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Accelerating the Decarbonization of Residential Heating

Role of Carbon Constraints in Energy Performance Certificates

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Executive summary

The saying goes that "Belgians are born with a brick in the stomach," meaning that owning a home is the quintessential Belgian dream. And why wouldn't it be? With a homeownership rate of over 70%[1], this dream is more reality than fantasy[2]. Belgian homeowners are known for their love of solid, well-built homes that can withstand the test of time, and this passion is reflected in their building policies. Yet, while the focus on energy efficiency is important—measured primarily through the lens of primary energy consumption—these sturdy Belgian homes still significantly contribute to Belgium's carbon emissions. So perhaps it's time to ask: should we not only cherish the quality of our homes but also aspire to limit their environmental footprint through the means of their energy consumption related CO_2 emissions?

Building on that, this study, executed on behalf of Luminus, delves into how adjustments to the Flemish Energy Performance Certificate (EPC) framework could accelerate meeting climate objectives by driving the adoption of low-carbon heating technologies, with a particular focus on heat pumps. By examining 135 archetypes that encompass a variety of building types and construction periods, this study applies its findings to real-world districts. This approach enables a detailed analysis of how policy enhancements could not only improve energy efficiency but also substantially reduce carbon emissions in the Flemish building sector.

Context and Objectives

Residential heating contributes significantly to Flanders' carbon emissions, and heating as a whole represented 72% of the Flemish final energy consumption in 2019[3]. Current policy tools, such as the EPC, emphasize energy performance through means of reducing the primary energy consumption, but do not directly take into account the associated carbon emissions. This study aims to:

- Assess the impacts of integrating of carbon constraints into the EPC framework
- Explore the role of electrification technologies, particularly heat pumps, in reducing emissions
- Examine the effects of the electricity-to-gas price ratio on renovation choices and carbon abatement

The analysis is grounded in archetypes developed earlier[4] and derived from Flemish EPC data. The results are then further explored for three selected districts: Brugse Poort (Ghent), Boxbergerheide (Genk), and Berendrecht (Antwerp). The study uses EnergyVille's Building Energy Calculation Service (EBECS) and Urban Energy Pathfinder (UEP) tools to simulate various renovation scenarios.

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[1] in Flanders

[2] Statbel. *Housing - Type of Ownership*. statbel.fgov.be. 2024.

[3] VEKA. *Warmte in Vlaanderen*. assets.vlaanderen.be. 2020.

[4] G. Reynders M. De Groote D. Aerts. *De snelste weg naar A*. energyville.be. 2022.

Findings

Not All A-Labels are Equivalent

The carbon intensity of electricity in Flanders was reported to be 0.195 kg CO_2/kWh in 2022[4], and is projected to drop further in the coming years due to grid decarbonization efforts [5]. In contrast, the carbon intensity for natural gas is significantly higher at 0.202 kg CO_2/kWh (condensing gas boiler with an efficiency of 90%). Electrification, especially through heat pump adoption, presents a substantial opportunity to reduce carbon emissions. Assuming conservative heat pump efficiencies, a fully electrified heating system could cut carbon emissions from space heating by over two-thirds compared to gas-based systems. As the proportion of green electricity continues to increase, the carbon savings will grow even further. In contrast, homes that continue to rely on gas will be left behind, and remain in high carbon emission situations associated with fossil fuels. This is shown in Figure 1, where the carbon emissions per m^2 of three scenarios, each reaching an A-label, are shown for the archetypes.

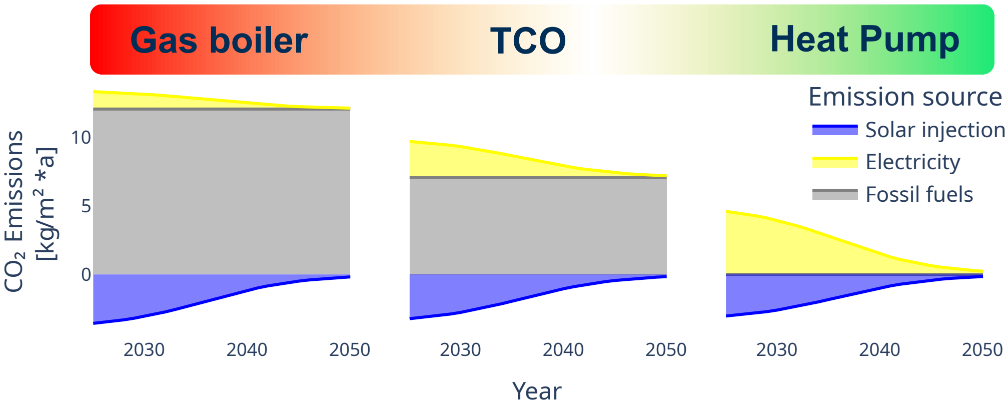

Figure 1: Yearly carbon emissions per m^2 of the archetypes for three A-label scenarios: A full gas boiler scenario (left), a TCO-optimized scenario (middle), and a full heat pump scenario (right)

Carbon Constraints as an Electrification Stimulus

The introduction of carbon constraints into the EPC framework—such as 6 kg/m² (low carbon) or 8 kg/m² (medium carbon)—drives the adoption of heat pumps across building types, particularly in terraced and semi-detached homes. Under the 6 kg/m² carbon constraint, heat pumps dominate as the preferred system from a Total Cost of Ownership perspective (Fig. 2).

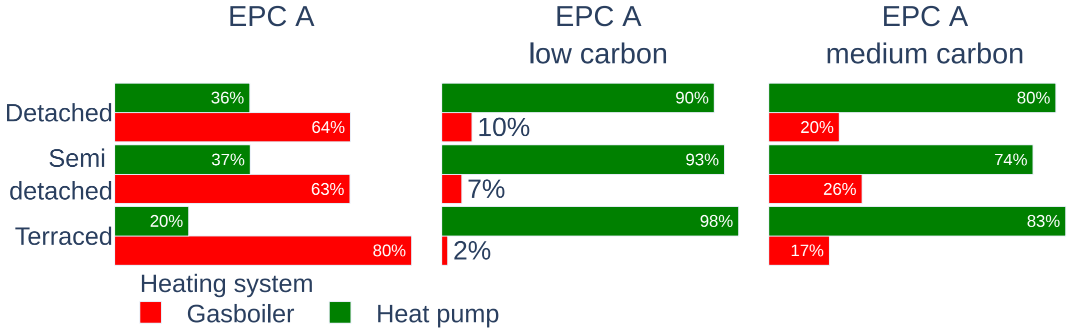

Figure 2: Heat pump adoption for the A-label, the A-label low carbon (6kg CO_2/m^2), and the A-label medium carbon (8kg CO_2/m^2).

Investment and Operational Cost Dynamics

While the initial investment costs for heat pumps are higher compared to gas boilers, this does not form an obstacle, as heat pumps have large impact when it comes to improving the EPC label. However, the long-term total cost of ownership (TCO) presents a financial hurdle, especially under unfavorable electricity-to-gas price ratios, as is the case in Flanders. As shown in Figure 3, a shift toward the French or Dutch price ratios would make heat pumps increasingly competitive in Flanders, even without the integration of a CO_2 constraint.

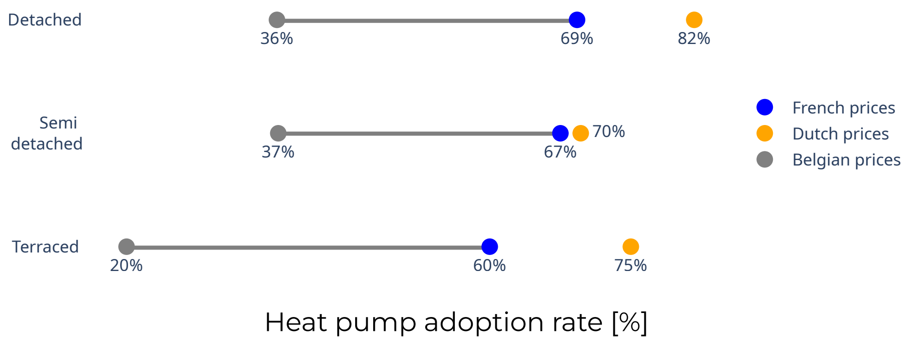

Figure 3: Comparison of TCO-optimized heat pump adoption rates per building type with Belgian, French and Dutch energy prices.

Carbon Abatement and Renovation Rates

In the current policy framework, to meet long-term climate goals, renovation rates must be increased to 3%-4% per year[5], while current estimates place this at 2.5%[6,6] to less than 1%[7,8]. In this study, we explored phased renovations, where homes first undergo partial renovations with a heat pump (to EPC label C with a heat pump[9]) and then receive further upgrades (to achieve EPC A), offer a cost-effective pathway to decarbonization. Figure 4 illustrates the carbon abatement potential of phased renovations and low-carbon EPC B[10] scenarios for Boxbergerheide (Genk), showing accelerated emissions reductions compared to standard A-label renovations.

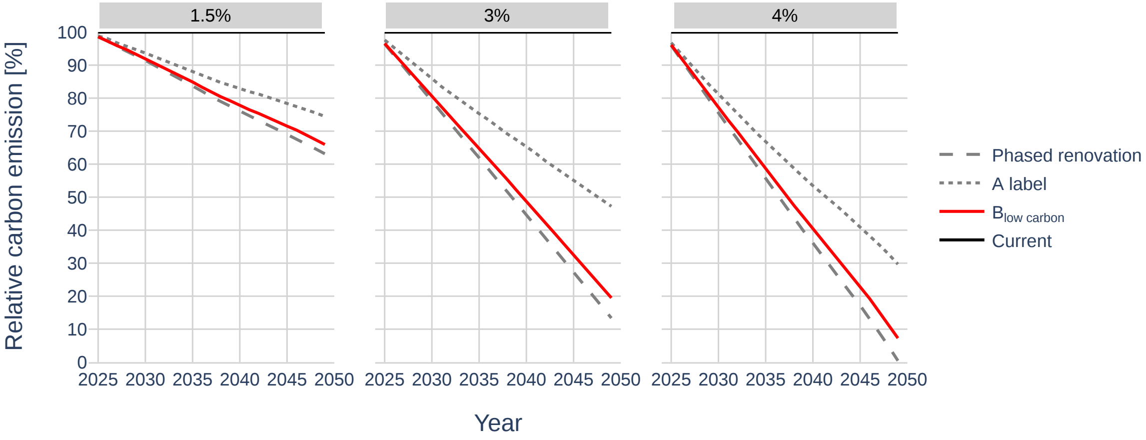

Figure 4: Carbon abatement rates for yearly renovation rates of 1.5%, 3% and 4% yearly renovation rates in Boxbergerheide (Genk).

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[5] Vlaamse Overheid. *Vlaamse langetermijnrenovatiestrategie voor gebouwen*. assets.vlaanderen.be. 2020.

[6] It is remarked that the renovation rate is estimated at 2.5%, but only a limited portion renovates to the 2050 goal.

[7] Euroconstruct. *New Construction and Climate Goals in Europe*. euroconstruct.org. 2018.

[8] EnergyVille. *DITUR: Digital Twin for Upscaled Retrofits*. energyville.be. 2022.

[9] Note that the phase 1 renovations have been limited to heat pump ready renovation packages.

[10] The low carbon EPC B scenario is an EPC B label with the added constraint of emitting less than 6kg CO_2/m^2

Affordibability of investment for Phased and District Specific Renovation Strategies Figure 5 shows the investment cost distribution for TCO-optimized phased renovations and A-label renovations for Boxbergerheide (Genk). It is shown that more than 83% of phase 1 renovations in could be fully funded through favorable loans ("Mijn Verbouwlening")[11], while this is only 55% in the case of an EPC A renovation.

Applying archetype findings to real districts underscores the importance of localized renovation strategies. A successful renovation strategy needs to carefully consider the socio-economical and demographical variances, as well as the unique building typology of each district. We investigate the impact of carbon limits and energy price changes on Boxbergerheide, and show that, while large scale transition to heat pump systems is not without its financial difficulties, it can be a win-win scenario when given the right policy context.

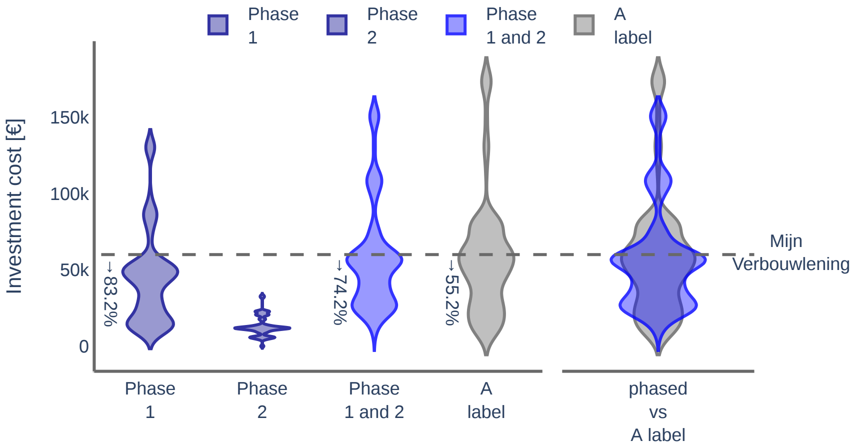

Figure 5: Comparison of investment costs for phased renovations and A-label renovations.

Conclusion

The findings of this study highlight the positive impact through policy action of:

- Accelerating the electrification of domestic heating as part of the path to meet building climate objectives. This could occur by **incorporating carbon constraints into the EPC**: A more comprehensive EPC framework, integrating carbon emission thresholds, would incentivize the adoption of low-carbon technologies and more accurately reflect a building's environmental impact, while leading to lower investment costs.
- Combining heat pumps and phased renovations can also facilitate the decarbonization of the residential building sector: **it lowers the upfront investment and leads to higher carbon savings** vs deep renovations.
- **Promote Electrification**: Policy incentives, including financial support for heat pumps, and specially measures to reduce the electricity-to-gas price ratio will be critical for decreasing the TCO of heat pumps and as a result accelerating electrification

This study demonstrates the potential of electrification—particularly through heat pumps—as a key decarbonization strategy for residential buildings in Flanders. By integrating carbon constraints into the EPC framework and shifting the focus from energy efficiency alone to also consider carbon emissions, policymakers can accelerate the adoption of low-carbon technologies while minimizing financial barriers. Achieving climate goals, however, will require a package of policy instruments to prioritize electrification.

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[11] Vlaamse Overheid. *Mijn Verbouwlening*. www.vlaanderen.be/mijn-verbouwlening. 2024.

1 Introduction

Decarbonizing residential heating is a key priority in the transition to a low-carbon economy. Various technologies, including heat pumps, have the potential to contribute significantly to reduction of carbon emissions. However, the effectiveness of current policy tools, such as the Flemish Energy Performance Certificate (EPC) framework, in promoting the adoption of low-carbon heating solutions may require further optimization. This raises important questions: To what extent can existing regulations be leveraged or adapted to support carbon reduction targets, and how can we advance toward sustainable and renewable residential heating?

At the behest of Luminus, this study by VITO/Energyville evaluates how well the EPC framework encourages Flemish homeowners to make carbon-conscious decisions, with a specific focus on the role of low-carbon heating technologies, such as heat pumps. The study examines how incorporating carbon emissions criteria into the EPC methodology could strengthen its effectiveness, while also considering the impact of factors like the carbon intensity of grid electricity and electricity-to-gas price ratio.

For the purpose of this study, a representative collection of buildings was established. These buildings were analyzed for their current energy use and emissions, as well as for the potential effects of various renovation scenarios. This analysis was conducted using the EnergyVille Building Energy Calculation Service (EBECS) and the Urban Energy Pathfinder (UEP). The assessment starts from building archetypes, following the same methodology used in earlier VITO studies, such as 'The Fastest Way to A'[12] and 'Hybrid Heat Pumps'[13]. Next, the insights gained from the archetype studies were applied to three districts to evaluate the potential impact of enhanced EPC criteria "in the field", assessing their effect on specific neighbourhoods.

Through scenario development and sensitivity analyses, this project aims to provide policymakers with objective, evidence-based insights into how existing tools like the EPC framework could be refined to better support the adoption of low-carbon technologies, ultimately contributing to the decarbonization of residential heating in Flanders.

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[12] G. Reynders M. De Groote D. Aerts. *De snelste weg naar A*. energyville.be. 2022.

[13] B. Vandevelde, G. Reynders, J. Verheyen, M. Sharifi, P. Vingerhoets. *Onderzoek naar beleidsmaatregelen omtrent hybride warmtepompen in bestaande woongebouwen*. vlaanderen.be. 2023.

2 The EPC Method

The Energy Performance Certificate (EPC) for residential units in Flanders assigns an energy label from A (very efficient) to F (very inefficient) and provides an objectifiable energy score that indicates the annual primary energy use per square meter . This assessment takes into account various factors such as insulation, heating system, and the presence of renewable energy installations. The EPC serves as a tool for comparing the energy performance of different properties and includes recommendations for enhancing the energy performance.
Therefore, the EPC plays a crucial role in decarbonization by setting minimum energy performance standards or offering incentives for building owners to improve the energy performance of their properties. However, while the EPC is designed to drive energy performance, a key challenge remains: buildings can still achieve an A label—indicating high energy performance—while relying on fossil fuels for heating and hot water. This means not all buildings with an A-label reflect the same level of carbon impact; some buildings, despite their top performance rating, continue to have a much higher carbon footprint than others.

2.1 Adjusting the EPC to reach the end goal of decarbonization

The current Flemish EPC methodology evaluates a building's energy performance primarily based on its primary energy consumption. This metric focuses on the total energy used, but it does not directly include the carbon emissions (CO$_2$ associated with that energy use). In contrast, the French system, known as the Diagnostic de Performance Énergétique (DPE), adopts a more holistic approach[14]. The DPE not only considers primary energy consumption but also carbon emissions.

Figure 6 compares the energy label categories used in both the Flemish and French systems, emphasizing the differences in their assessment criteria. This highlights the broader scope of the French DPE in addressing a building's contribution to carbon reduction.

Figure 6: The French and Flemish energy labels for residential units.

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[14] Ministère de la Transition Écologique. *Diagnostic de Performance Énergétique (DPE).* ecologie.gouv.fr. 2024.

3 Representing the Flemish building stock

The study aimed to balance working with a manageable dataset while ensuring the conclusions are broadly applicable across the entire region. To achieve this, a representative selection of archetypal dwellings was chosen, reflecting the diversity of building types and conditions found in Flanders. These archetypes were used to determine policy-based scenarios aimed at accelerating the decarbonization of the Flemish building portfolio. To further enhance the validity of this selection, a field test was conducted in three districts to assess how well the chosen archetypes represented real-world conditions. This process not only confirmed the relevance of the selected archetypes but also provided insights to inform broader policy and renovation strategies. By grounding the analysis in both archetypal representations and practical validation, the study provides a robust framework for understanding the challenges and opportunities within the Flemish residential building stock.

3.1 Archetypes

The study makes use of 135 archetypes based on the Flemish EPC dataset, which are identical from the 2022 position paper "De snelste weg naar A"[15], and the 2023 position paper "Winter is coming"[16]. This study focuses to single family homes of three typologies: detached, semi-detached and terraced buildings. The archetypes are further subdivided in construction periods, building size and insulation level. The archetype categories are shown visually in Figure 7.

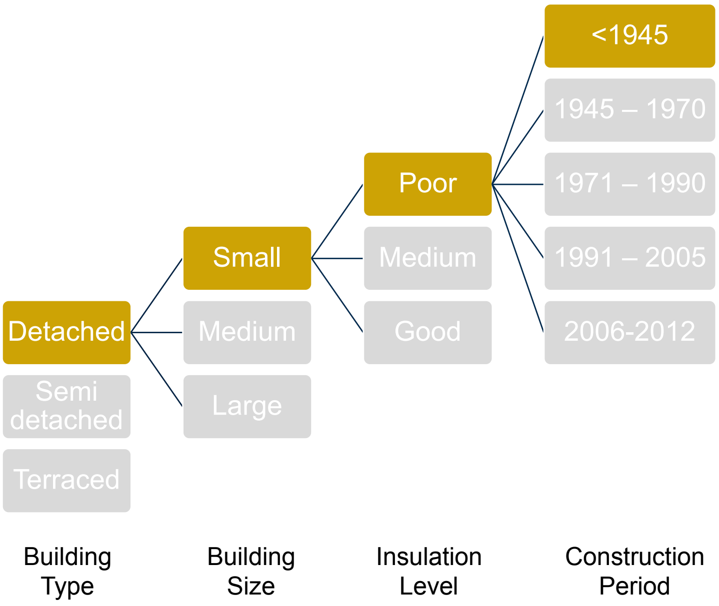

Figure 7: The archetypes, divided by their core properties

It has to be remarked that the study does not include apartements, and focuses on single family houses. Therefore, the results from this study apply to 94.2% of the Flemish residential building stock[17]. Apartments are not considered as applying the methodology entails a strong uncertainty in modelling the energy needs properly of multiple living units in an apartment

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[15] G. Reynders M. De Groote D. Aerts. *De snelste weg naar A*. energyville.be. 2022.

[16] B. Vandevelde C. Protopapadaki M. De Groote. *Winter is Coming. Where are the Heat Pumps?* energyville.be. 2023.

[17] Vlaamse Overheid. *Vlaamse langetermijnrenovatiestrategie voor gebouwen*. assets.vlaanderen.be. 2020.

building.

3.2 District approach

For the district approach, VITO/EnergyVille uses a range of specialized tools and datasets. The key tool is EnergyVille's Urban Energy Pathfinder (UEP)[18], a powerful data-driven model designed to simulate and assess energy performance in buildings across selected districts. By integrating open data with local factors and specific project details, UEP generates probabilistic models that provide a comprehensive view of energy use, efficiency, and potential improvements at both the building and district levels.

3.3 Renovation simulations

Once the current situation is assessed, either via the archetypes or the selected districts, the results are linked to the EnergyVille Building Energy Calculation Service (EBECS) tool[19]. This tool allows for the modeling of various renovation scenarios, helping to explore potential improvements in energy efficiency and sustainability.

The EBECS tool is able to provide detailed renovation advice by evaluating various aspects of a property and its inhabitants. Following a detailed assessment of the building's current state — including factors such as geometry, systems, energy consumption, and insulation — EBECS leverages EnergyVille's expertise to provide tailored recommendations for renovation paths and sustainable system upgrades.

The EBECS model operates on a monthly, steady-state energy balance calculation. This approach allows for the estimation of theoretical energy consumption, akin to the EPC methodology, or an approximation of actual energy usage. For the purposes of this study, which aims to assess the EPC methodology's scope, the focus is largely on estimating theoretical energy consumption. However, for the purpose of calculating carbon emissions, as well as the total cost of ownership (see section 3.4), the real consumption was used. The aim of the study is to find an optimal renovation package which satisfies the proposed boundaries for primary energy, as well as carbon emissions. Each boundary set is then evaluated for its effectiveness in reducing carbon emissions. **Renovation packages including a heat pump have been limited to heat pump ready packages (heating power below 105W/m^2)**. The boundaries are strict, meaning that they are always applied (i.e. a building will be retrofitted until it achieves the set of constraints).

A full overview of the renovation measures taken into account can be found is given in annex A.1.

3.4 Optimizing with respect to investment and total cost of ownership

Various combinations of potential renovation measures were evaluated for each building or archetype. The optimal renovation package was determined using one of two criteria: the lowest investment cost or the lowest total cost of ownership (TCO).

For the first criterion, the optimal renovation package is defined as the set of measures that achieves the lowest upfront cost while aligning the building with its long-term target. This

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[18] *Urban Energy Pathfinder*. vito.be.

[19] *EnergyVille Building Energy Calculation Service*. energyville.be.

approach will be referred to as **investment optimization**.

For the second criterion, the operational costs are considered in addition to the initial investment. The optimal renovation package is thus determined by the lowest TCO, which is defined as the sum of the initial investment cost and the projected annual energy costs over the time period of 25 years (from 2025 to 2050), in line with the expected lifetime of the renovation measures. Additionally, a discount rate of 3%[20] was used, as expressed in equation 1:

$$\text{TCO} = \text{investment} + \sum_{\text{fuel}} (c_{\text{fuel}} \times p_{\text{fuel}}) \times \gamma^n \tag{1}$$

Where c_{fuel} represents the energy consumption of gas, electricity, or oil, p_{fuel} denotes the corresponding fuel prices, and γ^n is the discount factor for a period of n years. If solar panels are installed, the summation also includes solar energy injection, valued at market-conform prices. This optimization method will be referred to as **TCO optimization** throughout this report. It is important to note that this calculation is simplified and does not account for potential (local) fluctuations in fuel prices over the period considered.

The initial investment associated with the renovation is attributed exclusively to energy-related upgrades. Costs related to aesthetic finishes, additional repairs, or other ancillary services (e.g., expert consultations) are excluded. In cases where external renovations are performed, such as external roof or facade insulation, the costs for finishing (e.g., plaster work or roof tiling) are included.

3.5 Energy prices and investment costs

This study includes price levels for electricity and gas from Belgium, France, and the Netherlands. These prices influence the cost-effectiveness of different heating systems and renovation measures, such as heat pumps versus gas boilers. The electricity-to-gas price ratio, along with its variants, has been incorporated to reflect realistic scenarios and its effect on renovation choices. Table 1 gives an overview of prices used, as obtained from [15].

	Electricity Price	**Gas Price**	**Ratio (electricity/gas)**
Belgium	0.3778€	0.0994€	3.80
France	0.25911€	0.1181€	2.19
The Netherlands	0.2515€	0.1500€	1.48

Table 1: Energy prices in Belgium, France and in the Netherlands for the second half of 2023. Source: [15]

Additionally, the investment and maintenance costs for various renovation measures within the EBECS model were based on established data and are updated on a regular basis through indexation. For this study, the heat pump costs have been updated to reflect current market conditions, while other costs, including insulation and solar PV, remain consistent with the most recent updates from prior studies, unless otherwise specified.

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[20] This value is in line with previous VITO studies [3][12][5]

3.6 Carbon intensity of electricity

This study uses both current CO_2 intensity of grid electricity, as well as future expectations of the emission factor. Whenever a constant emission factor is used, it will be 0.171kg/kWh reflecting current emissions, which is aligned with Paths2050[21]. For the future carbon intensity, five-yearly values were obtained in alignment with Paths2050, and a logistic decay function was fitted in order to obtain yearly values, as is shown in figure8.

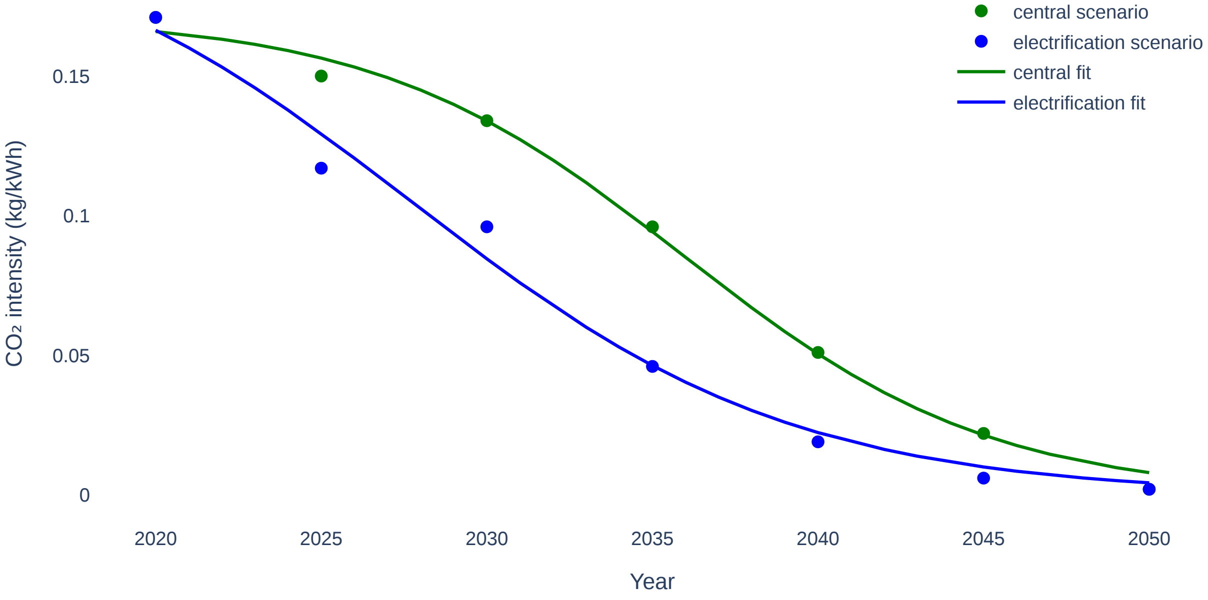

Figure 8: Logistic decay function for electricity emissions fitted on five-yearly values obtained from Paths2050.

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[21] *Paths2050 - The power of perspective*. Paths2050.energyville.be.

4 Results

4.1 Scenario development

The study simulates potential modifications to the existing Energy Performance Certificate (EPC) calculation logic in Flanders, with the primary aim of reducing carbon emissions. As discussed earlier, addressing carbon emissions is critical for achieving climate goals, and evaluating different approaches can provide valuable insights for effective policy implementation.

To determine these modifications, we compare the Flemish EPC calculation method with the French Diagnostic de Performance Énergétique (DPE). The latter already incorporates a carbon emission threshold as part of its assessment. table 2:

	Baseline	**Reference case**	**mixed 1** $\mathbf{A}_{lowcarbon}$	**mixed 2** $\mathbf{B}_{lowcarbon}$	**mixed 3** $\mathbf{A}_{mediumcarbon}$	**mixed 4** $\mathbf{B}_{mediumcarbon}$
Description	EPC A	DPE A	EPC A French CO_2	EPC B French CO_2	EPC A Milder CO_2	EPC B Milder CO_2
EPC [kWh/m^2]	100	70	100	200	100	200
CO_2 [kg/m^2]		6	6	6	8	8

Table 2: The defined cases to be discussed in this study.

For each scenario the effects of implementing a carbon emission threshold are considered on residential carbon emissions, the associated carbon abatement costs, and adoption rate of heat pumps. Through this exploration, we aim to identify strategies that can facilitate the advancement to a more sustainable and low-carbon residential building stock in Flanders. Unless otherwise specified, the results in this section are scaled to the relative occurrence of the archetypes in Flanders.

Figure 9 illustrates (a) the yearly carbon emissions per m^2, (b) the carbon abatement cost, and (c) the heat pump adoption rate for TCO-optimized renovations to three energetic targets (70kWh/m^2, 100kWh/m^2 and 200kWh/m^2), with a carbon constraint applied. For carbon constraints above 10 kg/m^2, decarbonization primarily occurs through building shell insulation, as indicated by the carbon emissions per m^2 and the constant heat pump placement rate in Figure 9 (a) and (c) respectively. As the carbon limit falls below 10 kg/m^2, carbon emissions decline rapidly, driven by increased electrification through heat pump installation. Both the heat pump placement rate and carbon emissions converge at a carbon constraint of 6 kg/m^2, indicating that, under these conditions, the carbon constraint is the dominant variable influencing the rate of heat pump placements. The carbon abatement cost[22], as depicted in Figure 9 (b), initially drops sharply for the 200 kWh/m^2 target due to the increased insulation required to meet its carbon goal. Around the 12 kg/m^2 carbon constraint, a slight rise in cost occurs, corresponding to a shift from building shell insulation (which reduces heat demand) to heat pump systems. These systems, although costly in operation, contribute significantly to carbon reduction. This pattern is also evident in the 70 kWh/m^2 and 100 kWh/m^2 scenarios. For carbon limits below 10 kg/m^2, the carbon abatement cost is similar for the 200 kWh/m^2 and 100 kWh/m^2 scenarios but displays a higher trend for the 70 kWh/m^2 scenario.

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[22] The carbon abatement cost is obtained by averaging the TCO and related CO_2 reductions.

Using the results obtained from figure 9, six scenarios were defined to be investigated in depth: The Flemish and French A-labels, the Flemish A-label with carbon constraints of 6kg/m^2 and 8kg/m^2, named $A_{lowcarbon}$ and $A_{mediumcarbon}$ respectively, as well as the Flemish B-label with carbon constraints of 6kg/m^2 and 8kg/m^2, named $B_{lowcarbon}$ and $B_{mediumcarbon}$ respectively. They are summarized in table 2.

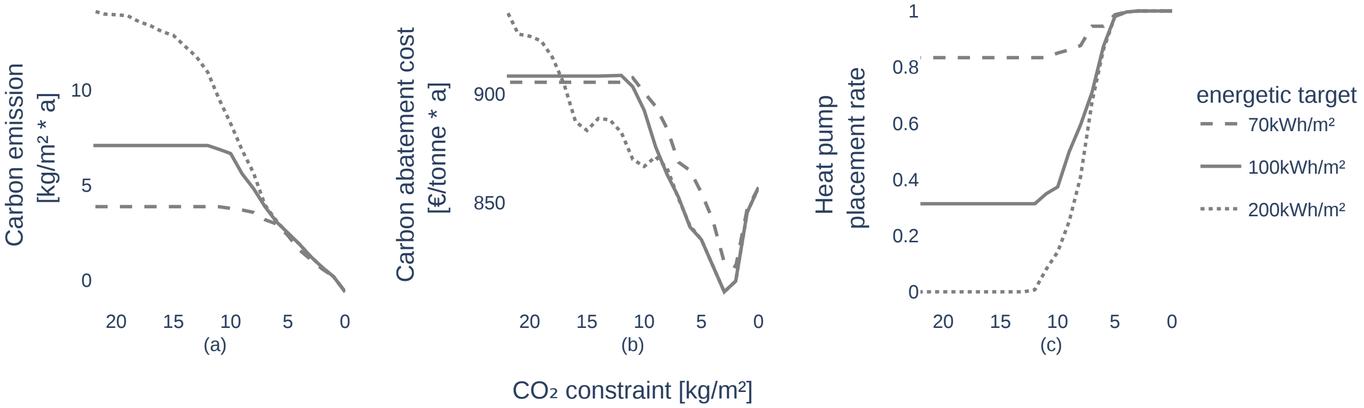

Figure 9: Impact of carbon constraints on (a) carbon emissions, (b) carbon abatement cost, and (c) heat pump adoption rate, based on TCO - optimized renovation decisions.

4.2 Archetypes

Electrification is seen as a major pathway to decarbonization of heating and cooling, which makes up about 50% of all energy consumption in the EU, of which more than 70% comes from fossil fuels, and makes up 80% of the final energy consumption of the residential sector[23]. The emphasis on electrification is further reinforced by European Union's goals to double the placement rate of heat pump systems and the phase out of stand-alone fossil boilers[16]. Figure 10 shows the simulated adoption rate of heat pumps in Flanders for the scenarios of (a) the Flemish A-label and (b) the French A-label.

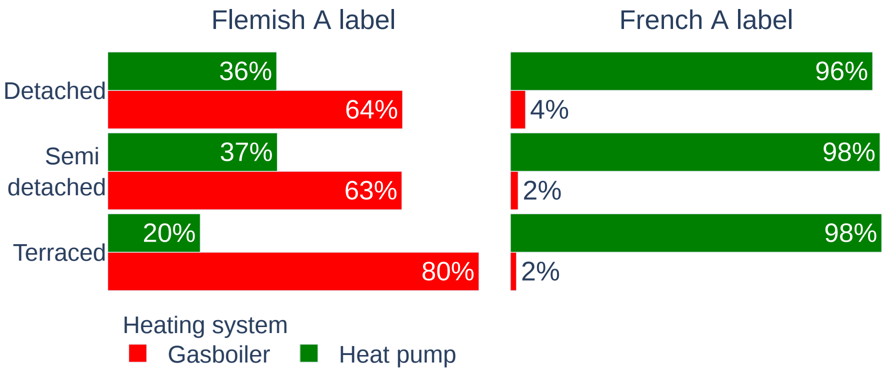

Figure 10: The amount of buildings for each building type that opt for a heat pump in their TCO optimized renovation choice while achieving the Flemish A-label, or the French A-label.

Starting on the left, the optimal choice of heating system in the Flemish A-label is clearly towards gas based boilers, representing 80% of the heating systems in terraced buildings, and almost two thirds of the heating systems in semi-detached and detached buildings. This dominance of gas boilers coincides with results reported before[24]. In contrast, the French A-label strongly favors heat pump systems as the optimal choice for heating solutions. Here, over 95%

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[23] European Commission. *Heat Pumps*. energy.ec.europa.eu. 2024.

[24] G. Reynders M. De Groote D. Aerts. *De snelste weg naar A*. energyville.be. 2022.

of the buildings opt for a heat pump, regardless of its typology. However, this increased preference for heat pumps, as well as the more strict energetic constraints of the French A-label do not come for free. This shown in Table 3, which notes a 5.4% increase in initial investment over the Flemish A-label, and a 7.9% increase in the total cost of ownership. Note that the absolute change is €19/m^2 for the investment, less than half of the €42/m^2 difference in Total Cost of Ownership, due to the unfavorable electricity-to-gas price ratio in Flanders.

	TCO [€/m^2]	**Investment [€/m^2]**	**CO_2 reduction [%]**
Current situation	407	0	0
Flemish A-label	534	348	74
French A-label	576	367	91

Table 3: Comparison of initial investment (CAPEX) and total cost of ownership (TCO) between the as is situation, the Flemish A-label and the French A-label. These costs have been weighted to the frequency of the building archetypes in Flanders.

In a next step, the Flemish A or B-label are combined with strict CO_2 constraints. Figure 11 shows the optimal choice of heating system for EPC A and B-labels with carbon constraints of 6kg/m^2 and 8kg/m^2. Figure 11 shows that the strictest CO_2 constraint results in renovations where the heat pump becomes the dominant choice of heating system, representing over 90% for each building type. In the $\mathrm{A}_{mediumcarbon}$ and $\mathrm{B}_{mediumcarbon}$ scenario, the presence of heat pumps is somewhat diminished, but still remains the dominant choice. For terraced buildings, a minor difference in the adoption of heat pump systems is observed, with 83% for the $\mathrm{A}_{lowcarbon}$ scenario, versus to 81% in the $\mathrm{B}_{mediumcarbon}$ scenario. This difference is more pronounced for detached and terraced buildings, where respectively 80% and 74% of the optimal heating systems are heat pumps in the $\mathrm{A}_{mediumcarbon}$ scenario, as opposed to 61% and 62% in the $\mathrm{B}_{mediumcarbon}$ scenario

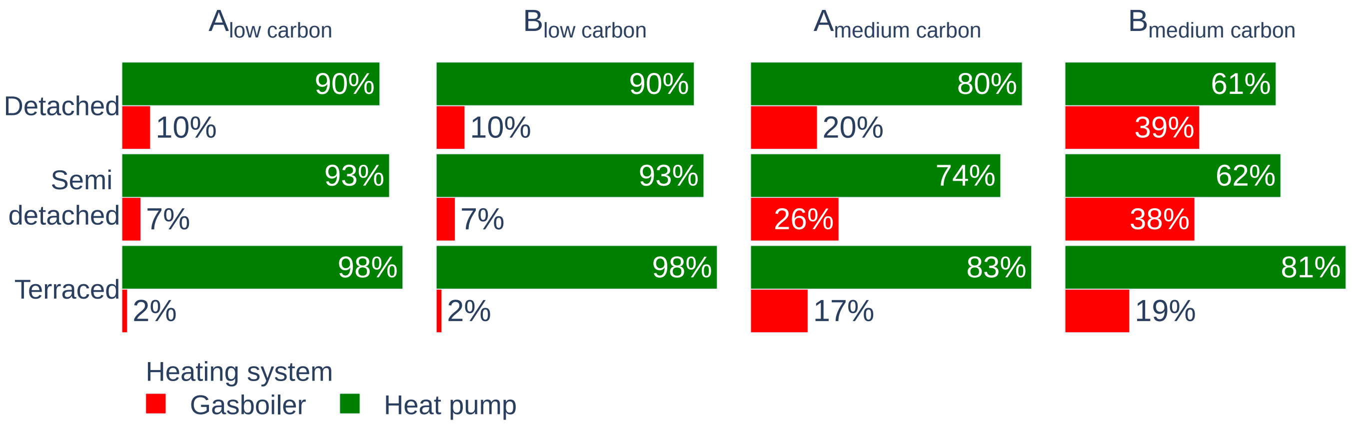

Figure 11: The amount of buildings receiving a heat pump in their OPEX optimized renovation package while achieving (a) the Flemish A-label and (b) the French A-label.

Table 4 shows the initial investment, the total cost of ownership, and the relative reduction in carbon emissions with respect to the current situation for each of the five scenarios, as well as the as is situation. Note that the Flemish A-label has the second lowest TCO of the scenarios (excl. the current situation), after the $\mathrm{B}_{mediumcarbon}$ scenario. However, it also has the second highest investment, with the French A-label being the only scenario that has a higher investment cost. Furthermore, of the scenarios shown, it is also the least effective for carbon abatement, which it owes to its high prevalence of gas boilers.

In addition, the effect of the electricity-to-gas price ratio is clearly visible in the difference between the resulting TCOs of the scenarios with Belgian, French, and Dutch prices. For both French and Dutch prices, the $B_{lowcarbon}$ scenario is the scenario with the lowest initial investment, and also the lowest cost of ownership. Furthermore, while the Flemish A-label has the lowest TCO when French and Belgian prices are applied, this no longer holds true for Dutch prices, where it has the highest Total Cost of Ownership.

The highest CO_2 savings are achieved when a strict CO_2 constraint of 6 kg/m² is applied, whether in combination with the Flemish label A or label B. This approach also results in moderately higher costs compared to the Flemish A-label (without carbon constraints). However, if the electricity-to-gas ratio becomes more favorable, these cost differences diminish, making the higher CO_2 savings more cost-effective under those conditions.

	TCO BE [€/m^2]	**Investment [€/m^2]**	**CO_2 reduction [%]**	**TCO FR [€/m^2]**	**TCO NL [€/m^2]**
Current situation	407	0	0	444	509
Flemish A-label	534	348	74	527	556
French A-label	576	367	91	513	517
$\mathbf{A}_{lowcarbon}$	552	322	90	480	482
$\mathbf{B}_{lowcarbon}$	551	321	90	479	481
$\mathbf{A}_{mediumcarbon}$	536	311	85	478	487
$\mathbf{B}_{mediumcarbon}$	528	298	83	478	492

Table 4: Overview of initial investment, the total cost of ownership, and the relative carbon abatement relative to the current situation. These costs have been weighted to the occurence of the building variants in Flanders.

The results of this section show that a significant reduction in CO_2 emissions can be achieved by an increase in heat pump adoption, and that this increase can be stimulated by the addition of carbon constraints. This, however, does not necessarily imply that shell renovation is no longer necessary. Figure 12 shows the average proportion of the upfront investment allocated to system upgrades (heating systems, PV systems, ventilation and batteries) and building shell upgrades. For scenarios with a carbon constraint (which includes the French DPE A label), a larger proportion of the upfront investment is allocated to system upgrades.

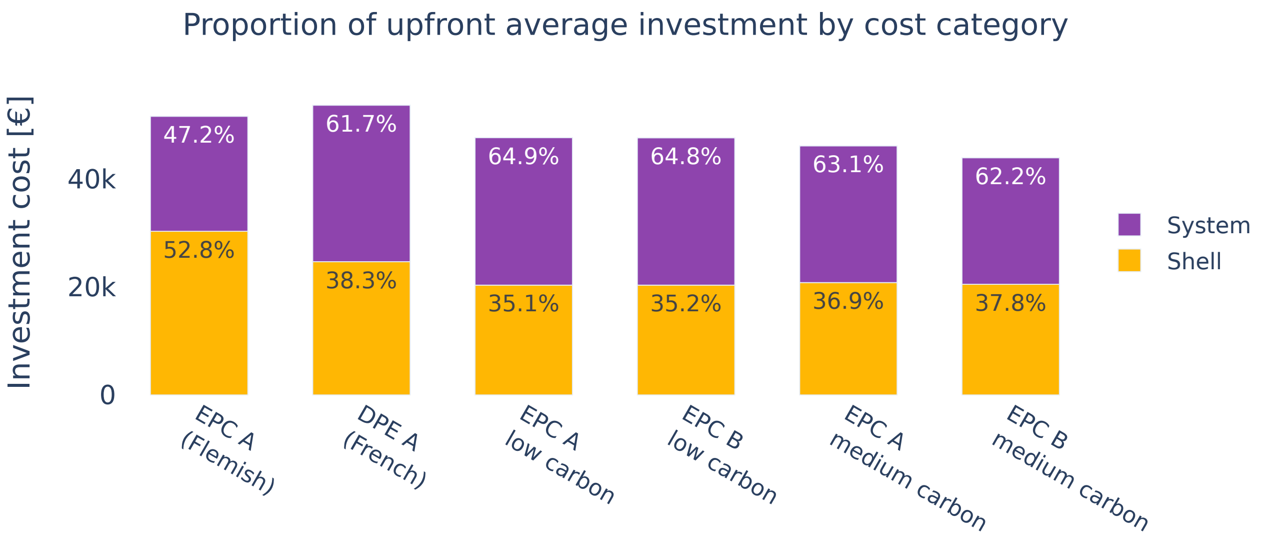

Figure 12: Bar chart showing the average proportion of upfront investment for the 6 scenarios.

4.3 TCO, Investment and optimal renovation packages

Previous studies have conducted similar analyses as presented in this study. In the previous VITO study 'De snelste weg naar A' (2022), heat pumps represent 84% of the archetypes' optimal heating systems according to the investment-optimized scenario. In contrast, the TCO-optimized scenario did not result in any additional heat pumps[25]. The past five years have been particularly volatile for the building sector, marked by the disruptions of the COVID-19 pandemic and the energy crisis, which have significantly increased renovation costs and energy prices. These recent changes explain why the TCO-optimal results for the archetypes (Figure 13) deviate from the 'De snelste weg naar A': on average, 25% of the building archetypes receive a heat pump, as opposed to none in the earlier estimates. Additionally, for the lowest initial investment scenario (not shown), only 60% of buildings are equipped with a heat pump system, a significant decrease from the 84% reported in the 'De snelste weg naar A'.

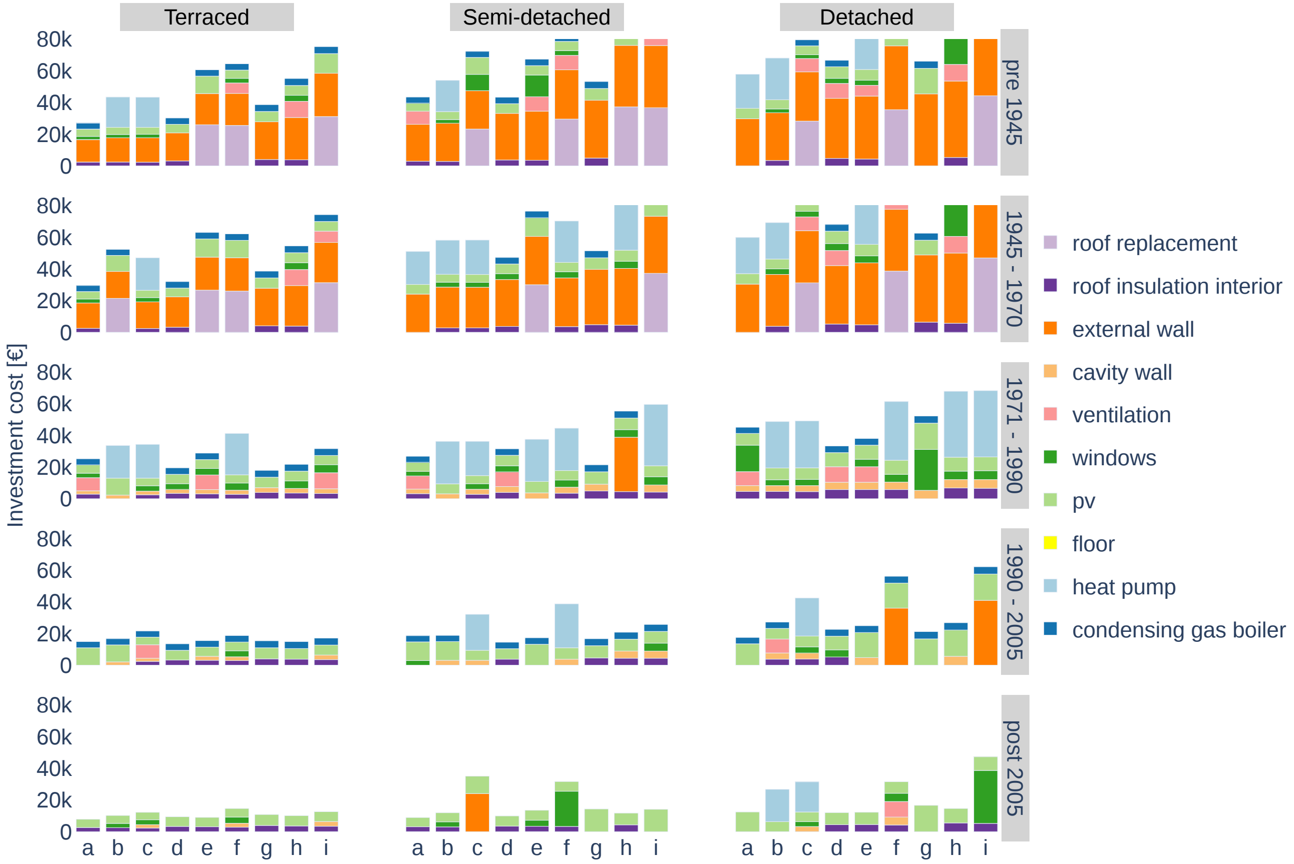

Figure 13: The OPEX optimized renovation packages of the building archetypes. Note that, for the purpose of comparison with [3], and unlike the discussion following Figures 4 and 5, the results have not been scaled to their relative occurrence in the Flemish building stock.

Interestingly, the majority of the heat pumps are placed in buildings with construction periods between 1945 – 1970 and 1971 – 1990. This result can be explained as follows: wall cavities are rare for buildings constructed before 1960. This combined with their often lower insulation level leads them to more expensive renovation measures, such as roof replacements and external wall insulation. Taking a close look at the buildings constructed between 1945

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[25] G. Reynders M. De Groote D. Aerts. *De snelste weg naar A*. energyville.be. 2022.

and 1990 reveals that those that opt for a heat pump, are typically the same buildings that are able to forego a large cost such as a roof replacement or external wall insulation, and instead opt for more cost efficient measures such as cavity wall insulation, or roof insulation from interior[26]. For buildings after 1990, only few buildings receive a heat pump. Here, this is often because the insulation level is already quite high, and cavity wall insulation, combined with another building shell measure and a PV system is therefore often sufficient to reach an A-label. It is important to note that, for comparative purposes—and unlike the discussion following Figures 4 and 5—these results have not been scaled to reflect the relative frequency of each archetype in the Flemish building stock. The differences in these results are due to large variations and uncertainty in energy prices and renovation costs. While heat pumps need a sufficiently high level of building envelope performance for their efficient operation, the rising renovation costs affect both gas and heat pump systems in a similar way. This could explain why fewer heat pumps were chosen when focusing on minimizing initial investment, as prices of different retrofit measures may have shifted relative to one another. The deviation becomes clearer when looking at the change in energy prices. In the second half of 2020, the gas and electricity prices for household consumers in Belgium were €0.0498/kWh and €0.2702/kWh respectively, a ratio larger than 5[27]. In contrast, the prices used in this study are those of the second half of 2023, €0.0994/kWh for gas and €0.3778 for electricity, bringing this ratio down to below 4. This shift significantly improves the business case for heat pumps, as is evident in the TCO optimized scenario.

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[26] Heat pump renovation packages are limited to being heat pump ready, as discussed in the methodology section.

[27] European Union. *Eurostat energy prices for household consumers*. eurostat. 2024.

4.4 Carbon intensity of electricity

With electrification having the potential to be a major contributor towards the decarbonization of residential carbon emissions, it is critical to understand its impact. In 2022, the carbon intensity of electricity in Flanders was 0.195 kg/kWh[28], In comparison, the carbon intensity for a condensing gas boiler (with 90% efficiency) is 0.202 kg/kWh, as reported by [4]. [29]

In Flanders, green electricity accounted for 21.6% of total production in 2022, whereas green heat production was only 7%, as shown in Figure 14. As the electricity mix rapidly transitions towards greener production, electrification becomes an increasingly effective decarbonization strategy. It is expected in Paths2050[30] that the emission factor of electricity will further decline to being all but CO_2 neutral[31] by 2050, which will further improve the carbon efficiency of heat produced by heat pumps. In contrast, fossil-fuel-powered boilers depend entirely on the fuel's specific emissions value, so their carbon intensity remains constant over time.

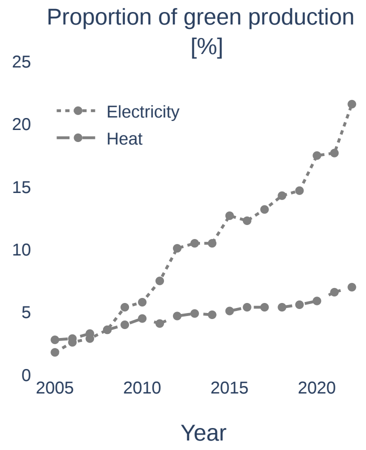

Figure 14: The proportional amount of green production for heat and electricity consumption in Flanders. Source: [17]

Assuming a heat pump is powered entirely by the electrical grid and considering a conservative efficiency of 300%[32], a heat pump alone could reduce carbon emissions from space heating by over two-thirds. This estimation does not account for additional factors, such as self-consumption from photovoltaic (PV) systems, which would further reduce emissions.

Figure 15 illustrates three renovation scenarios for A-label renovations of the building archetypes: (1) all buildings with a gas boiler (left), (2) buildings renovated using a TCO-optimized choice (middle), and (3) all buildings renovated with a heat pump (right).

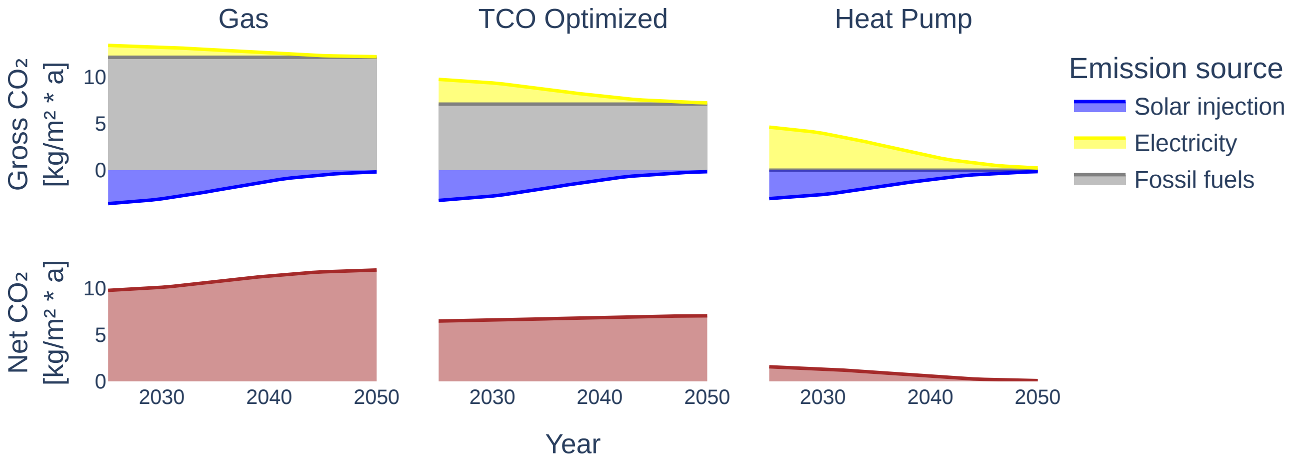

Figure 15: The CO_2 emissions per m^2 for three scenarios of the A-label: (1) all buildings with a gas boiler (left), (2) all buildings renovated using a TCO-optimized choice (middle), and (3) all buildings renovated with a heat pump (right).

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[28] VEKA. *Emissiefactoren*. vlaanderen.be. 2024.

[29] Note that a CO_2 intensity 0.171kg/kWh was used in this study, which is aligned with Paths2050 [5]

[30] *Paths2050 - The power of perspective*. Paths2050.energyville.be.

[31] An intensity of 0.002kg/kWh is expected for the central scenario, and 0kg/kWh in the electrification scenario.

[32] Note that a pessimistic SCOP of 3 was chosen purposefully for this comparison. Real world SCOP values are often significantly higher, leading to an even larger CO_2 reduction when replacing a gas boiler with a heat pump.

The carbon emissions are calculated based on the expected carbon emission factors (see section 2). The gross emissions (top row) are divided into fossil fuel emissions, electricity emissions (incl. self-consumption from photovoltaic systems), and emissions from solar injection (shown as negative emission values). The net emissions (bottom row) are the sum of these three sources.

After renovation, electricity consumption and photovoltaic injection alter the carbon emissions due to the expected decrease in carbon intensity of electricity, while fossil fuel emissions remain constant. In the gas boiler and TCO scenarios, the **net emissions increase over time**, which might seem counterintuitive at first, given the shift to greener electricity. However, a closer look shows that the "offset" from solar injection is greater than the emissions from electricity consumption. As the carbon intensity of electricity *decreases*, both the emissions from electricity consumption and solar injection also *decrease*. When the solar injection exceeds electricity consumption, the total emissions *increase*. This effect does not occur in the heat pump scenario, where full electrification leads to electricity consumption emissions outweighing the solar injection offset, making it the only scenario where net emissions decrease over time.

4.5 Renovation rates and phased renovations

Phased renovations are often applied by households to space their investments in time and thereby improve the affordability of their building renovations. However, lock-in effects can be a major drawback to such an approach.
To investigate the effect of prioritizing electrification, a phased renovation method was applied, and its results compared to the Flemish A label. In our example, the phased renovation consists of two renovation moments: first a building is renovated to an EPC C label with a heat pump. Then, after 10 years, it is further renovated to an A label. The first renovation is always chosen in function of the renovation to an A label, as to avoid possible lock-in effects.

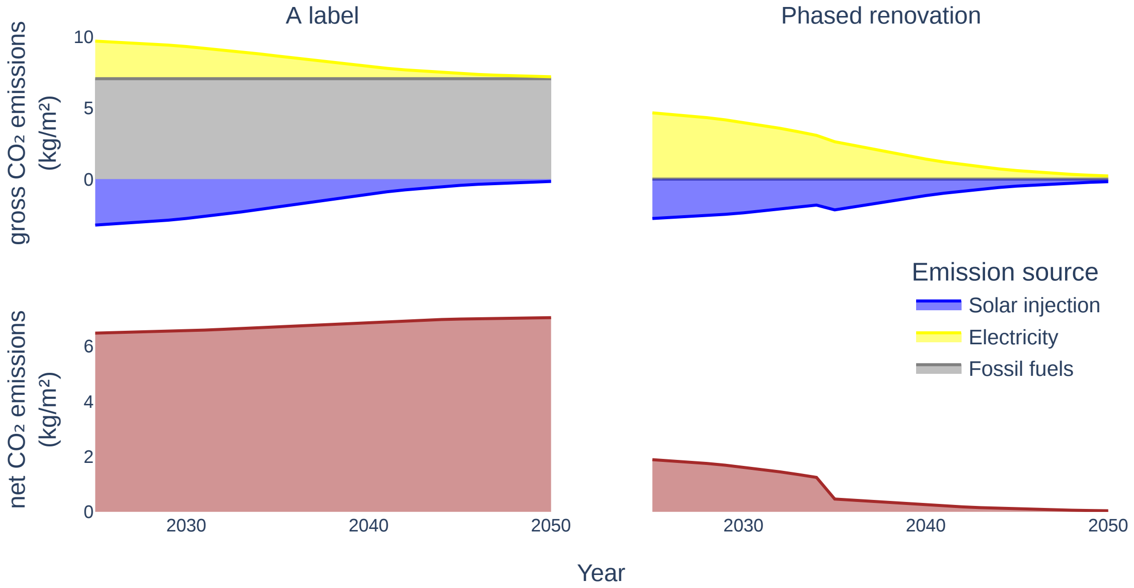

Figure 16: The carbon emission per m^2 of the OPEX optimized renovation packages of an A-label (left) and a phased renovation with a heat pump in phase 1.

Figure 16 shows a stacked area chart of the carbon emissions of the building archetypes for A label renovations (left) and phased renovations (right), and taking into account the future carbon intensity of electricity. The phased renovation shows a significantly lower carbon emission, and, unlike the A label, reduces its net emissions despite the solar offset (see section 4.4).

Figure 16 illustrates an optimal scenario, assuming all buildings are renovated simultaneously, which demonstrates the full potential of large-scale electrification. However, a more realistic approach involves a yearly renovation rate. Figure 18 presents the carbon emissions relative to the current situation for phased and A-label renovations, evaluated at renovation rates of 1.5%, 3%, and 4%.[33].

It is important to note that even at these renovation rates, the phased renovation scenario never achieves 100% A-label renovations. This is illustrated in Figure 17, which shows the total number of renovated buildings at a 3% renovation rate and the proportion achieving an A-label in the phased renovation strategy.

The results clearly demonstrate that for each of the three renovation rates, phased renovation—i.e. prioritizing heat pumps over building shell insulation—yields a greater carbon abatement. Notably, the phased renovation at a 3% renovation rate achieves a higher carbon abatement than the A-label renovation at a 4% rate, as shown in Figure 19.

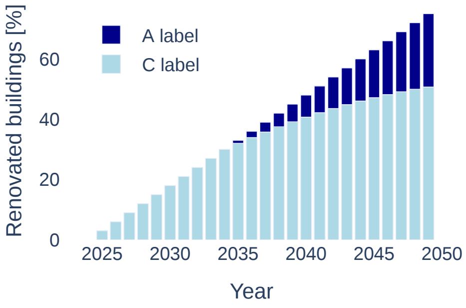

Figure 17: Proportion of renovated buildings with a 3% renovation rate. For non phased renovations, the amount of renovated buildings is equal to the sum of A and C label renovations.

In short, when optimizing TCO for renovation, step-wise renovation towards decarbonization can realize higher CO_2 reductions, if heat pumps are prioritized and lock-in is avoided.

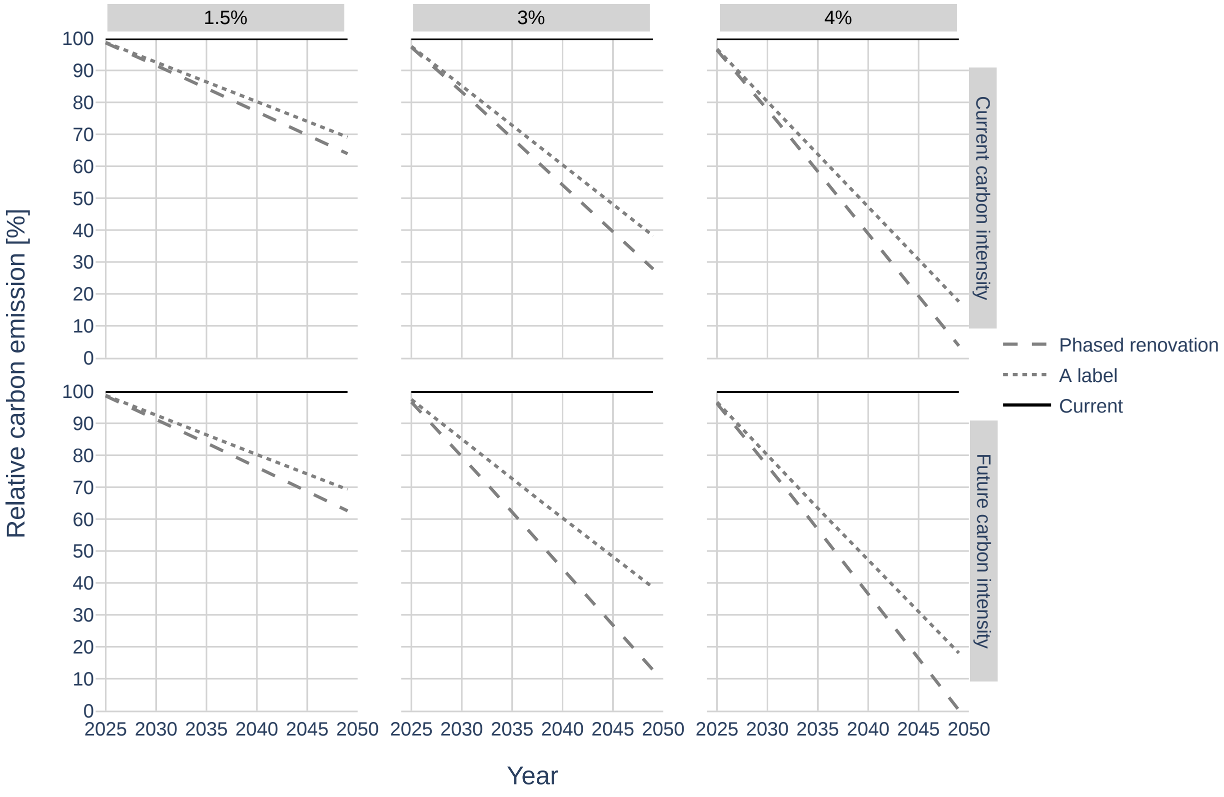

Figure 18: The relative yearly carbon emission of EPC A-label and phased renovations with renovation rates of 1.5%, 3%, and 4%, with respect to the current situation.

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[33] To mitigate any selection bias, this calculation was repeated many times, with results averaged

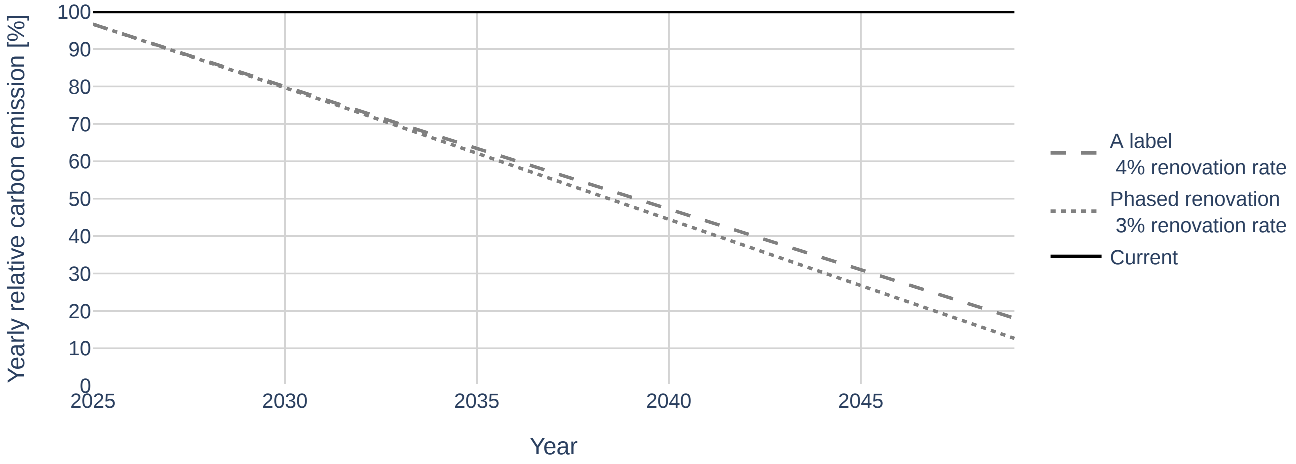

Figure 19: Relative yearly carbon emission (w.r.t. the current situation) for the A-label scenario with a 4% renovation rate, and the phased renovation scenario with a 3% renovation rate.

4.6 Districts

The archetype results demonstrate that electrification of residential heating, particularly through heat pump systems, plays a crucial role in carbon abatement. By setting energy targets that are tailored to the specific characteristics of different building types, significant carbon reductions can be achieved without necessarily increasing investment costs beyond those required to meet an EPC A-label. However, the electricity-to-gas price ratio remains a significant barrier to widespread adoption. It is important to recognize that the archetype results, despite being scaled to their relative occurrence in Flanders, may not directly translate to specific districts due to local variations in social, demographic, and geographic factors. To account for these variations, the archetype results were applied to three distinct districts: Boxbergerheide in Genk, Brugse Poort in Ghent, and Berendrecht in Antwerp. These districts were selected based on their distribution of building typologies and construction periods, as well as to capture diverse social contexts, such as the 50/50 split between owners and tenants in the social housing district of Brugse Poort, and the predominance of homeowners in Boxbergerheide. Figure 20 illustrates the distribution of building types and construction periods across these districts.

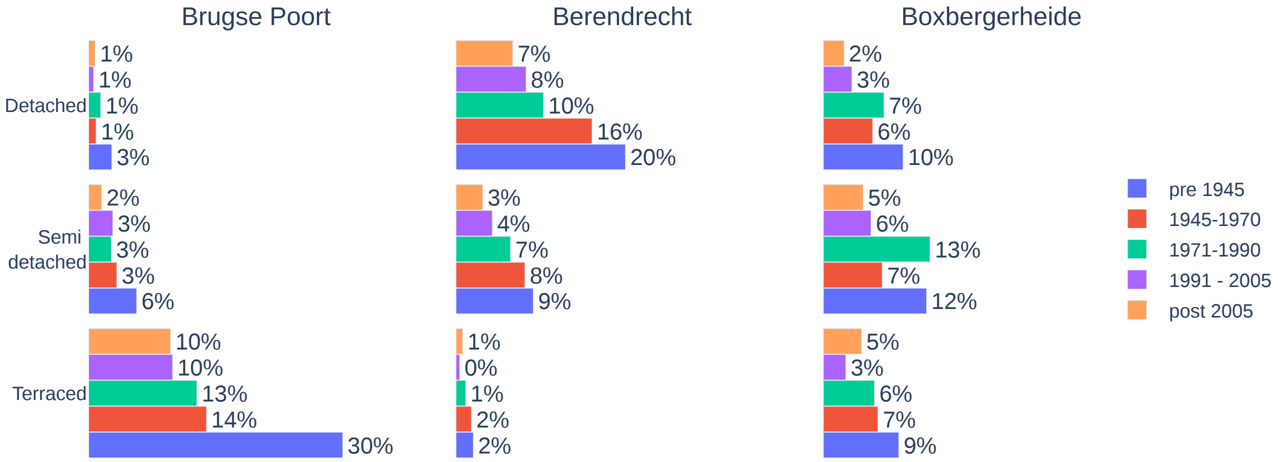

Figure 20: Distribution of construction periods and building types in Brugse Poort, Berendrecht, and Boxbergerheide.

Figure 21 shows results for the following five scenarios: The standard Flemish A-label, the A and B-labels with 6kg/m^2 and 8kg/m^2, $A_{lowcarbon}$ and $A_{mediumcarbon}$, and $B_{lowcarbon}$ and $B_{mediumcarbon}$. For detached buildings, all of the districts show a preference for gas boilers, but much less pronounced than the archetype buildings, where 90% of detached buildings favoured a gas boiler. In contrast to this, terraced and semi-detached buildings strongly opt for gas boilers. It's clear that, as in the archetype discussion, at low carbon constraints of 6kg/m^2, the carbon limit is the driving factor in the TCO-optimized choice of heating systems, as only minor differences are observed between both scenarios for each district. Of the three districts, Berendrecht shows a higher heat pump placement rate at this carbon constraint. At a medium carbon constraint of 8kg/m^2, the difference between an A-label and a B-label is more pronounced. This is largely due to the increased flexibility of opting for a heat pump system instead of a typically costly building shell renovation. This alternative allows buildings to meet their carbon targets more efficiently.

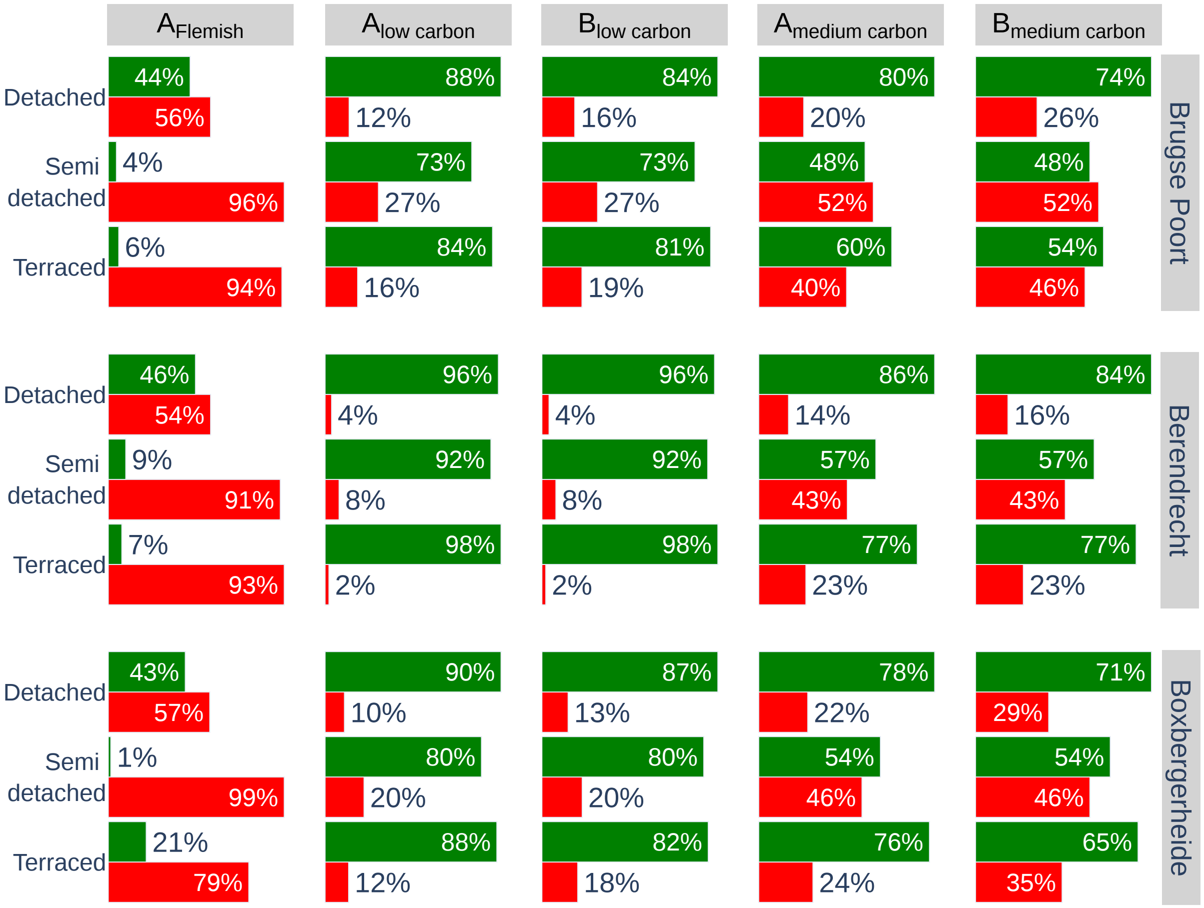

Figure 21: Overview of TCO - optimized choice of heating system for the carbon scenarios for the districts Brugse Poort (Ghent), Berendrecht (Antwerp), and Boxbergerheide (Genk).

4.7 Investment, total cost of ownership and carbon emissions

As reported by the Flemish Energy and Climate Agency (VEKA), the yearly renovation rate requiring a building permit is at 0.6%, and, including renovations not requiring a permit, is estimated at 2.5%[34]. However, only a limited number of these renovations pertain to a one-time renovation to comply with the 2050 goal of an A-label. In addition, other reports estimate this renovation rate to be 1% or lower[35,36]. One of the primary blockers to (energetic) building renovations is its high upfront investment cost, particularly for low income households[37]. A key goal of the long term strategy of Flanders is therefore to increase the already existing willingness to invest[6]. Figure 22 shows the **investment cost** for several renovation strategies in the Boxbergerheide district of Genk: A phased renovation (as described in section 4.5), the $B_{lowcarbon}$ scenario and the existing A-label. As a reference, the value Flemish "My renovation loan"[38] is added, a favourable loan of up to €60 000, available to homeowners wanting to invest in an energetic renovation[39]. Here, it is clearly shown that the investment pressure on home renovation drops significantly for the phased renovation and the $B_{lowcarbon}$ scenarios, with respectively 74% and 72% of home renovations able to have their entire investment funded by this loan, as opposed to only 55% in the A label scenario. This decrease in investment pressure is even higher for phase 1 of the phased renovation, where 83.2% of buildings are eligible to be fully funded.

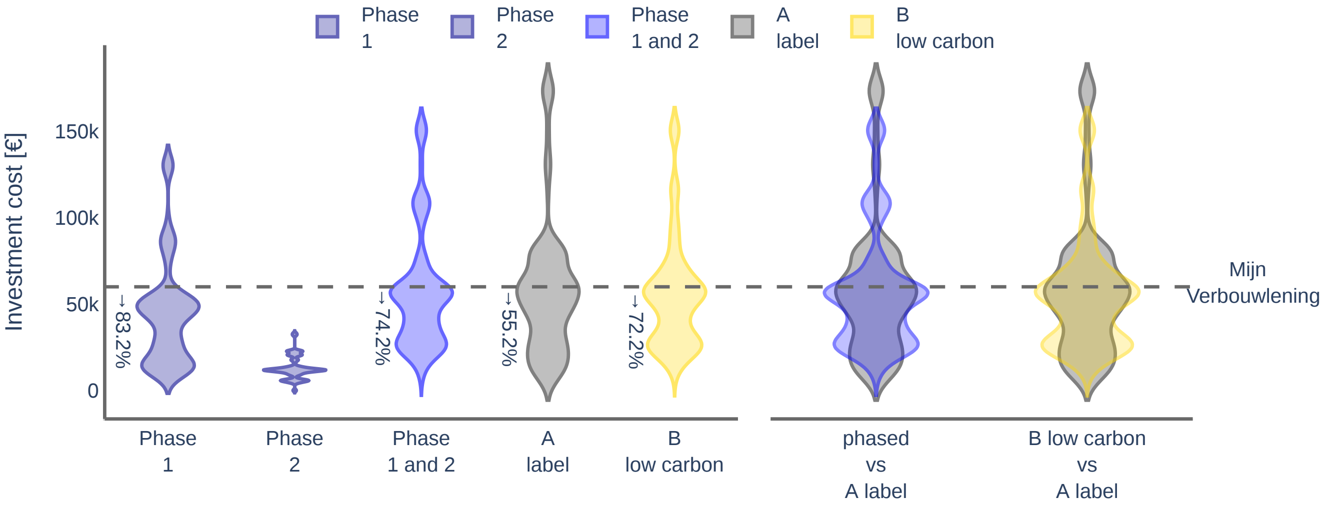

Figure 22: Investment distribution for several renovation strategies: the EPC A-label, the $B_{lowcarbon}$ scenario, and a phased renovation with focus on electrification. Here, phase 1 corresponds to an EPC-label C with a heat pump, and phase 2 is the follow-up renovation to an EPC-label A following phase 2.

Figure 23 shows the **total cost of ownership** of the renovation scenarios for the same district. In addition to the TCO calculated with Belgian energy prices, the scenarios have also been calculated with a price shift. Namely, in the first ten years the current Belgian energy prices

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[34] Vlaamse Overheid. *Vlaamse langetermijnrenovatiestrategie voor gebouwen*. assets.vlaanderen.be. 2020.

[35] Euroconstruct. *New Construction and Climate Goals in Europe*. euroconstruct.org. 2018.

[36] EnergyVille. *DITUR: Digital Twin for Upscaled Retrofits*. energyville.be. 2022.

[37] Erik Laes et al. *How do policies help to increase the uptake of carbon reduction measures in the EU residential sector? Evidence from recent studies*. 2018. DOI: `10.1016/j.rser.2018.05.046`.

[38] "Mijn verbouwlening" in Dutch

[39] Vlaamse Overheid. *Mijn Verbouwlening*. www.vlaanderen.be/mijn-verbouwlening. 2024.

are assumed, and the fifteen years after that the French energy prices. This approach reflects a potential shift in the price ratio between electricity and gas, anticipating that over the next decade, the ratio could shift from its current value of 3.8 to the French benchmark of 2.2[40]. As discussed in section 4.2. the TCO-optimization favors gas boiler heating systems in case of an A-label renovation. This is reflected in the lower segment of the TCO distribution of the A-label scenario. The TCO average of each scenario[41] is shown as a dashed line on Figure 23. It can be seen that the B$_{lowcarbon}$ scenario after a price shift is the only scenario where the average TCO drops below the A-label average. Furthermore, this scenario shows a large decrease in outliers, owing to the lower energetic target set out in the B-label.

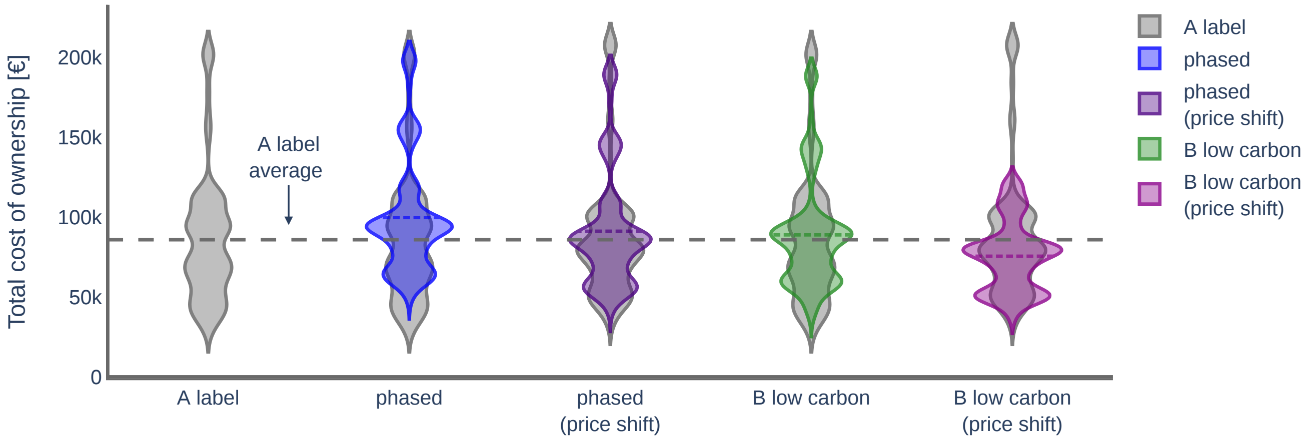

Figure 23: Total cost of ownership distribution for several renovation strategies: the EPC A-label, the EPC B$_{lowcarbon}$ label, and a phased renovation with focus on electrification

Figure 24 shows the relative carbon emission of the three scenarios with respect to the current situation, for renovation rates of 1.5%, 3%, and 4%. It is seen that both the B$_{lowcarbon}$ and the phased renovation scenarios significantly accelerate carbon abatement over the A-label renovation, owing to their high rates of electrification through heat pumps (100% in the phased renovation). Although the only scenario capable of achieving near-zero emissions is the 4% renovation rate with full electrification in the phased renovation approach, the B$_{lowcarbon}$ scenario also performs well, and significantly better than the A-label. Looking back at the investment and TCO results in Figures 22 and 23, it is clear that both these scenarios have a lower entry barrier, due to their favourable initial investment compared to the A-label. However, when considering operational costs, it becomes evident that, except for the $Blowcarbon$ scenario with a price shift, this transition will result in higher costs. This emphasizes the necessity of a price shift in Flemish energy prices if the deployment of heat pumps is to be significantly accelerated.

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[40] Note that the Flemish government intends to reduce the electricity-to-gas price ratio to 2.5. *This note is given without a reference, as it is part of ongoing government negotiations following the 2024 elections and was widely publicized.*

[41] note that the A-label violin has also been subjected to the price shift when it is compared to the price shifted scenarios. The average is, however, not shown, as it deviates less than 1% from the non shifted average.

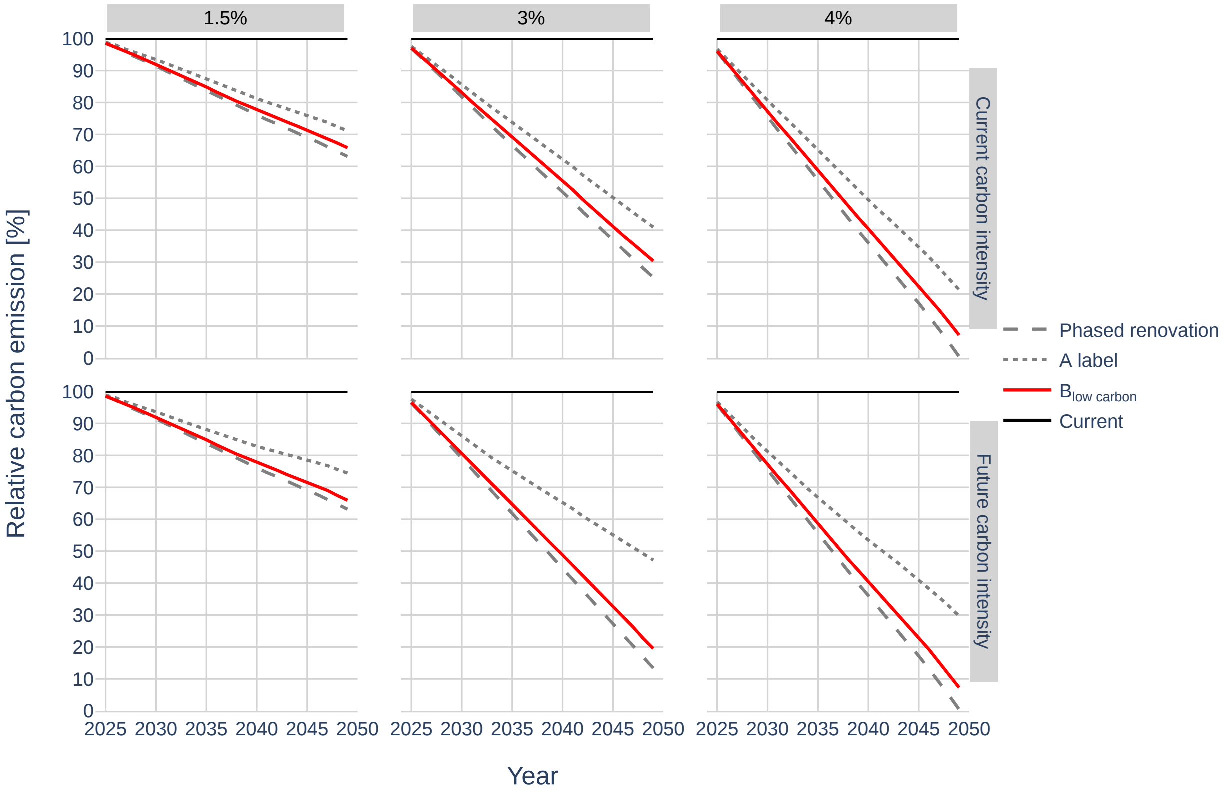

Figure 24: Renovation rates in Genk - Boxbergerheide, and the relative impact of the EPC A-label, the $B_{lowcarbon}$, and the phased renovation scenarios on carbon abatement.

5 Conclusion

This report emphasizes the critical role that electrification plays in decarbonizing residential heating of single family homes. By scenario assessment for both archetypal representations and practical validation (districts), the report provides a robust framework for understanding the challenges and opportunities within the Flemish residential building stock. The findings demonstrate that integrating carbon emission thresholds within the Energy Performance Certificate (EPC) framework can drive substantial carbon reductions by accelerating the adoption of heat pumps in existing buildings. Several key insights emerged from this study:

- Heat Pumps as a Key Solution: Under scenarios with strict carbon limits (6 kg/m²), heat pumps become the predominant heating system, significantly reducing carbon emissions. This highlights electrification's potential, especially when combined with building envelope improvements, to achieve carbon neutrality in residential heating. In contrast, gas boilers dominate as the preferred heating system in the Flemish A label when no carbon restrictions are assumed in the EPC assessment. Moreover, carbon constraints can lower the total investment barrier while still reaching high carbon reductions. For some dwellings, heat pumps combined with moderate insulation can be an alternative for strong insulation levels. This may lower the total investments while reaching similar carbon reductions. This approach enables immediate carbon abatement and long-term sustainability as the grid decarbonizes.
- Cost Implications and electricity-to-gas price ratio: While heat pumps offer long-term benefits in reducing carbon emissions, their high operational and investment costs are often a barrier for homeowners to adopt such a system. Phased renovation strategies—such as first installing a heat pump and then improving insulation—can alleviate these upfront cost pressures. If the electricity-to- gas ratio becomes more favorable (e.g. a ratio of 2.2 such as in France or a ratio of 1.5 such as in the Netherlands), the operational costs diminish, making the higher CO_2 savings more cost-effective, even under strict CO_2 constraints, as shown by the Total Cost of Ownership (TCO) optimizations. This highlights the necessity of policy interventions to address price disparities. One of these policy interventions is the introduction of the Emissions Trading System (ETS2)[42] which will impact the price ratio from 2027 onwards [19]. The Federal Public Service for Health, Food Chain Safety and Environment has previously estimated that the average energy costs of a household with a modal vehicle and a gas-heated, well insulated dwelling would increase by €177 per year, assuming an ETS2 price of €45/MWh[20].
- The results suggest that integrating carbon emissions into Flemish EPC assessments, akin to the French Diagnostic de Performance Énergétique (DPE), can promote low-carbon technologies like heat pumps and better guide homeowners toward carbon-neutrality. This strategy could be particularly effective when combined with a policy-driven shift in the electricity-to-gas price ratio.

Overall, achieving significant decarbonization in residential heating asks for a combination of policy support, financial incentives to lower upfront costs, and strategic renovation approaches that prioritize electrification. As the electricity mix on the grid becomes greener, the role of heat pumps in lowering emissions will continue to grow, underscoring the need to support their deployment across a variety of building types and districts.

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[42] European Union. *ETS2: Buildings, road transport and additional sectors*. climate.ec.europa.eu. 2024.

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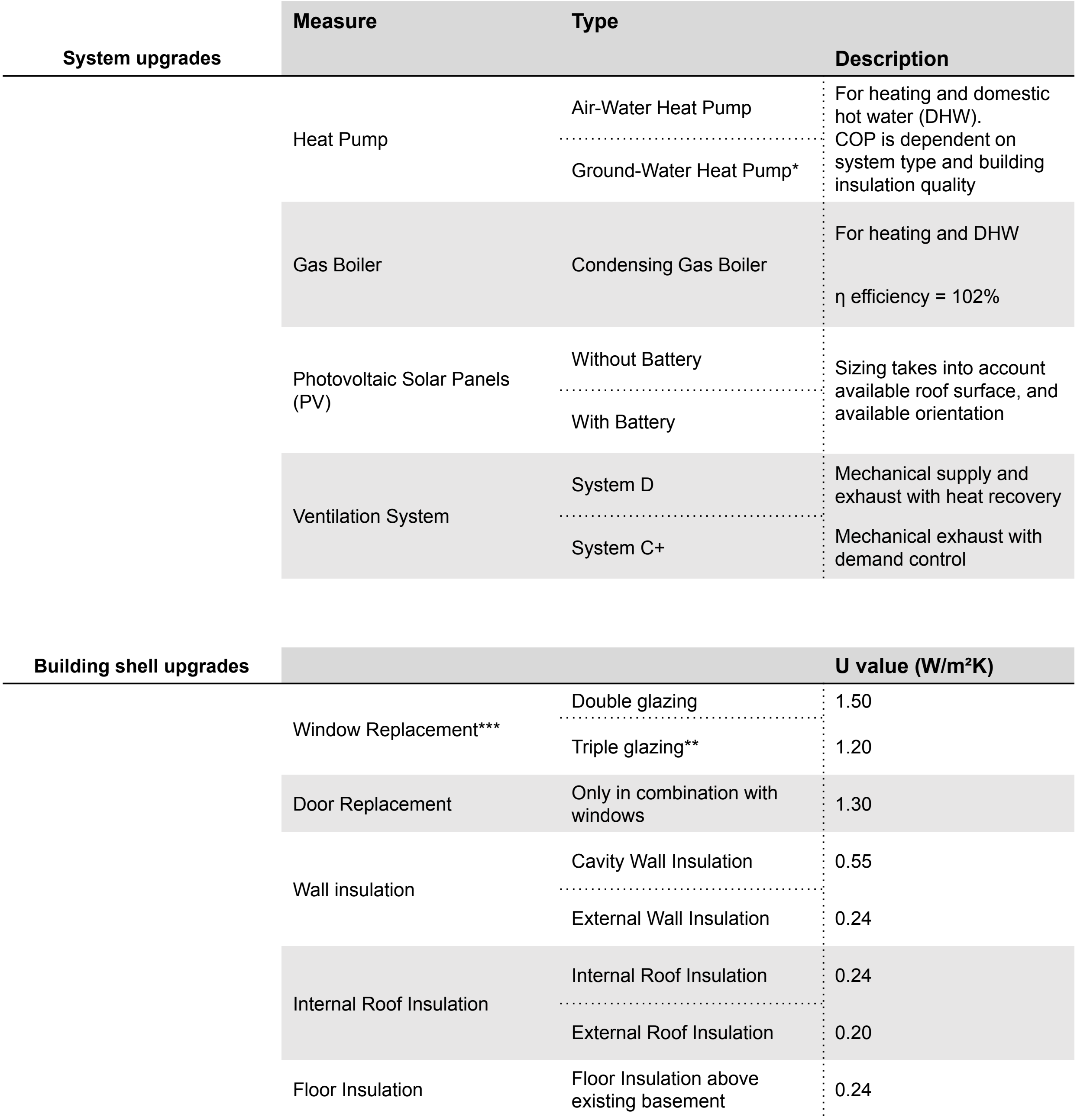
[23] *EPC residential units (Flanders)*. vlaanderen.be.

[24] *EPC residential units (France)*. ecologie.gouv.fr.

A Appendix

A.1

Table 25 gives an overview of the renovation measures taken into account for this study.



System upgrades	Measure	Type	Description
	Heat Pump	Air-Water Heat Pump	For heating and domestic hot water (DHW). COP is dependent on system type and building insulation quality
		Ground-Water Heat Pump*	
	Gas Boiler	Condensing Gas Boiler	For heating and DHW η efficiency = 102%
	Photovoltaic Solar Panels (PV)	Without Battery	Sizing takes into account available roof surface, and available orientation
		With Battery	
	Ventilation System	System D	Mechanical supply and exhaust with heat recovery
		System C+	Mechanical exhaust with demand control

Building shell upgrades			U value (W/m²K)
	Window Replacement***	Double glazing	1.50
		Triple glazing**	1.20
	Door Replacement	Only in combination with windows	1.30
	Wall insulation	Cavity Wall Insulation	0.55
		External Wall Insulation	0.24
	Internal Roof Insulation	Internal Roof Insulation	0.24
		External Roof Insulation	0.20
	Floor Insulation	Floor Insulation above existing basement	0.24

Figure 25: Renovation measures taken into account for this study.