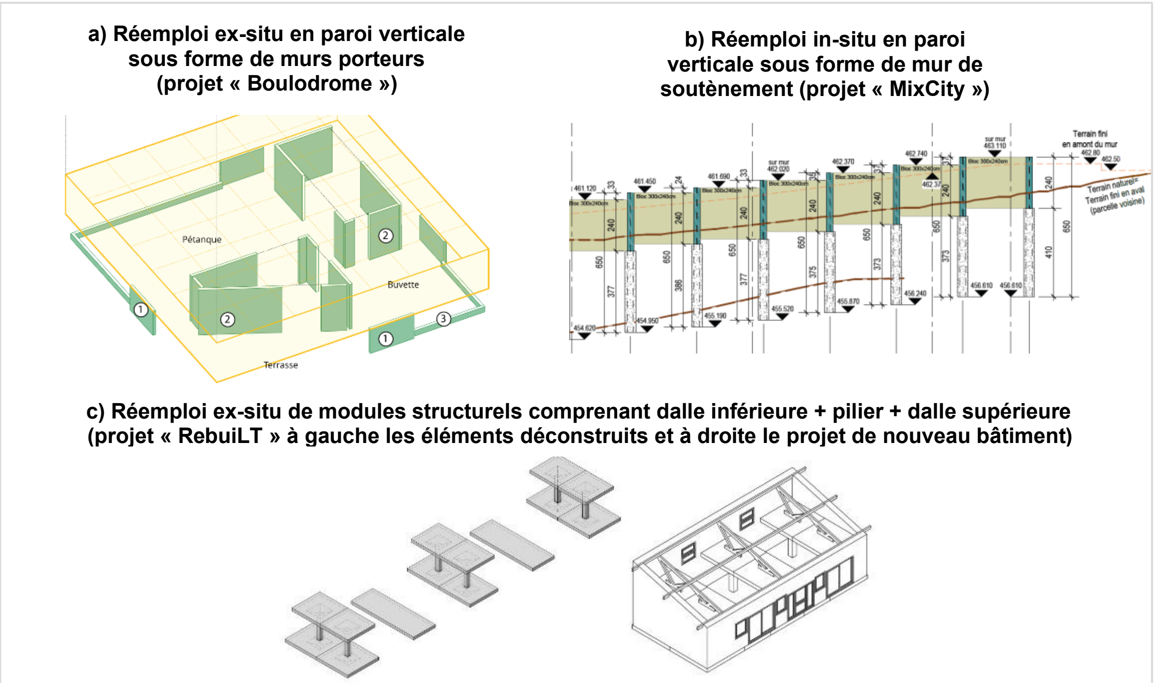


Figure 76 : Illustration des 3 projets de réutilisation des dalles de béton issues de la déconstruction du site de Renens (VD) ; le quatrième projet dénommé ConCreTe mené par la HEIA-FR n’est pas représenté

## 12.3 Procédure et méthodologie

La méthodologie utilisée pour calculer les émissions de GES de la chaîne logistique liée au réemploi du béton s'appuie sur celle développée dans le projet Reuse-LCA, tout en intégrant des spécificités propres aux opérations de déconstruction sélective des structures en béton.

### 12.3.1 Frontière du système

La Figure 77 illustre les périmètres de calcul de l'écobilan pour les différentes voies de démantèlement des structures en béton armé des bâtiments en Suisse. Le scénario conventionnel d'élimination du béton armé, tel que défini par la KBOB, implique une démolition (incluant la consommation de diesel par les engins de chantier), suivie d'une séparation des matériaux entre le béton et les armatures dans une unité de concassage. Environ 30% du béton restant est ensuite expédié en décharge.

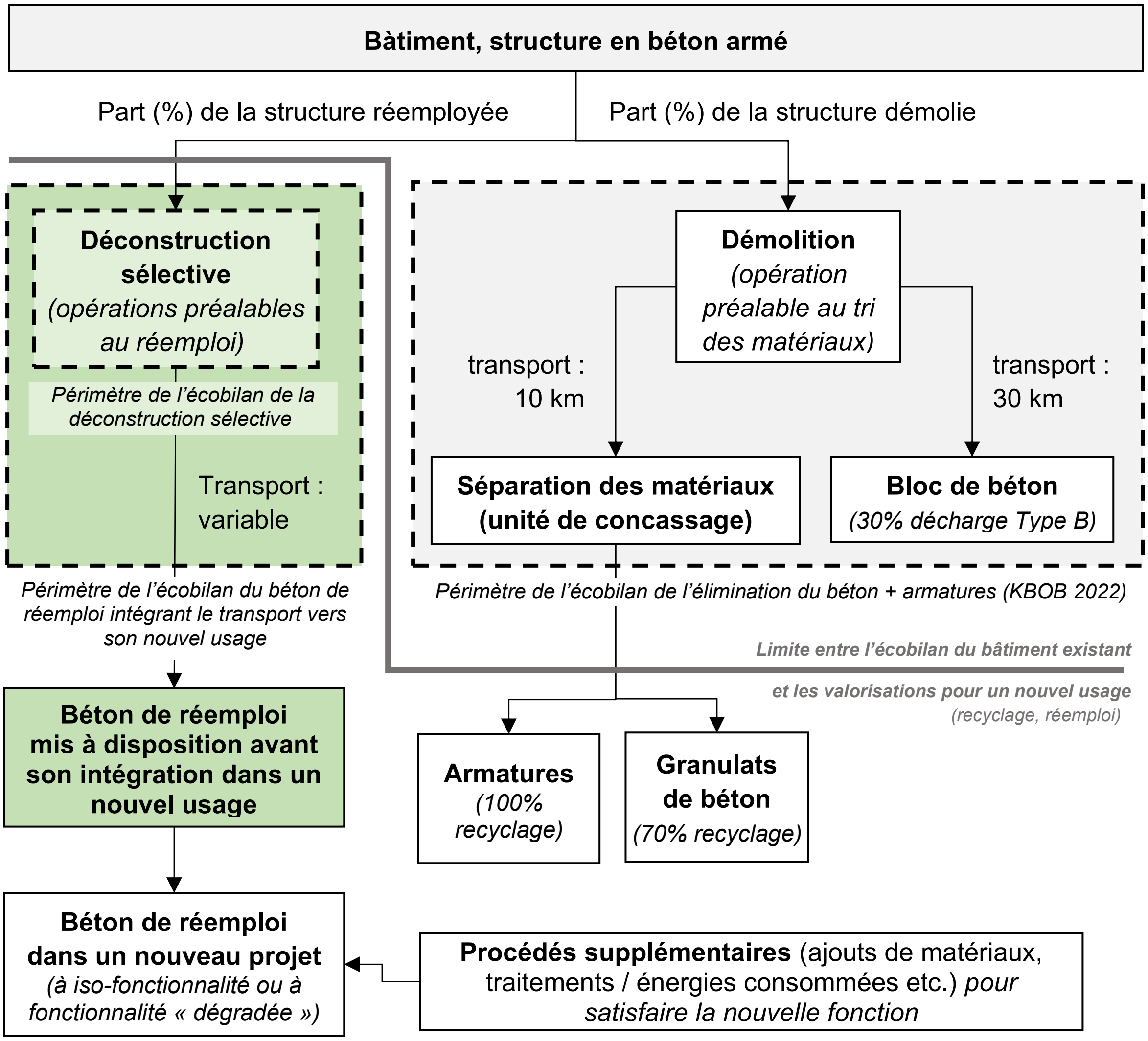


Figure 77: Description des étapes d'élimination du béton armé d'un bâtiment en reprenant les scénarios d'élimination standard de la KBOB 2009/1 :2022 (représenté à droite) et en y ajoutant le scénario de déconstruction sélective et réemploi tel que mis à œuvre dans l'étude de cas de Renens (VD) (à gauche) ; pour des raisons de clarté, ce graphique ne représente pas les petites fractions de béton après séparation en unité de concassage qui partent en mise en décharge de type B telles que modélisés dans la KBOB

Les règles d'allocation pour l'élimination des déchets sont établies conformément aux directives méthodologiques de la base de données du DETEC (*UVEK Database Protocol*) [40], ainsi qu'aux règles KBOB et à la norme SN EN 15804+A2. Le statut de fin de déchet intervient lorsqu'une opération de découpe sélective d'éléments dans le bâtiment existant est mise en place en vue d'un réemploi. Les éléments destinés au réemploi ne se voient attribuer aucun impact en termes d'émissions pour le bâtiment « donneur », comme illustré par la Figure 77. Par conséquent, les émissions de GES liées aux opérations de déconstruction sélective sont imputées au nouveau produit (béton de réemploi) pour ses nouvelles utilisations.

### 12.3.2 Détails des opérations et procédés pris en compte

Les procédés et activités associés à la déconstruction sélective (représenté par le périmètre vert clair dans la Figure 77) sont illustrés dans la Figure 78.

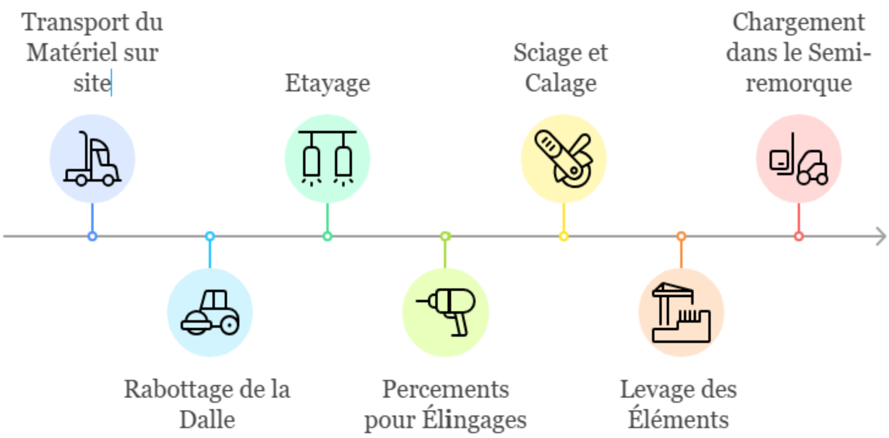


Figure 78: Opérations et procédés pris en compte dans l'écobilan de la déconstruction sélective avant la mise à disposition en sortie de chantier

*Transport du matériel sur site (étayage)*
Seul le transport du matériel d'étayage a été considéré, les autres matériels de chantier (scie, grue, etc.) sont exclus de l'étude. La distance entre le bâtiment à déconstruire et l'entrepôt de l'entreprise de démolition du matériel pour le transport du matériel d'étayage est connue (36 km). En l'absence de données précises sur le type de camion utilisé, un véhicule de 7,5 à 16 tonnes a été retenu par défaut pour le calcul des impacts.

*Rabotage de la chappe*
Une raboteuse électrique est utilisée pour retirer les revêtements de sol jusqu'à la surface supérieure des dalles, sans altérer la structure du béton sous-jacent. Cette étape permet d'isoler le béton brut en éliminant les couches superficielles (carrelage, mortier, etc.), sans générer de déchets de béton.

*Etayage des dalles*
Des systèmes d'étaiement sont déployés pour stabiliser la structure lors des découpes, compensant les modifications de la portance causées par le sciage des dalles et des armatures. Trois configurations sont utilisées :

- Etayage surfacique : 1 tonne/m$^2$ au sous-sol.
- Etayage linéaire : 2 tonnes/mètre linéaire au rez-de-chaussée et au sous-sol.
- Etayage ponctuel : aux quatre coins des éléments sciés.

Les étais, en acier galvanisé, pèsent entre 53 kg et 57 kg[11]. Une valeur moyenne de 55 kg a été prise en compte dans les calculs.

*Perçage de la dalle béton pour élingage*

Conformément au plan de déconstruction (Figure 79), quatre trous sont percés aux angles de chaque module de béton scié. Ces perforations permettent l'installation des élingues (câbles ou sangles de levage), essentiels pour soulever et transporter les éléments en toute sécurité. La méthode garantit une répartition homogène des charges lors du levage. Seule l'énergie de perçage est prise en compte dans l'écobilan. Les ajouts de matériaux (anneaux, plaque, écrous, etc.) et les pertes de matière liées au perçage de la dalle ne sont pas prises en compte.

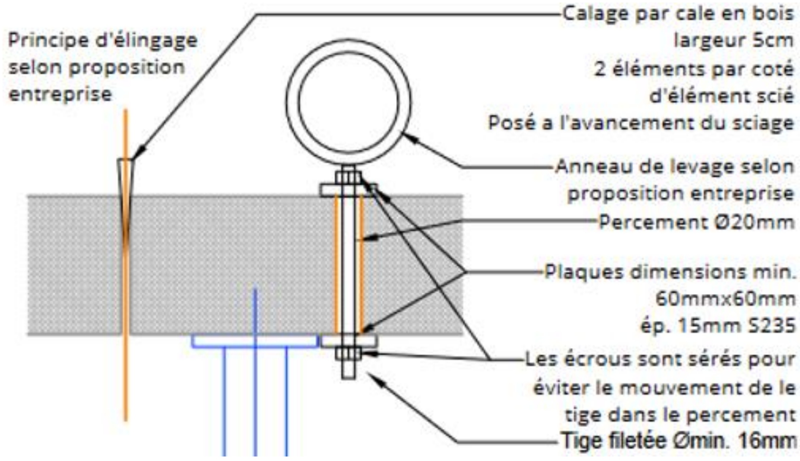


Figure 79 : Principe d'élingage des éléments en béton pour levage

*Sciage de la dalle béton suivant le plan de déconstruction*

L'intensité de sciage, exprimée en **mètres linéaires par mètre carré de dalle après sciage** (m/m²), est déterminée sur la base des dimensions des dalles spécifiées dans les plans de découpe ci-dessous (Figure 81 et Figure 82). Dans ce projet, les éléments en béton sont sciés aux dimensions exactes nécessaires pour être utilisées directement dans leurs nouvelles applications, sans besoin de sciages supplémentaires. La consommation d'énergie électrique pour le sciage est évaluée à partir des données fournies par l'entreprise responsable des travaux. Lorsqu'une découpe est réalisée à l'intersection de deux éléments, l'énergie consommée est répartie équitablement entre eux. De plus, le nombre de lames utilisées durant le processus de sciage est pris en compte, englobant leur production et leur élimination.

[11] https://biljax.com/product/heavy-duty-shoring-posts

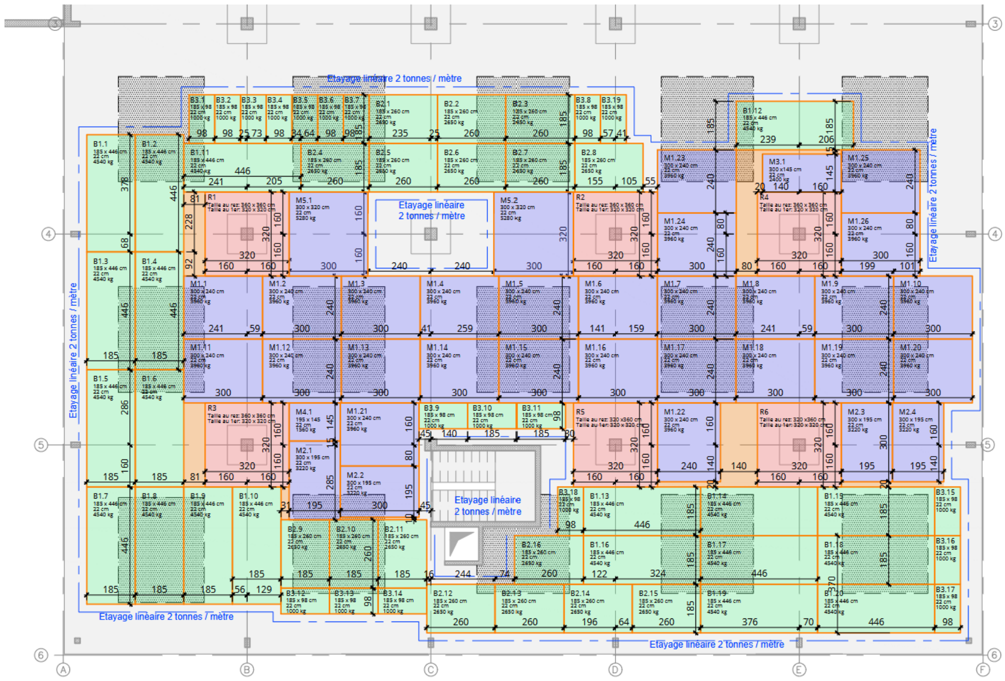


Figure 80 : Plan de découpe de la dalle sur RDC du bâtiment existant

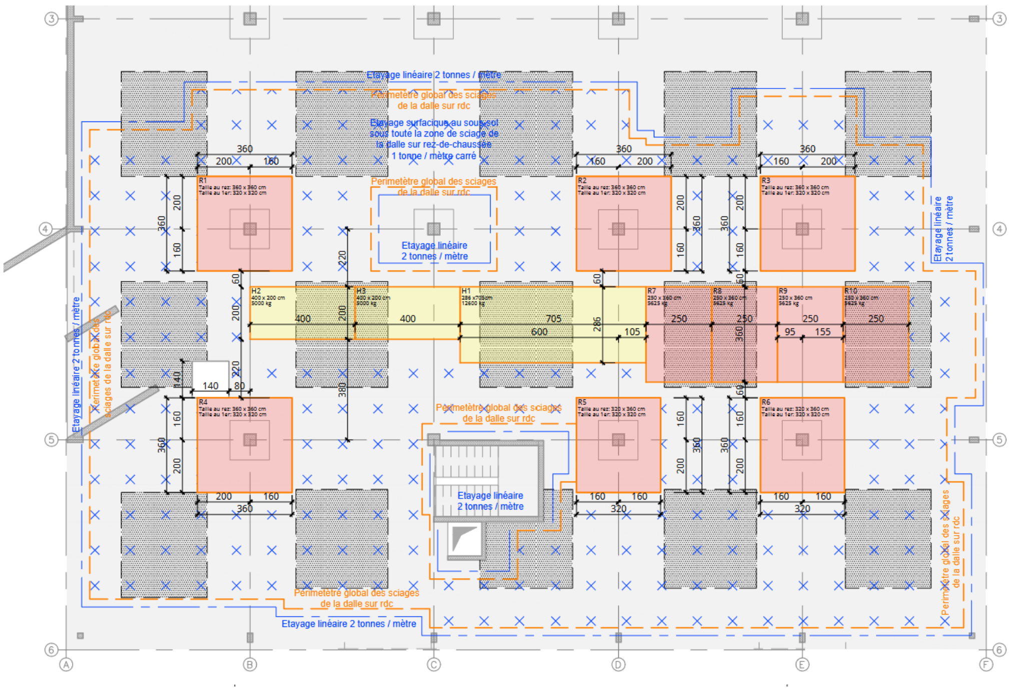


Figure 81 : Plan de découpe de la dalle sur sous-sol du bâtiment existant

### *Levage et chargement des modules de béton*

Après l'élingage et le sciage, les modules en béton sont soulevés une première fois pour être extraits du bâtiment et entreposés au sol. Ils sont ensuite levés une deuxième fois pour être chargés dans une semi-remorque. L'intensité énergétique de ces opérations dépend du type de machine utilisée, de la configuration du chantier, et des dimensions des dalles. Une estimation de la consommation d'énergie est effectuée proportionnellement au nombre de dalles manipulées. Cette consommation est calculée en se basant sur l'utilisation d'une chargeuse diesel de 100 kW, se déplaçant à une vitesse moyenne de 7,5 km/h.

### 12.3.3 Paramètres de calcul

Les différentes opérations de déconstruction sont modélisées à l'aide de formules de calcul et d'hypothèses détaillées dans le tableau ci-dessous.

Les données d'écobilan utilisées pour modéliser les différentes étapes sont les suivantes :

- Paramètres de sciage:
    - Puissance de la scie : 32 kW
    - Vitesse de découpe : Moyenne de 1,3 minutes/mètre linéaire (fourchette théorique : 0,5 à 2,9 min/m), définie selon Xiong et al. 2024 [41]
    - Facteurs influençant la vitesse : Épaisseur de la dalle, dureté du béton et taux d'armature.
- Remplacement des lames:
    - Hypothèse de durée de vie des lames provenant de Xiong et al. 2024 [41] : 22,5 m²/lame (m² de section sciée = longueur de sciage * épaisseur de la dalle).
    - Surface de découpe calculée à partir de l'épaisseur des dalles et des longueurs de découpe (Fig. 84-85), suivant une méthodologie standardisée (voir Fig. 1 du rapport annexe).
    - Emission de GES de la fabrication/élimination de la scie au diamant basé sur [41] : 19 kg $CO_2$-éq./kg selon Xiong et al [41]
- Rabotage:
    - spécifications techniques basées sur les données d'une référence commerciale[12]
- Etaiement, perçage pour élingage et levage :
    - les hypothèses sont reprises principalement de l'étude ACV du pavillon rebuiLT d'une thèse de master de l'EPFL de Zemp, 2023 [49].
    - Transport du matériel : Seuls les étais sont inclus dans le bilan (exclusion des autres équipements).
- Consommation énergétique : le mix consommateur CH de la KBOB est utilisé.

### 12.3.1 Indicateurs évalués

À l'instar des autres études de cas du projet Reuse-LCA, les émissions de GES fossiles ont été quantifiées. Les résultats obtenus sont également reproductibles pour les indicateurs environnementaux issus de la recommandation KBOB 2009/1:2022.

[12] https://www.protoumat.fr/catalogue/materiel-chantier-685/surfacage-beton-909/raboteuse-sol-rabot-beton-185/raboteuse-industrielle-electrique-gfp260-largeur-travail-240-golz-go-02853001014-79119.html)

Tableau 1: Paramètres de calcul de chaque opération de déconstruction des dalles en béton

| **Activité ou composant intégré.e à l'écobilan de la déconstruction sélective du béton** | **Unité** | **Paramètre de calcul** | **Paramètre fixe** | **Cette étude** | **Article de Xiong et al. 2024 en synergie avec Reuse-LCA** | **Etude EPFL (pavillon RebuiLT, un des projets « receveur » du cas d'études Renens/VD)** |
|---|---|---|---|---|---|---|
| **Transport (matériel d'étayage)** | [tkm] | nb : nombre d'étais | d = distance entre entrepôt et bâtiment (36 km avec camion 7.5-16 t ) m = masse d'un étai (55 kg) | *Nb*m*d*1.9* | Non inclus | Machines et étais : 36km, camion 3,5-7t. Grue de levage : 10 km, camion >32 t. |
| **Rabottage** | [kWh/$m^2_{dalle}$] | S : surface à raboter [$m^2$] | *v : vitesse de rabottage (61,6 $m^2$/h)* *p* : puissance de la machine (5.5 kW) (0,09 kWh/$m^2$) | $S/v * p$ | Non inclus | Non inclus |
| **Etayage** | [kg] | nb : nombre d'étais | m : masse d'un étai en acier galvanisé (55 kg) fp : facteur de perte d'étais lors du chantier (10%) | *fp*m*nb* | Non inclus | 55 kg/étais, 100 étais 10% de perte |
| **Perçage (pour élingage)** | [kWh] | Nb : nombre de trou à percer | t : temps de perçage (25s) p = puissance de la machine (2.4 kW) électricité réseau CH | *Nb*t*p* | Non inclus | Temps de perçage : 25s Puissance perçage : 2,4 kW élec réseau CH |
| **Sciage (éléments en béton)** | [kWh/l] | l : longueur de découpe [m] | e : énergie de sciage (0,7 kWh/m) *électricité réseau CH* | $l * e$ | *0,27 à 1,52 kWh/m générateur diesel* | 0,45 kWh/m *électricité réseau CH* |
| **Lames de sciage (remplacement)** | [kg] | $S_{dec}$ : surface de découpe | m = masse d'une lame (8,6 kg) d = densité de l'acier de la lame (7800 kg/$m^3$) ddv = durée de vie de la lame (22,5 $m^2_{découpé}$) | *($S_{dec}$/ f )*m*d* | lame de scie : ddv 15$m^2$ à 30 $m^2$, densité de 7850 et masse de 8,6 kg | Non inclus |
| **Levage (manutention avec une grue)** | kWh | *n* : nombre de levage [-] *l_h* : hauteur de levée [m] *d_h* : hauteur de descente [m] | *l_v* : vitesse de levage/descente (329 m/h) *r_v* : vitesse de rotation à 360° de la grue (3 mn) *p* : puissance de la machine (100 kW) | $n * (l\_h + d\_h + r\_v/60) * p/l\_v$ | Non inclus | Inclus |
| **Levage (manutention avec une chargeuse sur roues)** | kWh | *n* : nombre de chargement [-] *d* : distance transport [m] | *p* : puissance de la machine (100 kW) *v* : vitesse de déplacement de la chargeuse (7,5 km/h) | $n * d/1000 * p/v$ | Non inclus | Inclus |
| **Machines et outils (hors étaiement et hors maintenance des lames de la scie)** | - | - | - | Non inclus | Inclus (scie machine : 32 kg, 1000h de ddv lame de scie : ddv 15$m^2$ à 30 $m^2$) | Non inclus |

## 12.4 Résultats

### 12.4.1 Ecobilan des opérations de déconstruction

L'écobilan de chaque opération de déconstruction est présenté en Figure 82. Les résultats indiquent que l'étayage constitue la principale contribution aux émissions de gaz à effet de serre associées au réemploi des dalles en béton avec un taux de perte des étais sur chantier de 10 %. Cette étape représente une émission de GES de 14.6 kg $CO_2$-éq./$m^2$, soit 85 % de l'impact total. Cette forte contribution s'explique par la quantité d'étais perdus en place lors de la démolition et ne pouvant plus être réutilisés. L'émission de GES de leur fabrication, importante pour de l'acier galvanisé, est alors allouée à ce chantier de déconstruction.

Le remplacement des lames de sciage contribue à 10 % des émissions de GES, soit 1.7 kg $CO_2$-éq./$m^2$. Les autres postes d'émissions incluent :

- Le transport du matériel nécessaire aux opérations de déconstruction, avec 0.4 kg $CO_2$-éq./$m^2$
- Le rabotage, le levage et le sciage, chacune de ces opérations contribuant environ 0.1 kg $CO_2$-éq./$m^2$.

Le perçage, quant à lui, a un impact négligeable dans l'écobilan de la déconstruction et n'est pas visible sur le graphique.

Dans les sections suivantes, certains paramètres de calcul seront discutés, notamment leur variabilité sur les résultats des émissions de GES par m² de dalles découpées.

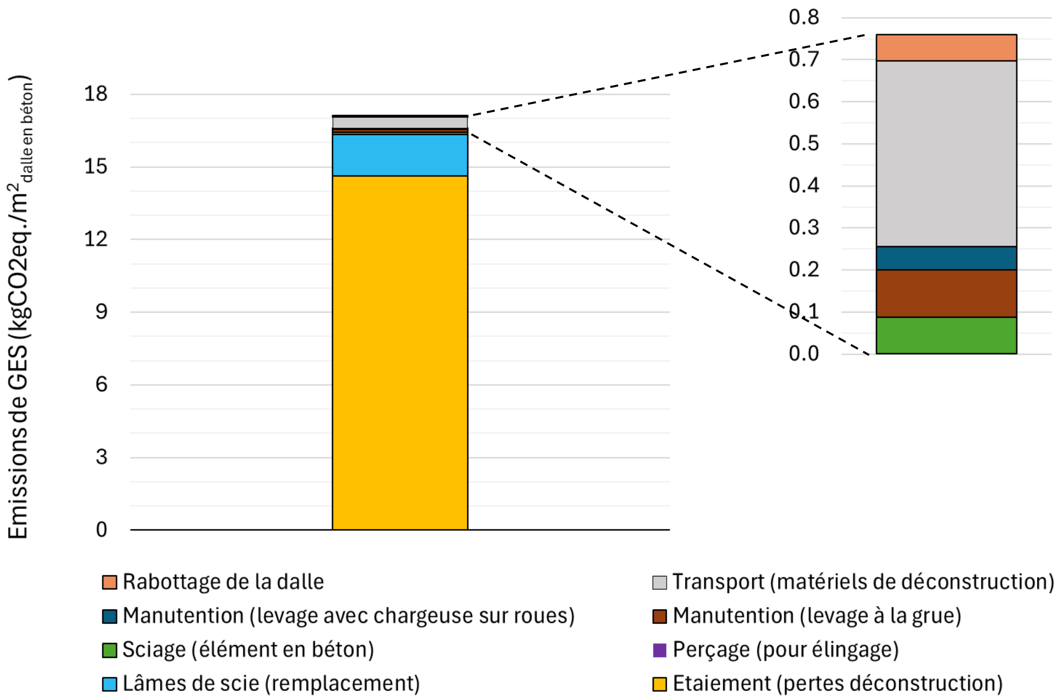


Figure 82 : Émissions de GES pour les différentes opérations de déconstruction par m² de dalle béton, en intégrant une hypothèse maximale sur le taux de pertes d'étais et les remplacements de lames de scie

### 12.4.2 Variabilité du taux de perte des étais

Dans la présente étude, l'hypothèse retenue est un taux de perte de 10 % de la masse d'acier d'étayage perdue lors de la démolition [49].

Par comparaison, sur les chantiers de construction classiques, les étais sont généralement réemployés plusieurs centaines de fois, avec un taux de perte inférieur à 1 %. La Figure 83 illustre la sensibilité des émissions de GES par m² de dalle au taux de réutilisation des étais. L'analyse révèle que leur impact s'atténue significativement au-delà de 100 cycles et devient négligeable.

Si l'approche de déconstruction actuelle nécessite laisser les étais en place, une méthode alternative permettrait de les récupérer en amont, prolongeant ainsi leur durée d'utilisation. Cette adaptation conduirait à un taux de perte conforme aux pratiques conventionnelles, compris entre 0,5 % et 1 %, soit 100 à 200 cycles de réutilisation, en cohérence avec la norme EN 1065 sur les systèmes d'étaiement et les observations empiriques sur les chantiers traditionnels.

À ce jour, aucune étude ne documente encore précisément l'impact des pertes dans le cadre de la déconstruction des structures en béton. Pour encadrer les résultats, deux scénarios ont été retenus :

- Scénario minimaliste (optimisé) : Perte d'étais de 1 % ce qui représente 4 kg $CO_2$-éq./m².
- Scénario maximisant (actuel) : Perte d'étais de 10 % ce qui représente 17 kg $CO_2$-éq./m².

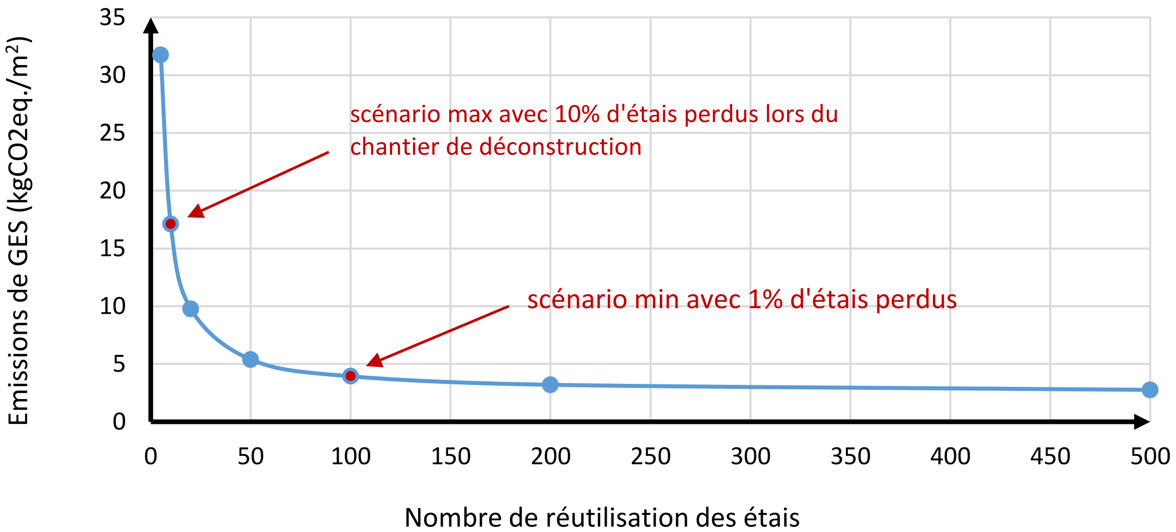


Figure 83 : Evolution des émissions de GES par m² de dalle réemployée en fonction du nombre de réutilisation des étais

### 12.4.3 Variabilité de l'intensité de découpe par dalle

La Figure 84 illustre la relation entre la superficie des éléments en béton après sciage et l'intensité de découpe (longueur de coupe par m²) pour différents projets. Les résultats révèlent que la longueur surfacique de découpe est multipliée par 2,2 entre une dalle de 20m² et une dalle de 2m². Cette augmentation entraîne une hausse proportionnelle de l'énergie nécessaire pour le sciage (par m²). Elle influence également l'usure des lames de scie et leurs remplacements, directement liée à la longueur totale de coupe.

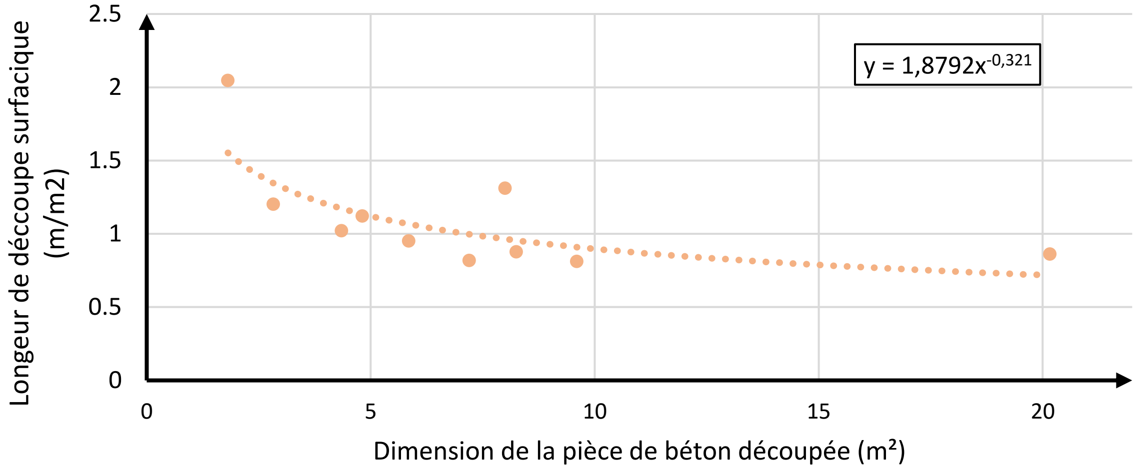


Figure 84 : Intensité de découpe surfacique en fonction de la dimension de la pièce

### 12.4.4 Variabilité des émissions de GES en fonction de la surface des dalles

Dans la section précédente, il a été mis en évidence que le sciage (énergie et usure des lames) est influencé par la dimension de l’élément, mais il ne s’agit pas du seul processus concerné ; le levage et le chargement des éléments est également fonction de la taille de l’élément. Cette relation est illustrée par la Figure 85, qui met en évidence la corrélation entre la surface des dalles et les émissions de GES associées à leur déconstruction. En raison de l’incertitude quant à la durée de vie des lames, trois scénarios ont été définis pour encadrer l'analyse :

| Scénario | Rythme de remplacement de la lame | Domaine d’application |
| --- | --- | --- |
| **Tendance de référence** | 22,5 m² de béton découpé (longueur * épaisseur) | Valeur médiane retenue comme base |
| **Tendance maximaliste** | 15 m² | Cas défavorable (usure accélérée) |
| **Tendance minimaliste** | 30 m² | Cas optimal (longévité maximale) |

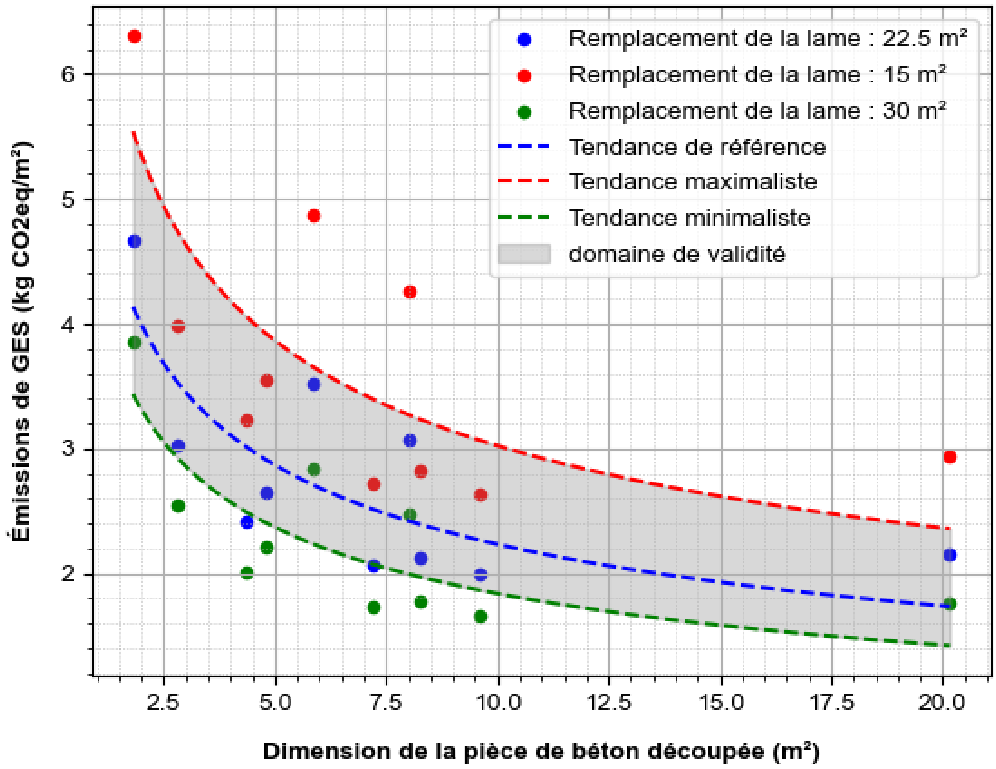


Figure 85 : Emissions de GES totales des étapes influencées par le format de la dalle (perçage + sciage + levage + chargement + usure des lames de scie) pour trois scénarios de durée de vie des lames de sciage (remplacement chaque 22.5 $m^2$, 15 $m^2$ ou 30 $m^2$ de surface de découpe)

L'émission de GES par m² de dalle diminue de façon non linéaire avec l'augmentation de sa surface. Cette diminution est particulièrement marquée pour les petites dalles (< 5 m²), comme le confirme l'étude de Xiong et al. [41]. Pour une dalle de 1,8 m², les émissions de GES sont 2× plus élevées que pour une dalle de 20 m² (entre 4 et 6 kg $CO_2$-éq./m² contre 2 à 3 kg $CO_2$-éq./m², respectivement).

Les trois hypothèses de remplacement des lames (tous 15 m², 22,5 m² ou 30 m² de béton découpé) montrent que l'usure des lames contribue significativement aux émissions pour les petites surfaces. Par ailleurs, l'écart d'émission entre scénarios s'atténue avec l'augmentation de la taille des dalles.

#### 12.4.5 Comparaison des émissions de GES : béton de réemploi vs béton neuf

La Figure 86 présente une comparaison des émissions de GES moyennes par $m^2$ de dalle entre :

- Dalle de béton de réemploi issue de l'étude de cas, acheminée à différentes distances par camion.
- Production et acheminement en camion d'une dalle de béton neuve : une dalle neuve de 22 cm livrée à 30 km. L'écobilan correspond à la donnée de béton sans armatures KBOB (ID 01.003) et d'acier d'armature (ID 06.003) avec un taux de ferraillage de 2%.

Les barres d'erreur intègrent la variabilité du taux de perte des étais (1 % à 10 %) et la durée de vie des lames (15 à 30 m², longueur * épaisseur).

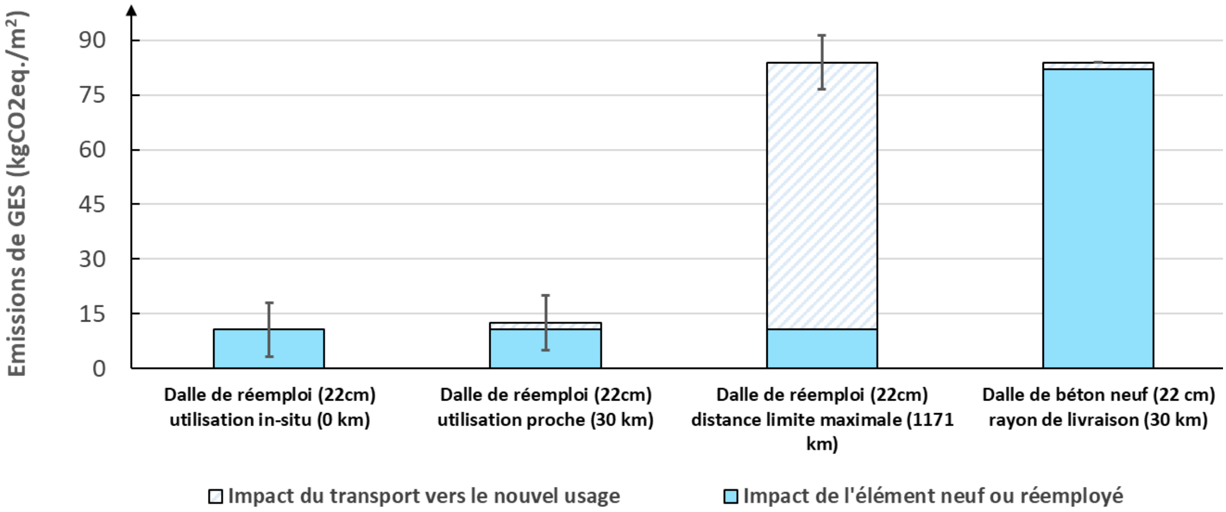


Figure 86 : Comparaison de l'émissions de GES par $m^2$ de dalle de béton réemployée et de béton neuf ; la barre d'erreur pour le béton de réemploi représente la variabilité associée au taux de pertes d'étayage (entre 1 et 10%) et du remplacement des lames (entre 15 et 30 $m^2$ de section découpé) ; l'absence de barre d'erreur pour le béton neuf signifie pas qu'il n'y a pas de variabilité associée au béton neuf mais celle n'est pas investiguée ici .

Les résultats excluant le transport (hachures bleues sur le graphe) montrent une réduction d'émission de GES de 82 % à 96 % pour les dalles de béton de réemploi par rapport à leurs équivalents neufs, avec respectivement entre 3 et 18 kg $CO_2$-éq./$m^2$ (moyenne 10,5 kg $CO_2$-éq./$m^2$) contre 80 à 90 kg $CO_2$-éq./$m^2$.

Le béton neuf coulé en place est généralement approvisionné dans un rayon inférieur à 30 km depuis les centrales de production en Suisse. En revanche, pour les dalles de réemploi, plusieurs scénarios de transport ont été étudiés : une réutilisation in situ (0 km), une réutilisation à proximité (30 km), ainsi qu'une distance maximale théorique où l'avantage carbone du réemploi s'annule par rapport au béton neuf. Cette distance critique, calculée à 1171 km, représente le seuil au-delà duquel les émissions liées au transport compensent entièrement les gains environnementaux du réemploi.

Cette analyse souligne l'importance stratégique de la localisation des projets receveurs : si le réemploi reste avantageux dans un périmètre régional (typiquement < 30 km), son bénéfice carbone s'amenuise progressivement avec l'éloignement, jusqu'à devenir négligeable au-delà de 1000 km — une distance peu réaliste en pratique, tant pour des raisons économiques que logistiques.

## 12.5 Conclusions et perspectives

Cette étude menée dans le cadre du projet Reuse-LCA apporte un éclairage sur la performance carbone de la collecte sélective d'éléments en béton destiné au réemploi. Les analyses, basées sur la méthodologie et les données de Reuse-LCA, ont utilisées les données d'un chantier de déconstruction à Renens (VD), et un des travaux menés en parallèle en lien avec le cas d'étude [49], et les travaux de modélisation des activités de sciage du béton [41].

Les émissions de GES sont directement corrélées à la longueur de découpe, avec un impact accru pour les petites dalles en raison d'un rapport surface/périmètre défavorable qui engendre une plus grande consommation de lames, d'énergie de sciage, et des manutentions plus fréquentes. Une optimisation du dimensionnement des éléments lors de la déconstruction permettrait de réduire significativement l'empreinte carbone par m².

L'analyse de contribution révèle que l'étaiement représente une part significative des émissions (85 %). En effet, des étais ont dû être déployés pour assurer le sciage et la collecte des dalles en toute sécurité, un taux de pertes a été considéré à 10 %. Le nombre d'étais à mettre en place et le taux de pertes dépendent pour beaucoup des caractéristiques de la structure du bâtiment et du chantier de déconstruction. Ainsi, pour d'autre projets de récupération de dalles en béton, la quantité d'étais perdus peut être différente, voire nulle, ce qui changerait fortement l'impact de la dalle de réemploi. Ce poste est donc à considérer avec attention pour une évaluation précise des impacts adaptée à chaque projet de déconstruction.

Concernant le sciage, le remplacement des lames de scie a une contribution aux émissions de GES plus importante que l'énergie consommée pour la découpe elle-même (10 % contre moins de 1 % des émissions). Bien qu'il y existe une variabilité associée à l'énergie de sciage (diesel ou électricité) et à l'utilisation d'étais selon les chantiers, la consommation de matériaux (étais et lames) peut se révéler bien plus impactante que la consommation d'énergie de toute l'opération de collecte.

À matériau équivalent neuf et hors transport, le réemploi des dalles de béton génère 82 à 96 % d'émissions en moins par rapport à un élément neuf en béton. Cependant, cet avantage s'amenuise avec la distance de transport, et est annulé après 1100 km d'acheminement en camion diesel. Ce seuil reste théorique et la limite de rentabilité économique du transport serait de toute manière atteinte bien avant. Elle montre toutefois que le réemploi conserve un intérêt environnemental même pour des distances régionales ou transfrontalières, par exemple entre Cantons voisins en Suisse.

Des limites subsistent dans cette étude :

- Activités omises : l'analyse pourrait être plus exhaustive en intégrant les activités telles que le transport des machines, ainsi que leur fabrication/élimination au prorata de leur durée d'utilisation sur chantier.
- Paramètres non considérés : l'intensité énergétique du sciage dépend de l'épaisseur du béton et de la densité d'armature en son sein. Des études complémentaires pourraient évaluer les différences de consommation de lame de scie et d'énergie en fonction de ces paramètres.
- Incertitudes sur des paramètres influents : cette étude montre que le remplacement des lames et la consommation et perte d'étais sont des facteurs influent dans l'écobilan. Des hypothèses simplificatrices ont été considérées pour inclure ces aspects. Des études complémentaires seraient nécessaires pour préciser des valeurs plus représentatives concernant la réutilisation des étais, leurs pertes sur chantier, la durabilité des lames de scie, et l'empreinte carbone de leur production.

**Equivalent fonctionnel neuf** : Comparer un élément de réemploi par rapport à son équivalent matériellement neuf est une hypothèse très simplificatrice dans le cas d'éléments structurels en béton. La comparaison du réemploi avec des solutions neuves doit être contextualisée selon l'usage final (dallage extérieur, mur porteur, etc.), en incluant les adaptations nécessaires p.ex dans des cas de réemploi avec une fonction structurelle (p.ex. ajout de câbles de précontrainte, de renforts métalliques). Pour un usage donné, ils existent également une diversité de solutions neuves avec des matériaux et des impacts différents. Des prochains travaux devraient évaluer ces différents scénarios pour mieux évaluer l'économie carbone d'un élément en béton de réemploi par rapport à des solutions neuves équivalentes en béton ou en d'autres matériaux. Finalement, le réemploi doit aussi être considérer de plus en plus comme une solution de conception parmi d'autres en la détachant du concept de « substitution » ou « d'évitement » par rapport à un équivalent neuf, l'objectif restant dans tout projet de bâtiment de réduire les émissions de GES liés à une construction ou transformation.

# 13 Appendix IV: adaptive reuse of windows frames in an existing building (Fayards) during an energy-related renovation (in french)

## 13.1 Introduction

Pour répondre aux attentes de la Confédération en termes de décarbonation, la rénovation du parc immobilier Suisse apparaît comme un sujet primordial. Cette rénovation du bâti existant permet notamment de réduire les consommations énergétiques des bâtiments. De nombreuses études sur le sujet de la rénovation ont souvent mis en avant le côté prioritaire du changement d'agent énergétique comme levier d'action pour décarboner le parc existant. Cependant, au fur et à mesure que le parc est décarboné sur l'usage (énergie d'exploitation), se pose la question des émissions de GES indirectes liés aux travaux de rénovation (matière / matériaux mis en œuvre). En effet, la nouvelle norme SIA 390/1 *« La voie climatique – bilan des émissions de gaz à effet de serre et de l'énergie dans les bâtiments »* publiée en 2025 précise que toute rénovation dispose d'un budget d'émissions de GES de 13 $kgCO_2e/m^2$/an pour la combinaison des phases de construction, d'exploitation et de mobilité lors d'une transformation. Pour la phase de construction, la valeur indicative donnée dans cette norme est de 5 $kgCO_2e/m^2$/an soit 300 $kg/m^2$ d'émissions de GES sur 60 ans de durée d'analyse du bâtiment après les travaux de rénovation. Dans ce cadre, différents leviers peuvent être actionnés en rénovation pour limiter ces émissions de $CO_2$-eq indirects pour les différents composants mis en œuvre dans une rénovation. Le réemploi fait partie de ces leviers qui permettent d'éviter les émissions indirectes au-delà des émissions directes liées au remplacement du producteur de chaleur.

La pertinence du réemploi pour des composants qui influencent la consommation énergétique du bâtiment reste donc ouverte et mérite d'être étudiée plus en détails. C'est notamment le cas des ouvertures comme les fenêtres. Plusieurs types de réemploi sont possibles : réemploi in-situ ou ex-situ de fenêtres (i.e., cadre + vitrage) ou réemploi adaptatif partiel du cadre et mise aux normes des vitrages. Ce réemploi adaptatif est un moyen très efficace de préserver des éléments en place et donc très simplement d'économiser des émissions de GES durant une transformation de bâtiment comme le représente la figure suivante.

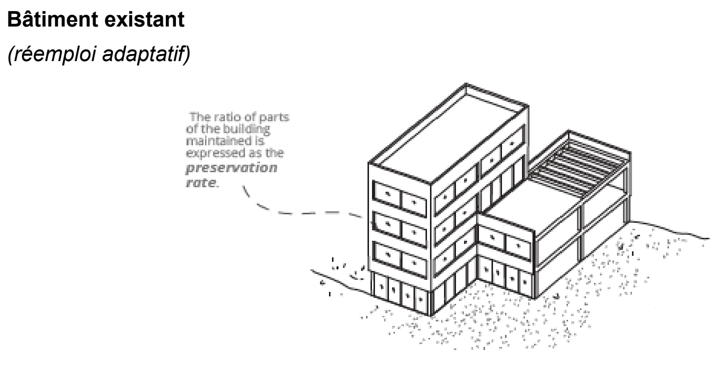


Figure 87: Représentation graphique d'un bâtiment existant pour lequel un réemploi adaptatif de sa structure et de ses composants d'enveloppe peuvent notamment être maintenus dans l'ouvage (graphique reproduit sur la base de Chaussebel et al 2023 [37]

Le réemploi in-situ ou ex-situ reste très rarement mis en œuvre à iso-fonctionnalité en raison des exigences thermiques actuelles pour les fenêtres d'enveloppe en neuf comme en rénovation. Un seul exemple dans les études de cas analysées dans Reuse-LCA concernent la valorisation de fenêtres neuves non conformes qui ont pu être réemployées dans le projet ELYS. Mais cet exemple n'est pas réellement un réemploi au sens strict. Finalement le réemploi adaptatif partiel du cadre et mise aux normes des vitrages est le plus prometteur. Appliquée de longue date aux bâtiments patrimoniaux, il permet d'économiser des émissions de GES liées à la fabrication d'un cadre neuf et d'améliorer les valeurs U des fenêtres après intervention. Cependant, selon qu'il s'agisse d'une rénovation complète ou partielle et en fonction des labels visés, le maintien de l'ancien cadre n'est pas toujours envisageable.

Peu d'études existent en Suisse sur ce sujet. La plus récente, menée en parallèle du projet OFEN Reuse-LCA, est l'étude FenSanReuse[13] coordonné par la Haute école spécialisée du nord-ouest de la Suisse (FHNW) sur mandat également de l'OFEN[14]. Le projet FenSanReuse se concentre sur la durabilité et la réutilisation des cadres de fenêtres existants, minimisant ainsi les déchets de construction et les coûts environnementaux associés à la fabrication de nouveaux cadres. Certaines données du rapport FenSanReuse sont par ailleurs utilisées et comparées dans cette étude du projet Reuse-LCA.

**Objectif de l'étude :**
Cette analyse a pour objectif de quantifier les émissions de GES qui sont économisées par le maintien en place de cadres de fenêtres dans un bâtiment. Puis, de vérifier sur l'écobilan complet du bâtiment, si le réemploi adaptatif des cadres de fenêtres permet de minimiser les émissions de GES globales et du domaine « Construction » au sens de la SIA 390/1 et dans quelles situations. Les calculs seront conduits pour différents scénarios de rénovation de fenêtres (i.e. cadre + vitrage) en tenant compte à la fois des émissions de GES direct (liées à l'énergie de chauffage) et émissions de GES indirectes (liées à la fabrication et/ou réemploi des cadres et vitrages).
Une étude de cas réelle en cours de planification servira de base aux calculs. Elle a été mise à disposition et cofinancée par notre partenaire SIG-éco21 à Genève.

## 13.2 Procédures et méthodologie

### 13.2.1 Type de réemploi et écobilan

La rénovation du projet Les Fayards (GE) correspond à un réemploi adaptatif du bâtiment et une réflexion a été menée sur la préservation des cadres de fenêtres.
L'écobilan est réalisé selon la méthodologie Reuse-LCA et les données de la recommandation KBOB 2009/1:2022. Comme les cadres et les fenêtres sont des éléments actifs, l'écobilan intègre à la fois la fabrication et l'élimination des composants (cadres, vitrages) ainsi que l'écobilan de l'énergie consommée par le bâtiment selon les règles en vigueur en Suisse (SIA 380/1, SIA 390/1).

### 13.2.2 Cas d'étude

Le cas d'étude est composé d'un ensemble de 5 bâtiments datant de 1990 à 1995, situé dans le canton de Genève (GE), pour une surface de référence énergétique (SRE) totale de 25'545 m$^2$ dont 95 % correspondant à une affectation résidentielle collectif. Le reste de la SRE est partagée entre plusieurs affectations (salle des fêtes, piscine et commerce). Le facteur de forme du cas d'étude est de 1.03 et le taux de vitrage moyen est de 16 % calculé sur la surface totale de façade et de toit. Les fenêtres initiales sont en cadre bois métal de modèle MEKO 32[15] du fabricant Berther AG et munis d'un double vitrage à lame d'air sec sans couche de traitement en surface. Les besoins de chaleur avant mesures de rénovation sont de 54 kWh/m$^2$ (bilan thermique SIA 380/1) avec des bâtiments chauffés au moyen de

[13] https://www.aramis.admin.ch/Default?DocumentID=73278&Load=true
[14] https://www.aramis.admin.ch/Texte/?ProjectID=51620&Sprache=fr-CH
[15] https://www.bertherfenster.ch/userfiles/downloads/Meko-32-Prospekt.pdf

chaudières à gaz. En 2024, ils font l'objet d'une rénovation globale afin de répondre aux exigences très haute performance énergétique (THPE) du canton de Genève. Plusieurs actions de rénovation de l'enveloppe du bâtiment sont en cours de définition pour répondre à ces critères, dont la rénovation des menuiseries.

*Choix de modélisation :*
Sur les 5 bâtiments de l'étude, seuls les bâtiments A, C et E sont modélisés car le bâtiment B est identique au A et le D au C. Par pondération de la SRE, les résultats de l'étude correspondront à l'ensemble des bâtiments de l'étude de cas.
Les bilans thermiques (selon SIA 380/1) et les écobilans sont réalisés pour plusieurs scénarios de rénovation qui comprennent des actions sur les fenêtres et sur le remplacement du système de chauffage (passage à un chauffage par pompe à chaleur air-eau ou saumure-eau et sonde géothermique). Les PAC sont supposées correspondre deux types de coefficient de performance annuel (COPA) : faible et élevé pour traduire les différents niveaux de performance de l'enveloppe thermique entrainant des niveaux de température de distribution de chaleur plus ou moins élevés (voir au point 13.2.5).

### 13.2.3 Périmètre de calcul

Le Tableau 2 présente les éléments pris en compte dans le périmètre de calcul de l'écobilan. L'analyse se focalisant sur le réemploi adaptatif des cadres et en raison de la phase du projet, les autres mesures de rénovation de l'enveloppe (toiture, façade, plancher bas) permettant de répondre aux exigences du label THPE du Canton de Genève, équivalent aux exigences Minergie-P® ne sont pas quantifiées plus en détails d'un point de vue de l'écobilan.

Tableau 2 : Eléments pris en compte dans le périmètre de calcul

| Ecobilan du bâtiment | Aspects | Prise en compte dans le périmètre de calcul |
|---|---|---|
| **Indirecte (matériaux)**<br>*Domaine « Construction » selon SIA 390/1* | Structure | Non |
| | Enveloppe du bâtiment | Rénovation des menuiseries : oui<br>Autres mesures sur l'enveloppe : oui *(mais non évalué dans cette étude car scénario identique entre les variantes comparées)* |
| | Aménagements intérieurs | Non |
| | Installations techniques | Non |
| **Directe (énergie opérationnelle)**<br>*Domaine exploitation selon SIA 390/1* | Chauffage | Oui |
| | Eau chaude sanitaire | Non |
| | Electricité (éclairage, ventilation, autres usages) | Non |

### 13.2.4 Choix des scénarios (avec et sans réemploi adaptatif)

Différentes variantes ont été étudiées pour comparer les émissions de GES selon les choix de rénovation des fenêtres. Dans les variantes de cadre maintenu en place (réemploi adaptatif), seul le changement des anciens joints par de nouveaux joints est pris en compte, les cadres restant en place et ne sont pas démontés. La Figure 88 présente les différentes variantes de rénovations à partir du cas initial V0 avec les fenêtres existantes.

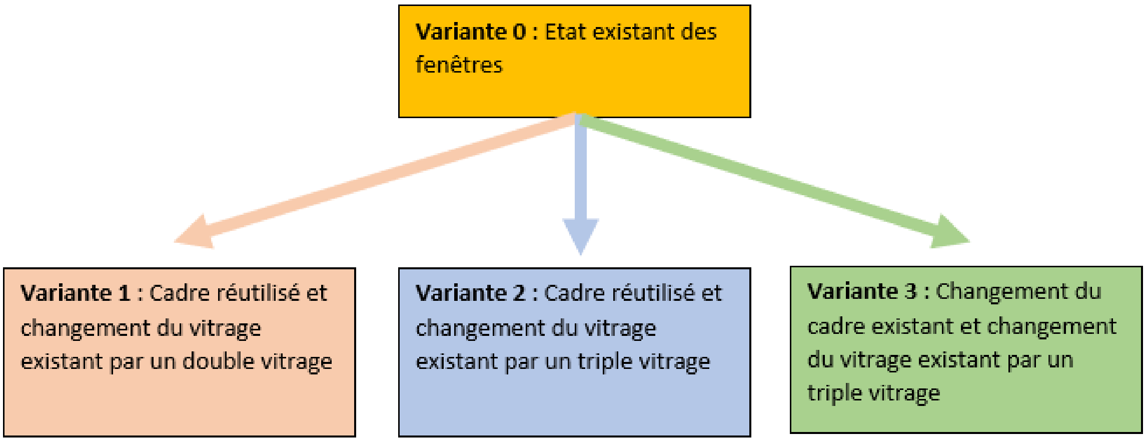


Figure 88: Variantes étudiées

Dans les variantes 1 et 2 le cadre existant est conservé avec un remplacement du vitrage respectivement par du double vitrage et du triple vitrage. Un remplacement des joints sera réalisé pour les variantes 1 et 2. Dans le cas présent, le remplacement des joints est exigé afin de répondre aux normes acoustiques[16]. La variante 3 correspond à un changement total de la menuiserie par une fenêtre triple vitrage avec un cadre en bois-métal. Le triple vitrage étant plus lourd que le double, un renforcement du cadre existant est nécessaire en variante 2.

### 13.2.5 Hypothèses et données

Les valeurs utilisées pour les propriétés thermiques sont issues de trois sources différentes : entreprise de fenêtre partenaire (Wider SA) et bureau d'ingénieurs, expertises internes HEIG-VD et valeurs du rapport OFEN FenSanReuse[17] notamment pour la valeur Uf du cadre à conserver. Le croisement de ces sources amène une plage de possibilité sur cette valeur comprise entre 1.4 et 2 W/m$^2$.K. La valeur retenue est 1,9 W/m$^2$.K suite à l'expertise des partenaires du projet. Pour les variantes 1, 2 et 3, les données caractéristiques sur les fenêtres sont issues de fiches techniques. L'ensemble des données est récapitulé dans le tableau ci-dessous.

Tableau 3: Récapitulatif des données techniques pour V0, V1, V2 et V3

| | **V0** | **V1** | **V2** | **V3** |
|---|---|---|---|---|
| Type de vitrage | Double, lame d'air, sans traitement de surface | Double, lame d'argon, avec traitement de surface | Triple, lame d'argon, avec traitement de surface | Triple, lame d'argon, avec traitement de surface |
| U vitrage (W/m$^2$.K) | 2,8 | 1,1 | 0,7 | 0,7 |
| Facteur g | 0,72 | 0,55 | 0,5 | 0,5 |
| Transmission lumineuse (%) | 0,8 | 0,77 | 0,69 | 0,69 |
| Réflexion Lumineuse (%) | 0,12 | 0,11 | 0,15 | 0,15 |
| Type de verre | X | VSG | VSG | VSG |
| Masse du vitrage (kg/m2) | X | 51 | 75 | 75 |

[16] L'étude de cas servant à cette analyse se situe à proximité d'un aéroport (Genève)
[17] https://www.aramis.admin.ch/Texte/?ProjectID=51620&Sprache=fr-CH

| | | | | |
|---|---|---|---|---|
| Pont thermique PSI | 0,7 | 0,06 | 0,05 | 0,037 |
| U cadre (($W/m^2.K$) | 1,9 | 1,9 | 1,9 | 1,1 |
| Type de cadre | Existant | Existant | Existant | Bois-métal |

La durée de vie prise en compte pour les fenêtres est de 30 ans. La réduction d'émissions de GES annuelle grâce à la diminution des besoins de chauffage et par le changement de producteur de chauffage sera calculée pour cette période.
Concernant les joints, d'après l'offre faite par l'entreprise de fenêtre, la mise en place de trois joints en caoutchouc vient accompagner le remplacement de fenêtre dans les trois scénarios de rénovation :

- un joint en néoprène sur le périmètre du vitrage intérieur et extérieur
- un joint de battue sur le périmètre du cadre
- un joint phonique sur le périmètre du cadre

Les masses linéiques des joints sont issues de fiches techniques et diffèrent en fonction du type de joint. Pour les joints sur le périmètre, la masse linéique a été estimée à 33 g/m et pour le joint de battue et le joint phonique à 73 g/m. La surface totale de fenêtre est de 4'437 $m^2$ réparti sur 1'128 fenêtres sur les 5 bâtiments, avec un pourcentage de cadre moyen de 19,9%. Les longueurs totales de joint en néoprène, de battue et phonique sont respectivement de 25 964 m, 8 626 m et 8 626 m. Concernant la masse surfacique des cadres existants, elle est estimée[18] à 21,9 $kg/m^2_{cadre}$ pour une surface totale de cadre de 831 $m^2$ sur la totalité du cad d'étude.

Concernant le COPA des deux PAC utilisés comme référence dans notre étude afin de définir le niveau de performance de l'enveloppe thermique, ils seront respectivement de 2.7 et 5.3 selon la PAC choisie.

## 13.3 Résultats

### 13.3.1 Emissions de GES indirecte

Le Tableau 4 montre les émissions de GES de la fabrication et de l'élimination des différents types de cadres de fenêtre ainsi que la conservation avec remplacement des joints d'un cadre existant selon le cas d'étude. Sans surprise, le cadre conservé à une valeur très faible (1.8 kg $CO_2$-eq./$m^2_{Fenêtre}$) bien en deçà du cadre bois-métal neuf à 58.6 kg $CO_2$-eq./$m^2_{Fenêtre}$ soit -97% de réduction d'émissions de GES. Les autres valeurs de cadres de fenêtre sont reportées également pour information.

Tableau 4 : Emissions de GES des différentes technologies de cadre par m² d'ouverture de fenêtre (source KBOB)

| | **Cadre conservé*** | *Cadre bois* | *Cadre PVC* | **Cadre bois-métal** | *Cadre aluminium* |
|---|---|---|---|---|---|
| Emission de GES fabrication + élimination (kg $CO_2$-eq./$m^2_{fenêtre}$**) | 1.8 | *36.2* | *53.2* | 58.6 | *132* |
| ** constitué uniquement par l'impact des nouveaux joints*<br>*** m² d'ouverture de fenêtre* | | | | | |

**Ces valeurs sont ensuite ramenées par m² de SRE et additionnées avec les autres composants de la fenêtre.** Selon le Tableau 5, la rénovation de la menuiserie représente entre 0.36 $kgCO_2$-eq/$m^2$/an et 0.54 $kgCO_2$-eq/$m^2$/an d'émissions de GES selon la variante choisie.

A partir de la valeur indicative de la nouvelle norme SIA 390/1 pour une transformation (5 $kgCO_2$-eq/($m^2$.an),) les émissions de GES des fenêtres sur ce bâtiment représentent entre 7% et 11% du budget carbone des travaux de la rénovation pour les scénarios V1 et V3, V2 étant situé au milieu avec

[18] Ökobilanz von Holzfenstern und Holztüren, energie schweiz, 2020

9%. Si l'on analyse plus précisément la part du nouveau cadre neuf dans l'écobilan de la fenêtre, on constate qu'il représente 13% des émissions de GES de la fenêtre, ce qui est bien moins important que la part du vitrage. Il reste alors à vérifier si le maintien du cadre existant permet d'obtenir des performances thermiques aussi bonnes qu'un cadre neuf pour avoir globalement un gain d'émissions de GES ou a minima une équivalence sur les domaines « Construction » et « Exploitation » de la SIA 390/1.

Tableau 5 : Récapitulatif des émissions de GES des éléments de la fenêtre pour les trois variantes de rénovation

| | **Emissions de GES** *($kgCO_2$-eq./$m^2_{SRE}$.an)* | | |
|---|---|---|---|
| **Variante** | V1 | V2 | V3 |
| **Vitrage** | 0.357 | 0.463 | 0.463 |
| **Cadre** | - | - | 0.071 |
| **Joints** | 0.007 | 0.007 | 0.007 |
| **Total** | **0.364** | **0.470** | **0.541** |

En termes de déchet, le remplacement du cadre induit 18,2 tonnes de déchets directs et 25,4 tonnes de déchets indirects soit au total 43,6 tonnes de déchets. Cela représente 1,7 kg/$m^2_{SRE}$ de déchets.

### 13.3.2 Bilan thermique des scénarios

Le bilan thermique de chaque variante a été réalisé à partir d'un modèle thermique de bâtiment de référence simulé sur le logiciel Lesosai en phase SIA 31 (avant-projet). La Figure 89 présente les besoins de chauffage du bâtiment exprimé à l'aide du besoin de chaleur ($Q_h$).

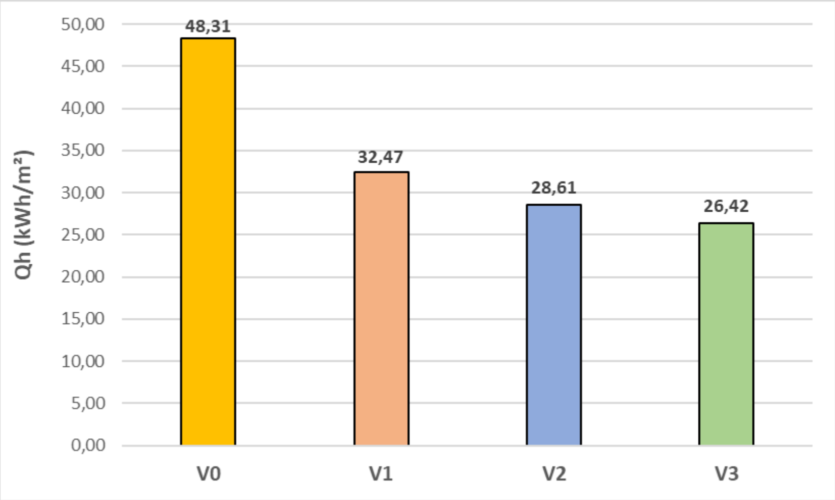


Figure 89 : Evolution du bilan thermique en fonction de la variante de rénovation des menuiseries

Le passage de V0 à V1 permet de réduire de 33% les besoins de chauffage. Entre les variantes de rénovations, la diminution du Qh est moins importante avec respectivement une baisse de 0.9 kWh/m$^2$ et 1.2 kWh/m$^2$ entre V1 et V2 et entre V2 et V3. Toutes les variantes de rénovation des menuiseries permettent d'améliorer le bilan thermique par rapport à la variante de référence (V0).  Le remplacement intégral du cadre avec triple vitrage (V3) apporte la meilleure amélioration des performances thermiques de l'enveloppe.

Ces résultats montrent le potentiel de diminution important sur les besoins de chaleur liée au simple fait de rénover la menuiserie, quel que soit la variante de rénovation. Les exigences légales (GE) en matière de rénovation et les critères pour l'obtention du label THPE sont respectés pour les trois scénarios de rénovation avec un $Q_h$ inférieur à 35 kWh/m$^2$ sur la partie bilan thermique.

#### 13.3.3 Emissions de GES totale (indirecte + directe) des scénarios de rénovation

A partir des résultats précédents d'écobilans des travaux de rénovation (maintien ou remplacement des cadres et remplacement des vitrages) et du bilan thermique des scénarios de rénovation, l'écobilan global des émissions de GES directes et indirectes a été calculé.
La Figure 90 montre une analyse comparative de l'émission de GES totale (émission directe et indirecte combinées) de chaque scénario de rénovation des fenêtres V0 à V3. Une variation du système de chauffage est ajoutée à ces scénarios, à savoir une PAC COPA 2,7 et une PAC COPA 5,3). L'analyse des résultats est la suivante :

- **Cas de la PAC avec COPA 5,3 (en vert)** : L'émission de GES totale diminue de 12 % entre la variante V0 (1.69 kg $CO_2$-eq./m$^2$.an) et la variante V1 (1.49 kg $CO_2$-eq./m$^2$.an). Elle est similaire dans les variantes V1, V2 et V3 avec une différence de seulement 2 % (entre 1.49 kg $CO_2$-eq./m$^2$.an et 1.46 kg $CO_2$-eq./m$^2$.an). Cela suggère que l'essentiel de la décarbonation est atteint dans la variante V1 où le cadre est conservé avec double vitrage, tandis que les variantes V2 et V3 apportent une amélioration négligeable. Entre V2 et V3, le gain sur le CO2 émis sur l'énergie d'exploitation (émissions directs) compensent parfaitement le CO2 émis liée au nouveau cadre (émissions indirects). Il n'y a donc pas de bénéfice à changer le cadre et cela permet d'éviter 43,6 tonnes de déchets.
- **Cas de la PAC avec COPA 2,7 (en bleu) :** les réductions relatives et absolues d'émission de GES totale liées à chaque variante par rapport à la variante V0 sont plus importantes que dans le cas avec une PAC avec COPA 5.3. L'émission de GES totale La variante V1 induit une diminution d'émission de GES de 20 % par rapport à V0. Les variantes V2 et V3 diminuent encore les émissions de respectivement 5 % et 8 % par rapport à V1. Le gain sur les émissions directs est supérieur au CO2 émis par le nouveau cadre entre V2 et V3. Le changement de cadre est donc l'option la plus efficace environnementalement parlant.

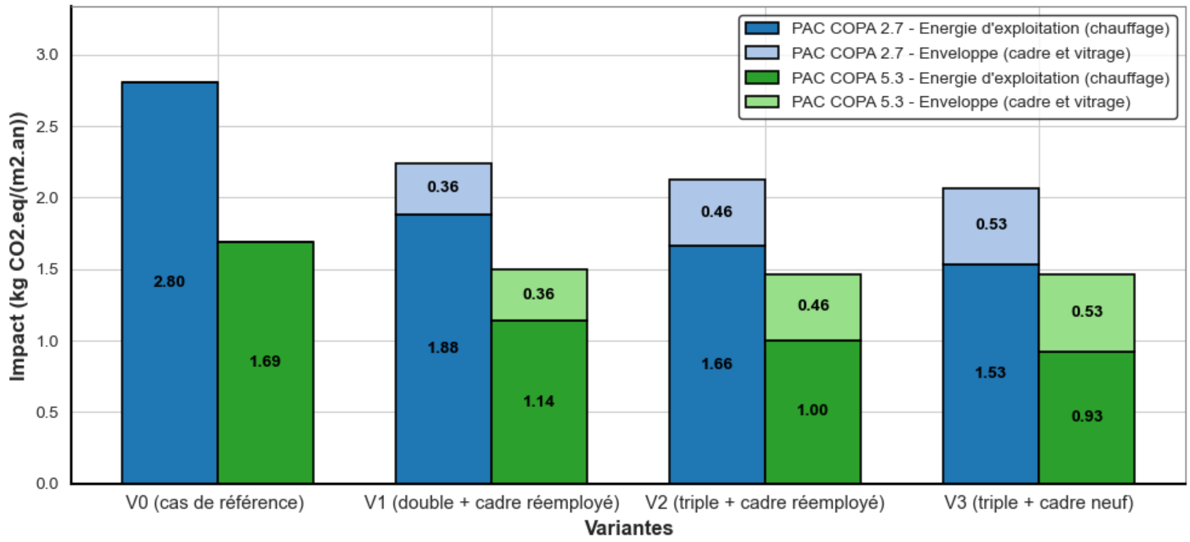


Figure 90 : Emissions de GES des différents scénarios pour deux types de PAC couvrant les besoins de chauffage

Les résultats démontrent ainsi la pertinence d'un réemploi du cadre en fonction de la configuration du bâtiment et notamment en fonction du producteur de chaleur. En utilisant les émissions carbones pour de l'électricité certifié correspondant à un mix énergétique très faible, les écarts entre les deux types de PAC traduisant le niveau de performance de l'enveloppe tendent à se réduire, avec un CO2 indirect lié à la conservation du cadre qui prend de l'importance en proportion à mesure que l'agent énergétique se décarbone.
Il n'est toutefois pas possible de comparer directement ces résultats à ceux de l'étude OFEN FenSanReuse[19] menée en parallèle, en raison d'hypothèses divergentes concernant le cadre de fenêtre de référence. En effet, dans notre étude, la différence de performance thermique entre le cadre existant et le cadre neuf (ΔUf) est de 0.8 W/(m²·K), alors qu'elle est de 0.2 W/(m²·K) pour la variante « Renovationfenster » et de 0.4 W/(m²·K) pour la variante « Fensterersatz Kunststoff » dans l'étude FenSanReuse. Ces différences seront discutées plus en détail dans la section 13.4, afin de mettre en perspective des deux approches.

### 13.3.4 Analyse de contribution de l'émission de GES totale

Afin de quantifier la contribution à l'émission de GES totale de chaque élément de la phase de construction, d'exploitation et de démantèlement, une analyse de contribution a été réalisée. La Figure 91 met en évidence les différents postes d'émission sur le cycle de vie d'un m² de SRE du bâtiment pour la variante V3 avec un chauffage sur PAC géothermique (COPA 5.3).

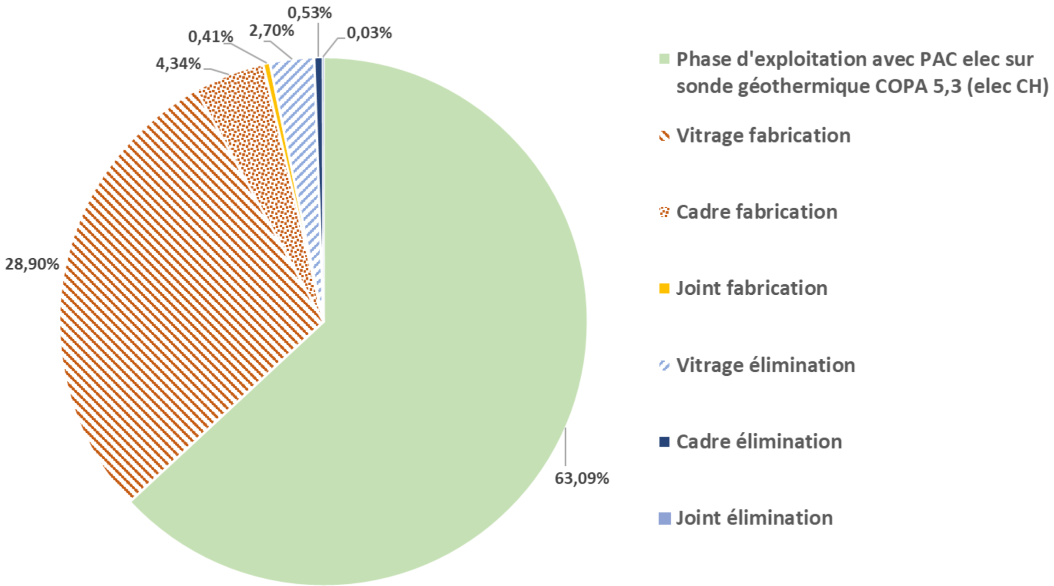


Figure 91 : Graphique de la répartition des émissions de GES du cas d'étude de la variante 3 avec une PAC haute performance sur sonde géothermique

Même avec un moyen de chauffage très efficient d'un point de vue émission de GES, la phase d'exploitation reste le principal poste d'émission de GES avec 63,1 %. A noter ici que les émissions de GES pour la phase d'exploitation sont calculées sur les besoins de chaleur utile du bâtiment. La fabrication du vitrage représente le deuxième poste avec 28,9 % des émissions totales. Les autres postes d'émissions de GES, notamment la fabrication et l'élimination des joints ou encore l'élimination du cadre, sont considérées comme secondaires avec moins de 0,6 % des émissions de GES totales. Le cas de figure présenté ci-dessus correspond à la variante où la phase d'exploitation est la moins prédominante. La part des émissions liée à ce poste dans toutes les autres variantes sera donc plus élevé.

Il faut bien préciser que la part du cadre dépendra du type du cadre choisi. Un cadre en aluminium augmentera la part de cet élément dans le bilan tandis que le cadre en bois aura l'effet contraire (voir Tableau 4). L'impact du type de cadre sur l'effet d'un remplacement est analysé dans la discussion.

## 13.4 Discussions

Les résultats de cette étude partant d'une problématique concrète sur un projet en cours de planification ont montré que le réemploi de cadres de fenêtre sur un bâtiment de 25'545 m$^2$ de SRE économise pour des cadres en bois-métal 55 tonnes de $CO_2$-eq soit 2,14 kg.$CO_2$-eq/m$^2_{SRE}$ soit 44 tonnes de déchet directs (liés aux cadres) et indirects (liés à l'extraction des métaux composant le cadre). Dans le cadre de l'écobilan comparatif de plusieurs scénarios de rénovation du bâtiment intégrant les matériaux et l'énergie de chauffage après travaux, il n'y a pas systématiquement de bénéfices par rapport à la variante réemploi de cadres. Le bénéfice, s'il y en a, reste notamment fonction du cadre existant, de la technologie choisie pour le nouveau et du producteur de chaleur en place.

Pour mieux évaluer ces différents cas de types de cadres et de producteur de chaleur, une analyse complémentaire est proposée.
La question d'une rénovation optimale de menuiserie d'un point de vue environnemental est multifactorielle. Les trois facteurs prédominants sont :

- **Matériaux du nouveau cadre** : plus la fabrication et l'élimination du cadre est carbonée, moins le changement total de la menuiserie est la solution optimale
- **Type de producteur de chaleur** : plus la production de la chaleur est carbonée, plus les mesures de réduction des besoins de chauffage par une meilleure isolation (réduction du Qh) auront un effet important sur la réduction de l'émission de GES en phase d'exploitation.
- **Date de fabrication de la menuiserie à rénover** : plus la menuiserie est ancienne, plus ses performances thermiques sont mauvaises et le remplacement du cadre aura davantage d'impact sur la performance environnementale de la rénovation.

La Figure 92 présente un graphique multifactoriel intégrant les trois facteurs clés précédemment identifiés, permettant d'évaluer la pertinence environnementale du remplacement total d'une menuiserie par rapport à un simple changement de vitrage. Ce graphique illustre l'interaction entre les performances thermiques du cadre existant et celles du nouveau cadre, ainsi que leur impact sur les besoins de chauffage et les émissions de GES associées à la phase d'exploitation. Plus l'écart de performance thermique entre l'ancien et le nouveau cadre est important, plus la réduction du $Q_h$ est significative, entraînant une baisse des GES liée à l'exploitation, dépendant également du mix énergétique du système de chauffage employé (représenté par la ligne en pointillé).

En parallèle, la production et l'élimination du nouveau cadre génèrent des émissions de GES, dont l'ampleur varie en fonction du matériau et du processus de fabrication (illustré par la ligne continue). Lorsque la courbe des économies de GES durant la phase d'exploitation (ligne pointillée) dépasse celle des émissions induites par la fabrication et l'élimination du cadre (ligne continue), il devient optimal, du point de vue environnemental, de procéder à un remplacement complet de la menuiserie. À l'inverse, si les émissions liées à la fabrication et à l'élimination du cadre excèdent les économies réalisées en phase d'exploitation, il est préférable de conserver le cadre existant et de ne remplacer que le vitrage.
Il convient de préciser que ce graphique est basé sur les spécificités de notre cas d'étude, notamment en ce qui concerne le facteur de forme et le pourcentage de vitrage. Le pont thermique linéique est maintenu constant dans nos simulations, avec une valeur moyenne de PSI de 0.05 W/(m.K). Bien que cette valeur puisse théoriquement varier selon les configurations, son impact sur les résultats reste marginal.

Il est important de noter que ce graphique ne prend pas en compte la temporalité des émissions de carbone émis ni la trajectoire de décarbonation du mix électrique suisse sur la durée de vie des fenêtres[20]. Ces deux hypothèses venant jouer en faveur du réemploi du cadre, dans les cas où l'analyse environnementale montre des résultats similaires entre le remplacement du cadre et sa conservation (au point de croisement des lignes continue et pointillée), il serait judicieux de privilégier la réutilisation du cadre, car certaines hypothèses non prises en compte dans ce cadre d'étude sur 30 ans péjorent l'option de réemployer le cadre.

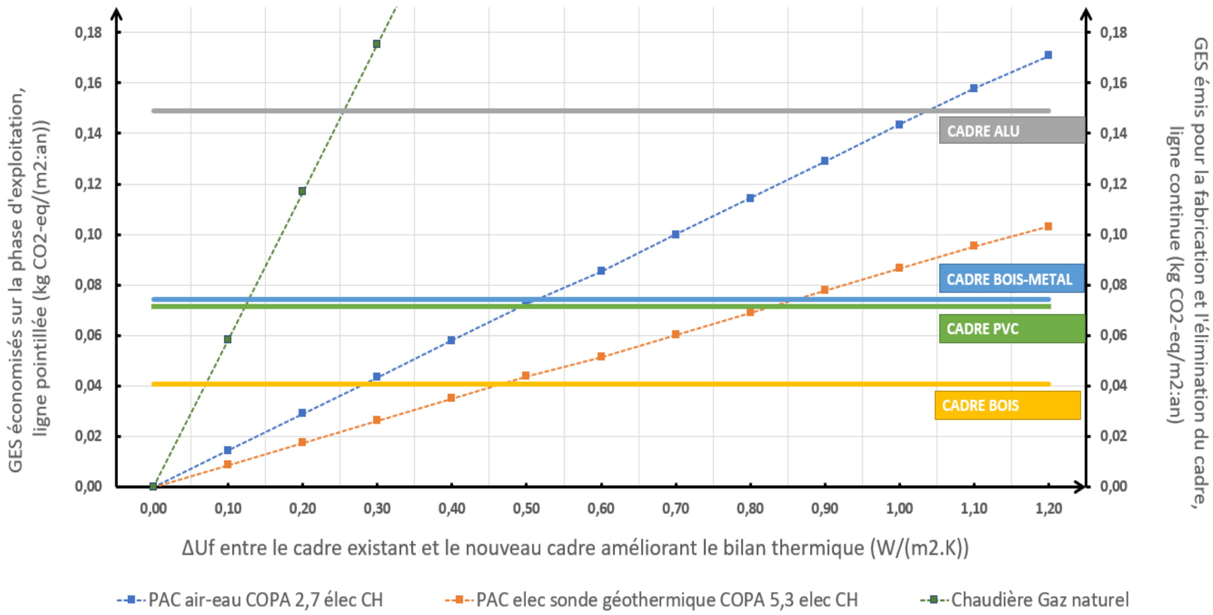


Figure 92: Abaque d'aide à la décision pour déterminer la pertinence de maintien d'un cadre de fenêtre établi pour le bâtiment d'étude (facteur de forme 1.03 et taux de vitrage (window wall ratio) de 16 %)

De cet abaque, pour un bâtiment équipé d'une pompe à chaleur haute performance (COPA 5,3), on en tire que le réemploi du cadre est favorable sur les émissions de GES dans les configurations suivantes :

- Pour un changement de cadre vers une variante alu, toutes les situations sont favorables au réemploi du cadre
- Pour un changement de cadre vers une variante bois, le ΔUf entre ancien cadre et nouveau cadre doit être inférieur à 0.45 W/(m$^2$.K)
- Pour un changement de cadre vers une variante PVC, le ΔUf entre ancien cadre et nouveau cadre doit être inférieur à 0.83 W/(m$^2$.K)
- Pour un changement de cadre vers une variante boit-métal, le ΔUf entre ancien cadre et nouveau cadre doit être inférieur à 0.85 W/(m$^2$.K)

Le même raisonnement s'applique pour les deux autres producteurs de chaleur représentés sur ce graphique d'aide à la décision.

Les résultats obtenus à partir de cet abaque confirment les conclusions formulées dans le projet OFEN FenSanReuse, à conditions et hypothèses équivalentes. En effet, que l'amélioration de la performance thermique liée au remplacement du cadre soit faible (ΔUf de 0.2 W/(m²·K)) ou modérée (ΔUf de 0.4 W/(m²·K)), les gains énergétiques obtenus ne compensent pas l'impact environnemental additionnel associé à la fabrication et à la mise en œuvre d'un nouveau cadre en PVC lorsque le

[20] PowerCheck : https://powercheck.ch/

producteur de chaleur est une PAC air-eau avec un COPA de 2.7. Ainsi, dans les variantes étudiées, la réutilisation du cadre existant s'avère être une stratégie plus avantageuse d'un point de vue environnemental, en particulier en matière de réduction des émissions de gaz à effet de serre.

## 13.5 Conclusions et perspectives

Les résultats de cette étude reflètent l'importance de la rénovation des menuiseries dans le processus de décarbonation du parc immobilier suisse notamment lorsque le réemploi in-situ est possible. La réutilisation des cadres de fenêtres existants, combinée à un changement de vitrage et joints, s'avère être une option particulièrement efficace pour réduire les émissions de GES totales, en minimisant à la fois les émissions des travaux et permettant d'éviter 1.7 $kg/m^2_{SRE}$ de déchets directs et indirects.
Les variantes étudiées montrent qu'une réduction d'émission de GES importante est déjà atteinte avec la conservation du cadre et le remplacement des joints et du vitrage par du double vitrage (V1), en considérant le compromis entre amélioration du bilan thermique et énergie grise travaux par rapport à l'état initial (V0). Les améliorations supplémentaires apportées par des actions de rénovation plus ambitieuses comme la conservation du cadre et la mise en place d'un triple vitrage (V2) ou le remplacement de la menuiserie par une fenêtre en triple vitrage neuve (V3) sont globalement moins significatives, et leur intérêt est plus important si le producteur de chaleur est fortement carboné ou peu efficient.

Enfin, le graphique d'aide à la décision, prenant en compte des facteurs tels que la composition du cadre, le type de production de chaleur, et la date de construction de la menuiserie, offre une approche multifactorielle pour déterminer l'option de rénovation optimale du point de vue de l'émission de GES. Cette approche souligne l'importance d'une évaluation contextuelle pour chaque bâtiment, afin de maximiser les bénéfices environnementaux des interventions de rénovation. Il est important de souligner que le nombre de cas figure où la conservation du cadre est la solution optimale tend à croitre notamment par le fait que le mix électrique Suisse baisse d'année en année et sur la diminution effective de la part du cadre sur l'ensemble du vitrage.
Ainsi, la réutilisation des cadres existants lors de la rénovation des menuiseries présente un fort potentiel de réduction des émissions de GES tout en répondant aux objectifs de décarbonation, en particulier lorsque cette réutilisation est combinée à des stratégies de rénovation thermique ciblées et optimisées. À noter que cette étude ne traite pas du réemploi du vitrage lui-même, contrairement au projet FenSanReuse, qui a exploré cette piste et en a évalué les bénéfices potentiels. Une analyse complémentaire sur le sujet permettrait d'enrichir la compréhension des leviers environnementaux mobilisables dans les projets de rénovation. Ces conclusions viennent ainsi compléter les résultats de FenSanReuse, qui ont également démontré la pertinence environnementale du réemploi des cadres, notamment en comparaison avec des solutions neuves à gains thermiques modestes.