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Energy and Greenhouse Gas Emission Savings Through Serial Renovations by Applying the RENVELOPE System in Austria

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Abstract. To achieve international and national energy and greenhouse gas (GHG) emission targets, Austria requires rapid and scalable renovation methods for existing buildings. A comprehensive consortium is currently exploring the potential of serial renovations using the RENVELOPE-system in a research project. This paper presents findings on the number of eligible buildings in Austria and the potential energy and GHG emission reductions that could be achieved by renovating these buildings. First, the IIBW developed an integrative estimation model based on Austria's current building stock to quantify the target stock. Then, we calibrated parameters based on the energy sources used and the qualities of the building envelopes after renovation. Our findings indicate that the potential for serial renovations in Austria is substantial, with around 71,500 buildings potentially benefiting from RENVELOPE-renovations. By renovating these buildings, the main scenario predicts a 73% decrease in final energy demand (heating, warm water, and electricity) and a 75% decrease in GHG emissions per building on average. The savings potential aggregated across the target stock is therefore of major relevance to the Austrian climate balance overall. Our results emphasize that technological advances, particularly those that reduce the cost of prefabricated modules and enable the integration of renewable energies, as well as political adjustments, such as subsidy programs or changes to the legal framework (e.g. building and tenancy laws), can further increase this savings potential.

Keywords: Serial Renovations, Deep Energy Retrofits, Greenhouse Gas Emission Savings, Energy Savings, Renovations of Buildings, New Technologies, Potential, Austria

1. Introduction

The climate targets set at the international and national levels clearly indicate that a significant amount of energy and CO_2 savings can be achieved by upgrading the existing building stock to a sufficiently high standard through a massive wave of renovations. Existing buildings account for a significant portion of total energy consumption and carbon emissions, often due to outdated insulation and inefficient heating systems [1][2]. By modernizing these structures through deep energy retrofits, nation states can drastically reduce their environmental footprint while preserving the "embodied energy" already stored in original construction materials. Furthermore, increasing the pace of renovation addresses the growing challenge of aging infrastructure, improving the safety, comfort, and long-term economic value of the housing stock without the high resource costs associated with demolition and new construction.

In Austria, the push for accelerated building renovation is central to achieving the national goal of climate neutrality by 2040, a target more ambitious than the broader European Union timeline [3][4]. The country faces a critical challenge in modernizing its aging building stock, specifically regarding 'Worst Performing Buildings' that remain heavily dependent on fossil fuel heating systems such as oil and gas. To address this, in addition to the longstanding and widely available refurbishment subsidies of the *Länder*, the federal government has implemented the "Sanierungsoffensive" (Renovation Offensive), providing substantial subsidies and the "Raus aus Öl und Gas" (Out of Oil and Gas) bonus to incentivize homeowners and rental housing providers to switch to renewable energy and improve thermal insulation.

Despite all these efforts, the current renovation rate is insufficient to meet climate targets on time [5][6][7]. Efforts to date must be greatly expanded. To bridge the gap between current renovation rates and national climate targets, **serial renovation** offers a transformative alternative to conventional thermal retrofitting. While traditional methods are often labour-intensive, weather-dependent, and highly disruptive to residents over many months, the serial approach leverages industrial prefabrication and digital twins to a large part of the work to a factory setting. This results in significantly shorter on-site construction times, consistent high-quality insulation standards, and the ability to modernize entire building envelopes while they remain occupied. Serial renovation also plays a key role because it enables scalable systems that combine standardized upgrades to the building envelope with a switch to renewable energy sources.

The large-scale research project RENVELOPE [8] is an initiative to explore the capabilities and potential of an advanced serial renovation system with the aim of achieving energy, economic, and social benefits. The project focuses on prefabricated façade modules that incorporate insulation, windows, building technology, and roofing elements and are mounted directly onto existing structures. This method of serial renovation is called **the RENVELOPE-system**. It uses serial, prefabricated timber-frame elements that can incorporate a heat distribution system, for example a hydronic component-activation approach, or integrate building-services components and energy-active systems such as solar collectors.

Coordinated by AEE INTEC, RENVELOPE is funded by the Austrian Climate and Energy Fund as part of the "Vorzeigeregion Energie" program, in collaboration with Green Energy Lab. The project unites 18 research institutions, industry partners, and property management firms to develop scalable façade solutions applicable in Austria and beyond. This contribution is part of ongoing research within the RENVELOPE project.

Building on this background, an essential step is to translate technical suitability into measurable impact. This leads to two central research questions of this paper. First, which building typologies in Austria are most suitable for RENVELOPE-renovations, and what proportion do they represent within the national building stock? Second, assuming these buildings were renovated using the RENVELOPE-approach, what reduction in final energy consumption could be achieved, and how significantly would GHG emissions decrease? Together, these questions link technological feasibility with national-scale climate and energy implications. This paper presents the preliminary findings of the RENVELOPE project regarding the research questions outlined above. The final results of the entire project will be made public in March 2027.

2. Approach and methods

In assessing the potential for implementing RENVELOPE-renovations in Austria, in a first step, we identified the most suitable buildings ("target stock"). Through a bottom-up research approach and together with construction and building experts, we identified technological hurdles for RENVELOPE-renovations depending on building type. We then assessed the most suitable buildings by applying a set of key performance indicators. We excluded buildings that have undergone comprehensive renovations of sufficient quality in the last two decades. We also considered factors such as unsuitable building volumes, Austrian fire safety requirements, and difficulties with in-situ installation of necessary prefabricated modules. Through this multi-step procedure, we identified the buildings most suitable for the RENVELOPE-system and classified the entire building stock using a traffic-light scheme: *green* for the most suitable candidates; *yellow* for stock that generally benefits from RENVELOPE-renovations but faces greater technological or logistical challenges; and *red* for stock that cannot be considered suitable due to current technological or legal limitations at this point in time.

In essence, buildings are most suitable when a lot can be repeated across units and the site allows fast installation. In practice, the best candidates typically have/are:

- simple building geometry (rectangular volumes, limited setbacks)
- standardized, repetitive layouts and façades (many similar windows/balconies, similar floor plans across floors)
- 2–8 storeys (lower buildings do not achieve efficient renovation costs per usable m², while taller buildings are unsuitable due to fire safety regulations and technological hurdles)
- reinforced concrete frame or wall buildings, prefabricated concrete buildings
- poor existing energy performance (envelope and/or energy carrier)
- good site logistics and accessibility (space for crane, staging, delivery, scaffolding)
- façade/roof/window renewal needs attention anyway (so replacement aligns with life-cycle timing and avoids premature waste)

The most important segment is multi-family housing, but we found the non-residential building stock to have high potential as well. Public or semi-public buildings with standardized designs (e.g. some schools, kindergartens, administration buildings), especially when built “no-frills” often fulfil the criteria of suitability.

Among these candidates, "green" and "yellow" are best distinguished by the number of stories and the decade of construction. For example, buildings with 2-4 storeys and constructed between 1945 and 1980 are best suited for technical and legal reasons. However, we have deliberately included buildings constructed between 1990 and 2000 as "yellow" candidates, as they can and must benefit from improved building envelope performance if climate targets in the building sector are to be achieved. "Red" candidates currently excluded include single-family homes—despite future potential for row houses—alongside protected historic buildings, complex geometries, and tight inner-city sites with limited crane access. New builds since 2000 and recently deep-renovated properties were also omitted due to low marginal benefits.

Based on these theoretical considerations, we analysed the 2022 Austrian building register. While this database documents all buildings, it lacks critical information on thermal quality, insulation, and energy systems—data that remains strikingly rare and publicly unavailable in Austria. Consequently, we used proxies such as construction decade, number of stories, and building use to identify suitable candidates. Buildings with an estimated heating demand below approximately 50 kWh/(m²·a) were excluded as "sufficiently renovated," typically applying to structures modernized since the year 2000. However, 1990s-era retrofits remain in the target stock as they often fall short of current standards. Exclusion thresholds were refined using renovation rates documented by the IIBW and the Environment Agency Austria (UBA) for the last decades [5] [6]. It is categorized by legal form of housing provider and building characteristics. Finally, we applied correction factors for technical constraints, such as unsuitable construction types, articulated façades, natural stone materials, limited site access, or cases where poor building fabric makes reconstruction more viable than renovation, and others. By gradually narrowing down the remaining stock, we were able to develop a suitable quantification of buildings that are good candidates for serial renovation in Austria. The results are summarized in section 3.

In a second step, we estimated the potential savings in final energy and GHG emissions if the identified target stock was renovated using the RENVELOPE-system. The model compares the estimated final energy demand and associated GHG emissions of the targeted building stock in its current state ("before") with the improved energy performance realistically achievable after serial renovation ("after"). Final energy demand was calculated as the sum of space heating, domestic hot water, and household electricity (excluding heating electricity). For space heating, realistic heating demand values by building segment were combined with energy factors (to convert useful to final energy depending on the energy carrier) and CO_2 factors (to convert final energy into GHG emissions), allowing total energy demand and related emissions to be estimated for the building stock before and after renovation.

Table 1. *Most important model parameters to calibrate, and data source used for calibration and validation of main scenario and bandwidth scenarios*

Model parameters	Method and data used for calibration
Number of buildings	Result of 1st step estimation divided into 5 sub-sectors (residential building 4 sub-sectors according to envelope quality and share of fossil energy, non- residential buildings)
Average gross floor area per building according to building type, number of apartments, apartment size, etc.	Data provided by Statistics Austria on average values by building type (Austrian Building and Dwelling Register AGWR, and others)
Heat demand by sub-sectors	UBA data; example buildings analysed by EIV [9][10], TABULA project [1]], and other databases (Vienna housing fund and others)
Default values for hot water demand and electricity demand	EIV analyses [9][10] and Austrian legal guidelines (OIB guidelines, ÖNORM series)
Energy sources before renovation	Statistics Austria data on energy use of households [11]
Energy source mix after renovation (heat pumps, district and local heating, biomass and others)	Expert estimates, climate plans, literature [12]
System efficiency factors by energy system to convert useful energy demand into final energy demand	UBA-data, OIB guidelines, literature [13] [14]
CO_2 emission factors by energy source to translate final energy demand in GHG emissions	UBA-data, OIB guidelines, literature [13] [15]
PV yield and degree of coverage	Expert estimates, OIB guidelines, literature [9] [10]

We calibrated the relevant parameters of our models using several sources, including most importantly the parameters used by the Austrian Environment Agency (UBA) in their yearly calculations of energy savings through housing subsidies in Austria (referred to as "UBA-data in the following [13] [14]); the parameters used in the OIB guidelines ("Österreichiches Institut für Bautechnik") and in the calculation of energy performance certificates; the Vorarlberg Energy Institute's (EIV) estimates of energy consumption after renovations [10]; expert opinions generated by a Delphi method (a structured communication technique that uses multiple rounds of surveys and controlled feedback to build a consensus among a panel of experts); and suitable literature sources. The procedure is summarized in Table 1. Depending on the building envelope's thermal quality, the primary energy source—ideally heat pumps, district heating, or biomass—and the post-renovation photovoltaic potential, we modelled various scenarios for the energy performance after renovation. We thus determined the potential range for energy and greenhouse gas emission savings.

3. Results

3.1 First step: Identifying the target stock

According to the IIBW estimation model, the current potential for RENVELOPE-renovations is expected to be around 71,500 buildings (Table 2). The majority of these, around 54,500 properties, are residential buildings. Although this represents only 3% of all residential buildings (due to the high number of single-family and two-family houses in Austria), it accounts for 20% of all multi-storey residential buildings (defined as at least 2 storeys, at least 3 residential units). The targeted building stock also includes 17,000 non-residential buildings, which is 6% of all such buildings in Austria. In total, these buildings contain around half a million residential units, which accounts for 11% of the housing stock in Austria.

Table 2. *Identified target stock in numbers and shares*

Number of buildings	71,500
Of which residential buildings	54,500
Share of all residential buildings in Austria	3%
Share of all multi-family residential buildings in Austria	20%
Of which non-residential buildings	17,000
Share of all non-residential buildings in Austria	6%
Housing units in target stock	Approx. 526,000
Share of all housing units in Austria	11%

Figure 1 and Figure 2 provide more detailed information on the targeted building stock in terms of construction period and number of storeys. A striking number of the targeted buildings were constructed between 1980 and 2000. These buildings have been deliberately included in the RENVELOPE-potential, as their thermal and energy quality promises significant efficiency gains through the renovation work that will be necessary in the coming years. A higher proportion of buildings constructed before 1980 have already undergone comprehensive renovation and meet sufficiently high thermal and energy standards after renovation. These results relate primarily to residential buildings. In non-residential construction, the target number is relatively constant throughout the decades of construction at 3,000 to 4,000 buildings, mainly in the areas of “educational and healthcare buildings”, “administrative buildings”, “hotels and similar buildings”, and “offices”

Around 25,000 buildings in the target stock have three storeys. Other buildings are mainly found in the two-storeys segment. Taller buildings are more often residential than non-residential. Around 10,000 of the target buildings have five or more storeys.

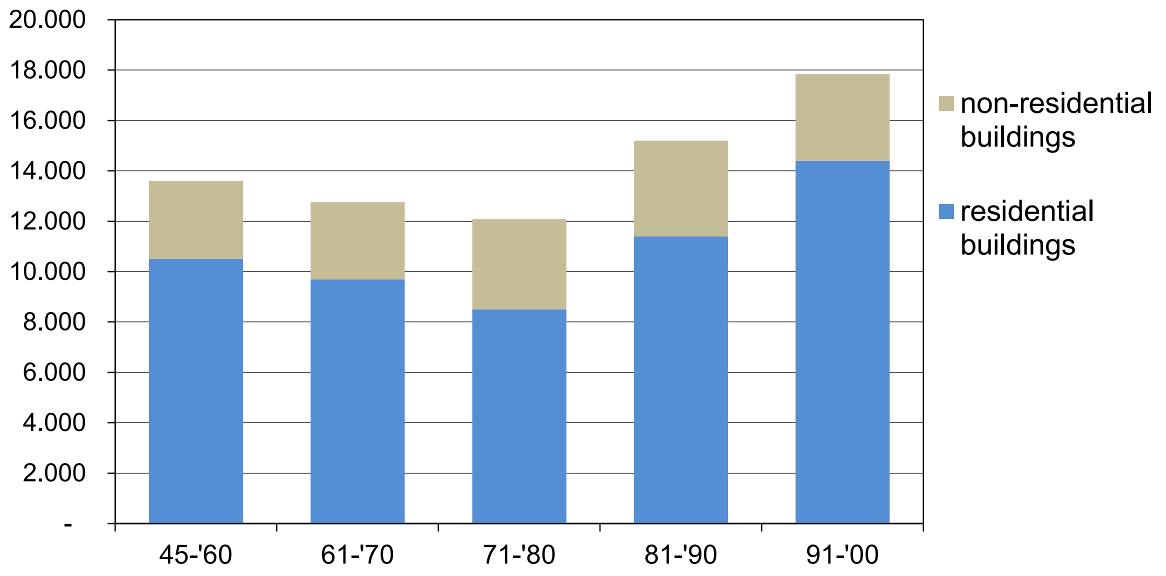

Figure 1. *Target building stock per decade of construction*

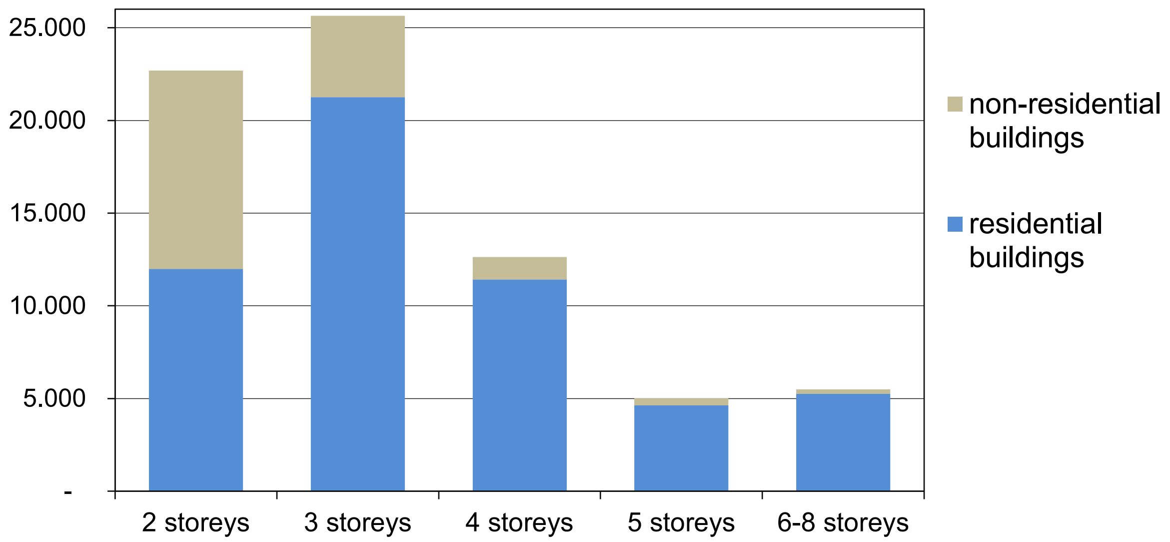

Figure 2. *Target building stock per number of storeys*

3.2. Second step: Estimating the energy demand and GHG-effects of RENVELOPE-renovating this stock

Figure 3 illustrates the significant reduction in final energy demand for heating, hot water, and household electricity in residential and non-residential buildings following a RENVELOPE-renovation. Across residential sub-segments, the average total final energy demand per square meter of gross floor area (GFA) drops from 209 kWh/m²a to 55 kWh/m²a (Figure 3). The most substantial decrease occurs in space heating, which falls from 171 kWh/m²a to 24 kWh/m²a. Non-residential buildings start with a higher average demand (228 kWh/m²a) than the targeted residential stock, but reach 62 kWh/m²a after renovation, with space heating again accounting for the most significant savings. In the most likely scenario, renovating these buildings could decrease their final energy demand by around 73%.

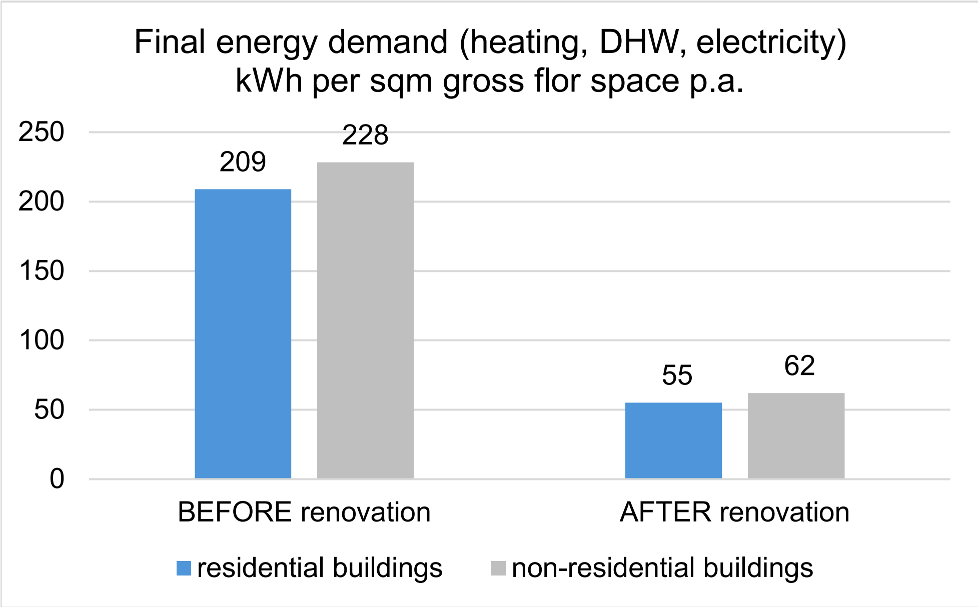

Figure 3. *Final energy demand before and after renovation*

The impact of a RENVELOPE-renovation on GHG emissions is even more pronounced: By combining substantial envelope improvements with a broad shift to renewable energy and on-site PV generation, annual CO_2 emissions are reduced from 42 kg to 9 kg per m² of gross floor area for average residential buildings and from 33 kg to 11 kg for non-residential ones (Figure 4). CO_2 emissions would decrease by 75% on average.

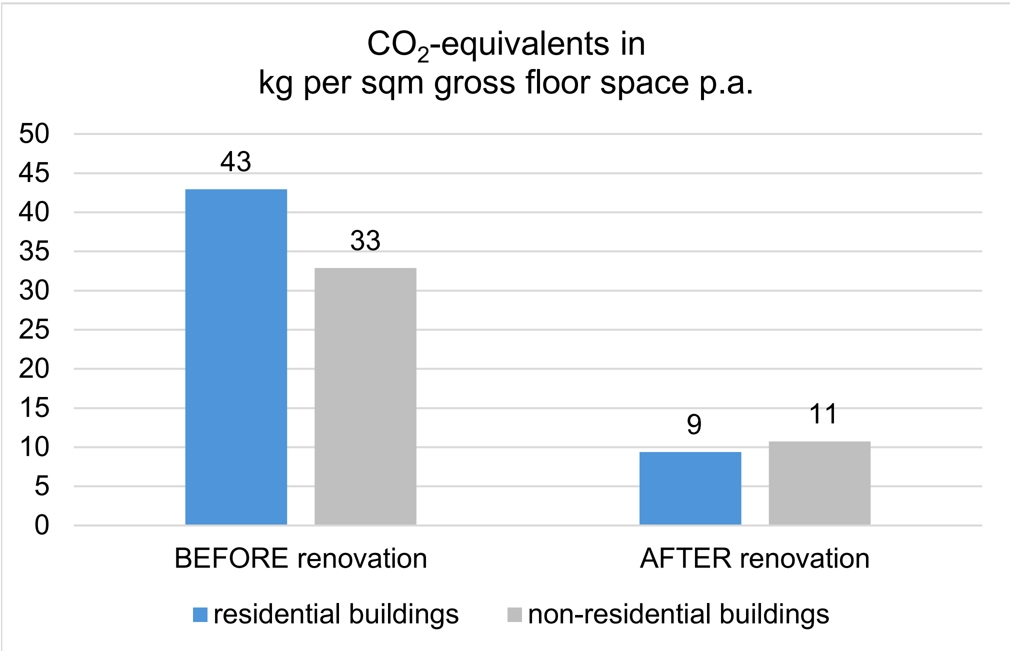

Figure 4. *CO2 equivalents before and after renovation*

By aggregating these savings per square meter of gross floor area (GFA) across the entire "target" building stock, the final energy demand would drop from 15.5 TWh to 4.2 TWh following RENVELOPE-renovations (Figure 5). This represents a substantial saving of approximately 11.4 TWh, or a 73% reduction compared to the baseline. Given that Austria's total final energy demand across all sectors is currently around 300 TWh, implementing RENVELOPE- renovations in the identified suitable buildings alone could save approximately 4% of the national total.

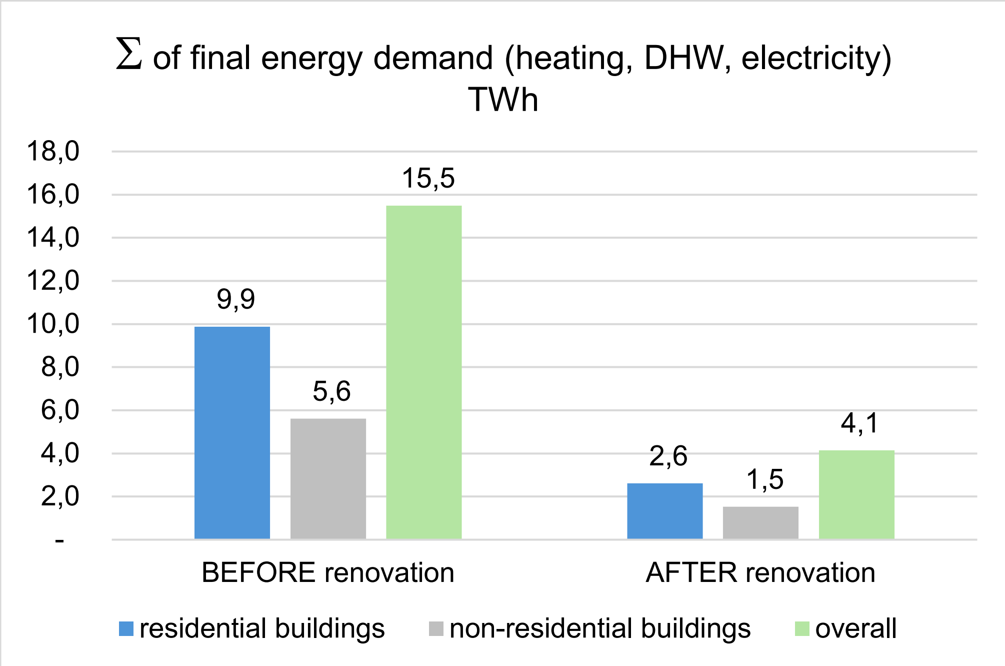

Figure 5. *Sum of final energy demand of target stock before and after renovation*

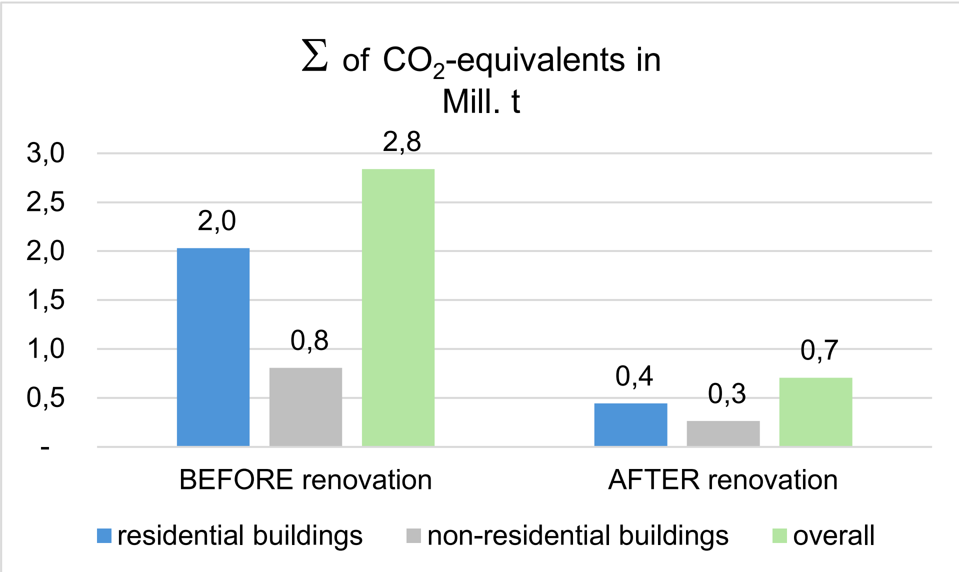

Figure 6. *Sum of GHG emissions of target stock before and after renovation*

The potential for CO_2 savings is even more pronounced (Figure 6). The target building stock currently produces approximately 2.8 million tons of CO_2 equivalents—a high figure reflecting its status as the thermally and energetically poorest multi-storey stock in Austria, characterized by fossil fuel reliance and poor insulation. Systematic RENVELOPE-renovations could reduce these emissions to 0.7 million tons, a 75% saving. This would significantly impact the building sector's GHG balance, which accounted for 7.3 million tons of CO_2 equivalents in the calculation year (excluding district heating and electricity generation). The calculated savings potential is therefore of major relevance to the Austrian climate balance overall [3] [15].

Our results emphasize that technological advances, particularly those that reduce the cost of prefabricated modules and enable the integration of renewable energies, as well as political adjustments, such as subsidy programs or changes to the legal framework (e.g., building and tenancy laws), can significantly increase the potential. The specific mechanisms for unlocking these additional potentials and the necessary legal adjustments will be explored in detail in the upcoming final report of the RENVELOPE project.

3.3. Bandwidth of estimation scenarios

The results presented are based on the parameters described and represent a medium-impact scenario for potential savings. In defining the post-renovation energy and thermal performance, we prioritized realistic over optimistic assumptions. By selectively adjusting key consumption and emission parameters, we also modelled both optimistic and pessimistic scenarios, establishing a robust range for potential savings (Table 3).

Optimistic scenarios assume, for example, continued improvements in the carbon intensity of district heating and electricity generation, or higher on-site PV coverage. Pessimistic scenarios primarily account for the gap between calculated demand and actual consumption. Post-renovation monitoring often shows higher real-world heat consumption after renovations [9] [16]—largely due to occupant behaviour—so some pessimistic cases assume space-heating consumption up to 40% above modelled demand. Additional pessimistic variants include higher post-renovation electricity use for heating and a slower decarbonization of the power supply.

Table 3. *Bandwidth of savings in final energy demand and GHG emissions*

	Overall final energy demand savings	Overall GHG emission savings
Main scenario	73%	75%
Average of optimistic scenarios	77%	84%
Average of pessimistic scenarios	68%	68%

4. Conclusions and outlook

The results clearly demonstrate the substantial potential for energy and CO_2 savings that RENVELOPE-renovations can unlock in the identified “target” building stock in Austria. Even under a pessimistic scenario, final energy consumption and CO_2 emissions of these buildings can be reduced by 68%. Under more realistic assumptions, savings increase to **73%** for final energy and **75%** for CO_2 emissions. This exceptionally high potential stems from major improvements to the thermal envelope and the consistent shift to renewable energy carriers. The analysis also accounts for the fact that part of household electricity demand can be supplied directly on-site by photovoltaic systems installed as part of the renovation.

RENVELOPE-renovations drastically reduce space heating demand so that the overall energy profile shifts fundamentally: in well-insulated buildings, heating requirements fall below those for hot water and household electricity. Consequently, additional post-renovation efficiency measures must prioritize hot water— e.g. through high-efficiency boilers, insulated storage, and low-flow fixtures—and electricity, e.g. using efficient appliances, LED lighting, and smart load management. In high-performance buildings, these strategies are essential as they target the largest remaining consumption areas. Ultimately, achieving a climate-neutral building sector also depends on the continuous decarbonization of the national power grid [2] [7].

When extrapolated to the entire target building stock, the resulting savings extend far beyond individual projects and become relevant to Austria’s overall energy balance. A broad rollout of RENVELOPE-renovations could sustainably and measurably reduce national final energy demand. The impact is even more pronounced for greenhouse gas emissions: renovating around 71,500 buildings with particularly poor energy and thermal performance—

upgrading them with significantly improved envelopes and renewable energy systems—could substantially accelerate the decarbonization of Austria’s building sector. RENVELOPE would therefore be not only a technical renovation solution, but a key lever for the climate-policy transformation needed in the building sector.

Underlying and related material

Further information and materials can be found on the project website: https://renvelope.at/

Author contributions

Alexis Mundt: Conceptualization, Methodology, Formal analysis, Data curation, Data analysis, Writing - original draft, Submission. Wolfgang Amann: Conceptualization, Methodology, Data analysis, Model conceptualization. Florine Leighton: Writing – review & editing.

Competing interests

The authors declare that they have no competing interests.

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