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THE IMPACT OF MATERIALS NEEDED FOR RENOVATION AND NEW HOUSING

A GLOBAL ENVIRONMENTAL IMPACT ASSESSMENT OF THE POLICY ACTIONS IN THE FLEMISH CLIMATE POLICY PLAN

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1 INTRODUCTION

1.1 CONTEXT OF THE STUDY

According to the Flemish Climate Plan, the CO_2 emissions related to the operational energy use of buildings have to be reduced by 35% in 2030 (in comparison to the reference year 2005). This means that during the coming years, different measures need to be taken to reach a more energy efficient building stock. The operational energy use of existing buildings can be reduced by improving the insulation level of the building envelope (roof, windows, façades, …), using more efficient heating devices, use of renewable energy, … Furthermore, the newly constructed buildings must be as energy efficient as possible.

Emissions of greenhouse gases are, however, not only linked to the operational energy use of a building. The materials added during renovation or new construction also cause CO_2 emissions during their production, use and end of life phase. Consequently, a correct view on the reduction of CO_2 emissions should consider the whole lifecycle of a building.

1.2 GOAL

The main goal of this explorative study is to get a better insight into the implications of the climate goals and the related specific actions on the construction sector. More specifically, we want to get insight into CO_2 emissions related to operational energy use and materials within buildings and the balance between them. What is the trade-off between the energy (and thus CO_2 emissions) saved thanks to energetic renovation and energy efficient new construction measures versus the impact (CO_2 emissions) occasioned by the additionally added materials (production, use and end of life (EOL) phase)? In order to avoid burden shifting, the study considers not only the implications of the climate goals in terms of global warming potential but also based on a broader set of impact categories (aggregated by ways of monetisation into a global environmental score)

By creating insight in the material flows and the related environmental impact and CO_2 emissions, the potential of a circular economy in the construction sector is investigated. Indeed, with circular construction, the CO_2 emissions and other environmental impacts linked to these materials can be reduced.

1.3 VISION AND GENERAL APPROACH FOR THE STUDY

The study uses a **bottom-up approach**, starting from the results and insights of specific cases and scenarios. Through the definition, assessment and analysis of a limited number of specific renovation and new construction cases (as representative as possible for residential buildings in Flanders), some insights in the relationship between environmental impact related to the operational energy of the building and related to the production, use and end-of-life (EOL) of construction materials are gained. This way, the effects of decisions or policy on a higher level (maximal reduction of greenhouse gases related to the operational energy use of buildings) can be made tangible.

Since the electricity mix used for operational energy use of buildings may significantly influence the outcome of the study, the effect of an evolving electricity mix is also analysed as part of a sensitivity analysis.

Due to the limited extent of this study, it is not possible to define a set of cases that is representative for the whole building stock in Flanders. However, based on a limited set of well-chosen cases and using a careful scaling-up, it is possible to gain insights into the balance between reducing the impact of operational energy use and increasing the impact of materials, as well as into the order of magnitude of both parameters. Different scenarios are tested, considering various typologies, energetic ambition levels and renovation rates.

Finally, although the policy goals focus mainly on CO_2 emissions, the study considers two environmental impact indicators, namely global warming potential expressed in kg CO_2 equivalents; and a monetized global environmental impact indicator (aggregation of 17 environmental impact categories) expressed in euro.

1.4 PROJECT TEAM

This project was carried out by the Laboratory *Environmental performance* of the BBRI. This laboratory has an extensive experience in environmental evaluation of construction materials, construction elements and buildings using life cycle analysis (LCA) and in the European and Belgian legislation. More specifically, the BBRI has been involved in the different developments of the TOTEM tool (www.totem-building.be). Furthermore, the lab has an extensive experience in research on construction and demolition waste and material use in the context of a circular economy. A close collaboration was set up with the BBRI laboratories focusing on *Circular and sustainable solutions* and *Heating and ventilation*. The BBRI has followed and/or formed all relevant actions on renovation in Flanders (policy, legislation, Renovatiepact, technical knowledge, tool, …).

1.5 STRUCTURE OF THE REPORT

The report starts with a brief overview of the different climate and energy policy plans relevant for the Flemish situation at the time of the study (Chapter 2).

Chapter 3 provides a general overview of the approach and methodology used for the study. The following chapters describe into more detail the methodologies and approach used for the LCA calculations (Chapter 4),and the specification of the levels of ambitions used for the case studies (Chapter 5).

The case studies and associated scenarios for renovation or new construction are described in further detail in Chapter 6.

Chapter 7 presents the results of the individual case studies, including a sensitivity analysis on the electricity mix. Chapter 8 focuses on the scaling up of the results to the Flemish building stock, considering different policy measures and renovation speeds.

The report is completed with a concluding chapter (Chapter 9), a description of the link with the OVAM study 'Potential of TOTEM for environmental impact reduction' (TOTEM Potentieelinschatting) (Chapter 10).

2 CLIMATE AND ENERGY POLICY IN BELGIUM AND FLANDERS

As stated in the introduction, the choices and actions specified in order to reach the climate goals might have a large influence on the construction actions taken in the coming years. As the context for the choices made in this study (E-levels, scenarios, …), this chapter provides a concise overview of the current policy plans and ambitions in Belgium and in the region of Flanders related to climate and energy.

Within the context of the European Clean Energy Package, Belgium must present a final version of the **National Energy and Climate Plan (NEKP) for the period 2021-2030** by December 2019. This plan sets the framework for the different members of the European Union for planning their targets, policy and measures related to climate and energy in order to reach the European goals.

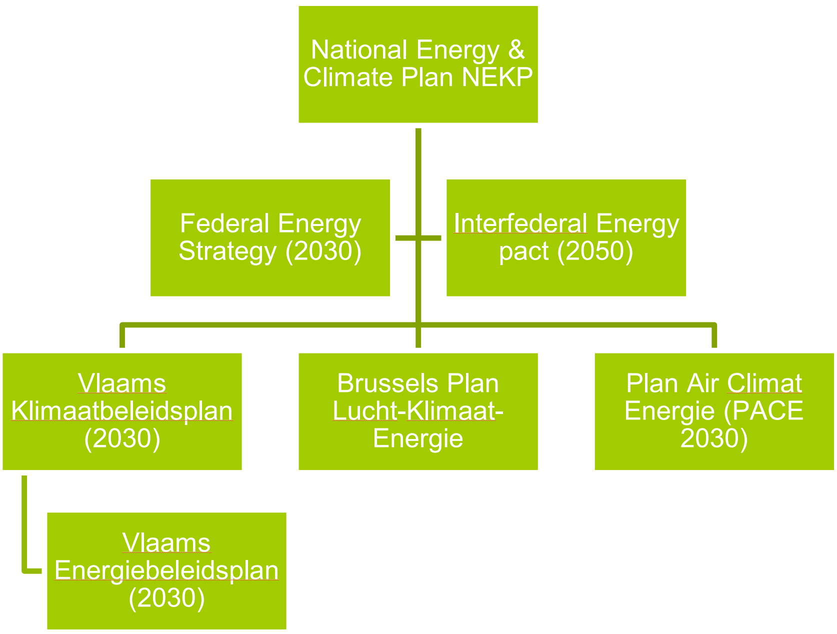


Figure 1. Overview of policy plans concerning energy and the climate relevant for Flanders

A draft version of the NEKP was presented to the European Commission on 31/12/2018. This plan consists of the national targets and is a composition of different regional and federal plans, related to the distribution of the different competences (see also Figure 1):

- At the Belgian level, the Federal Energy & Climate Plan (mainly consisting of the Federal Energy Strategy) was adopted on 30/03/2018. (https://www.nationaalenergieklimaatplan.be/nl)
- At the Flemish level, the DRAFT Energy plan and the DRAFT Climate plan (complimentary to each other) were approved on 20/07/2018. (https://www.lne.be/vlaams-klimaatbeleidsplan-2021-2030)

(https://www.energiesparen.be/sites/default/files/atoms/files/Energieplan%202021-2030%20Vlaamse%20Regering.pdf)

- The Walloon region has integrated its actions in the PACE 2030 (Plan Air-Climat-Energie). (https://energie.wallonie.be/servlet/Repository/plan-air-climat-energie-2030.pdf?ID=54248)
- The Brussels Capital region has approved its contribution to the draft National Energy & Climate Plan on 12/07/2018. (https://economie.fgov.be/nl/publicaties/ontwerp-van-geintegreerd)
- In December 2017, an inter-federal energy pact was approved, setting directions and targets for the Belgian energy system until 2050. (https://www.energiepact2050.be/)

The European Effort Sharing Regulation has set the reduction target of CO_2 emissions by 2030 with 35% (compared to 2005 level) for non-ETS sectors in Belgium. Belgium also has to contribute to the European target to improve the energy efficiency with 32.5% by 2030 (compared to 2007). In order to reach both goals, different measures and strategies are presented. Two main actions are a transition in the electricity production mix and a focused approach on renovation of the existing housing stock.

At the federal level, the **transition in electricity production mix** focusses on the switch from nuclear power to renewable energy. This means focussing on offshore wind farms in the North Sea and on the use of biofuels instead of fossil fuels.

In Flanders, the draft Climate Plan contains a specific chapter on **buildings** and the renovation of the housing stock. The proposed measures correspond largely to the measures in the draft Energy Policy Plan. Key actions are:

- A better maintenance and an accelerated renewal of old heating installations, including making the switch from fossil fuels (petrol) to electricity (heat pumps).
- More residential photovoltaic (PV) installations.
- More and better housing renovation.

Concerning the **housing renovation**, one of the proposed actions is to set more stringent obligations concerning the maximum E-level, namely going towards E60 for all deep housing retrofits by 2050, which is in line with the long term objective stated in the 'Renovatiepact[1]'. Another action consists in making energy renovation obligatory after a real estate transaction. It would be compulsory to take at least three of the following six renovation measures within 5 years after acquiring a dwelling:

- Insulation of the roof, walls or floor to the current energy standards (Umax = 0.24 W/m²K);
- Windows with energy performance according to current standard (Umax,w = 1.7 W/m²K, Umax,g = 1.1 W/m²K);
- Use of an energy performant heating system: condensing boiler or heat pump;
- Sanitary hot water (SHW) production using a heat pump boiler or a solar boiler.

Further reading and more details on these actions, as well as additional actions, are available at: www.lne.be/vlaams-klimaatbeleidsplan-2021-2030 and www.cnc-nkc.be.

[1] The 'renovation pact' is an initiative of the Flemish Government (taken in 2014) bringing together different concerned parties from the building industry to stimulate energetic renovation of housing. The pact includes long term goals for 2050 concerning the environmental performance of existing dwellings.

It should be noted that the Flemish Climate Plan also contains a chapter on Green & Circular Economy with direct or indirect implications for the construction sector: building passports, temporary use of buildings, discouraging non-recyclable materials, priority to circular solutions in public tenders, …

Note from the authors. The DRAFT version of the national plan is open for public consultation at the date of first drafting this report (July 2019) and some criticism was already expressed for the lack of concrete and quantified measures and the lack of coherency on national level, caused by the combination of several separate plans. This study used the draft NEKP (d.d. December 2018) as a basis for the definition of the levels of ambition for renovation. As the NEKP is subject to further changes throughout 2019, the most important elements for the construction sector, as presented below, should be considered as indicative and should be considered within the context of the goals set for this study.

3 GENERAL APPROACH

Within this study, the environmental impact of residential renovation and new construction activities in Flanders are assessed based on a limited number of case studies. For each case, the environmental impact of the material use for renovation/construction is calculated, together with the impact of the operational energy use of the renovated/newly built dwelling.

3.1 CALCULATION OF THE ENVIRONMENTAL IMPACT

The environmental impact is quantified using Life Cycle Analysis (LCA). The study considers two indicators:

- Global warming potential (expressed as kg $C0_2$ equivalents)
- A global monetised environmental score (expressed in Euros) which represents the aggregation of 17 individual environmental impact categories.

More information on the methodology is available in chapter 4.

3.2 CASE STUDIES

This study uses a set of reference buildings defined in the study on financial cost optimal EPB-levels for residential buildings carried out for the Flemish Energy Agency VEA in 2013 and 2015 (https://www.energiesparen.be/EPB-pedia/beleid/studies) [5,6]. These buildings are representative for different typologies in the Flemish housing stock. For this study, four representative reference buildings are selected: a terraced house, a detached house, an apartment building and a semidetached house. The first three buildings are considered as reference cases for renovation. The semidetached house is used to investigate the impact of additional new construction. More information on the reference buildings is given in chapter 6. For each reference building, different scenarios, corresponding to various energetic ambitions and measures are specified.

3.3 DEFINITION OF LEVELS OF AMBITION AND (RENOVATION) SCENARIOS

Three main levels of ambition have been specified for the renovation and new construction of buildings in Flanders based on national and regional climate plans and current and future regulation: (1) a basic level with minimal ambitions (≈ 3 renovations measures), (2) a mean level reflecting long term goals (≈ E60) and (3) a high-end level with maximised ambitions (≈ E30). The selection of the different levels of ambition is further specified in chapter 5.

For each reference building, different scenarios are defined to reach these ambitions. For example, a renovation to an E60-level can be achieved by insulating the building envelope or by focusing more on the technical installations. For each ambition level and each case, different scenarios have been developed.

3.4 SCALING UP TO THE FLEMISH BUILDING STOCK

Based on statistics of the Flemish housing stock, the results for the individual reference buildings are scaled up according to their building typology. A set of scenarios is evaluated, considering different levels of ambition for the renovation as well as different renovation speeds. Furthermore, the impact of considering additional new construction is added to the equation. This exercise provides some general insights in the (reduction in) CO_2 emissions and the global monetised environmental impact related to different renovation/new construction scenarios over the next 30 years. However, given the limited number of reference buildings, these results should be interpreted with care. This scaling up is described further in chapter 9.

4 LCA METHODOLOGY

4.1 GOAL

Within this study, Life Cycle Analyses (LCA) are carried out to evaluate the emissions of greenhouse gases associated with various energetic levels of ambition for renovation or new construction of several reference buildings. More specifically, the goal is to gain further insights in the impact related to the material use during renovation/construction versus the impact related to the operational energy use of the building.

4.2 SCOPE, METHODOLOGY AND HYPOTHESES

The life cycle analyses are performed following the MMG-methodology (cfr. life cycle stages, scenarios for transport and end of life, reference service life, impact assessment methods) [2,7]. This methodology also forms the basis for the online TOTEM tool (www.totem-building.be).

Nevertheless, in consultation with OVAM the calculations are performed within the specialised LCA software SimaPro for several reasons. Modelling in the specialised software allows to incorporate the material related impacts of the technical installations (e.g. for heating, sanitary hot water production, ventilation systems and PV panels), which are not available for modelling in the TOTEM tool at the date of these analyses. Furthermore, in Simapro the impacts related to different energy consumption profiles can be calculated based on EPB data (resulting from separate energy performance calculations). The TOTEM tool only allows for the calculation of the impact related to heating according to the degrees-days method, assuming a condensing gas boiler. Also, SimaPro allows for more freedom in the choice of materials that are used to model the specific building parts, which might be missing in the TOTEM tool to date. Finally, the specialised software allows to dig deeper into the LCA-results, or to perform sensitivity analyses on the results (e.g. using a different electricity mix).

Table 1 summarises the scope and main parameters of the life cycle analyses for the study.

Table 1. Scope and parameters of the life cycle analyses carried out within this study

Software	SimaPro v8.5.2.0
Database (Life Cycle Inventory)	Ecoinvent v3.4, allocation cut-off by classification
Reference study period (RSP)	30 years (start in 2020, end in 2050)
Reference service life (RSL) of materials	As in TOTEM [4]. The number of replacements is calculated as the nearest integer value of (RSP/RSLmaterial - 1).
Allocation and system oundaries	According to NBN EN 15978 [8]. The analysis considers the following modules: ▪ A1-A3 Product stage (raw materials supply, transport, manufacturing) ▪ A4 Transport of materials to the building site ▪ A5 Installation of materials on the building site ▪ B4 Replacements ▪ B6 Operational energy use (i.e. energy for heating, domestic hot water (SWW) supply, cooling and ventilation, auxiliaries and non-building related energy). ▪ C1-C4 Demolition, transport, waste processing and disposal of materials
Scenarios	▪ Scenarios for transport (module A4) and end-of-life of materials (modules C1-C4) are representative for the Belgian context [9]. ▪ The operational energy use (module B6) is calculated using the EPB methodology for residential buildings in Flanders (2015).
Life Cycle Impact Assessment (LCIA) indicators and methods	▪ Global warming potential (GWP) [kgCO_2eq.] ▪ Monetised global environmental impact indicator (TOTEM-score) considering 17 individual impact categories and expressed in euros [€] (see

	▪ ▪ Annex 1 – Monetised global environmental indicator) Both indicators are calculated with the MMG method 2014, update December 2017 (v1.05) [10].
Electricity mix	For the operational energy use, an electricity mix representative of the Belgian market (= national production + imports) for the year 2014 is used (latest mix available in Ecoinvent v3.4). This mix is kept constant for the entire reference study period. A sensitivity analysis is carried out where the electricity mix is changed after 10 years.
Renovation cases	According to NBN EN 15978 [8]. Only newly added materials during renovation of the buildings are assessed**.** The impact of (demolition of) existing materials is not assessed, since this impact belongs to the former lifecycle of the building.

4.2.1 Reference study period

In order to reflect the time horizon set by the Flemish authorities to the year 2050, the reference study period (RSP) for this LCA study was set to 30 years. This period starts the year of the renovation or new construction (2020) and ends in 2050.

Compared to a typical building LCA study considering a RSP of 60 years (RSP considered in Totem), the use phase of a study with a RSP of 30 years is shorter. Therefore, less material replacements need to be considered. Although the end-of-life (EOL) related impact of the building will most likely take place beyond the considered 30 years period, it is still included in the results because it relates to construction actions taken at the start of the RSP (2020). Figure 2 illustrates how impacts increase over time for a typical building or renovation action. In this study, distinction is made between construction materials (e.g. insulation, bricks, plaster, …) and material related impact of technical installations (e.g. ventilation ducts, ventilator, condensing gas boiler, expansion vessel, …). The EOL impact is represented by means of diagonally hatched bars because in reality it occurs beyond the considered RSP of 30 years, but it is included within the scope of the study.

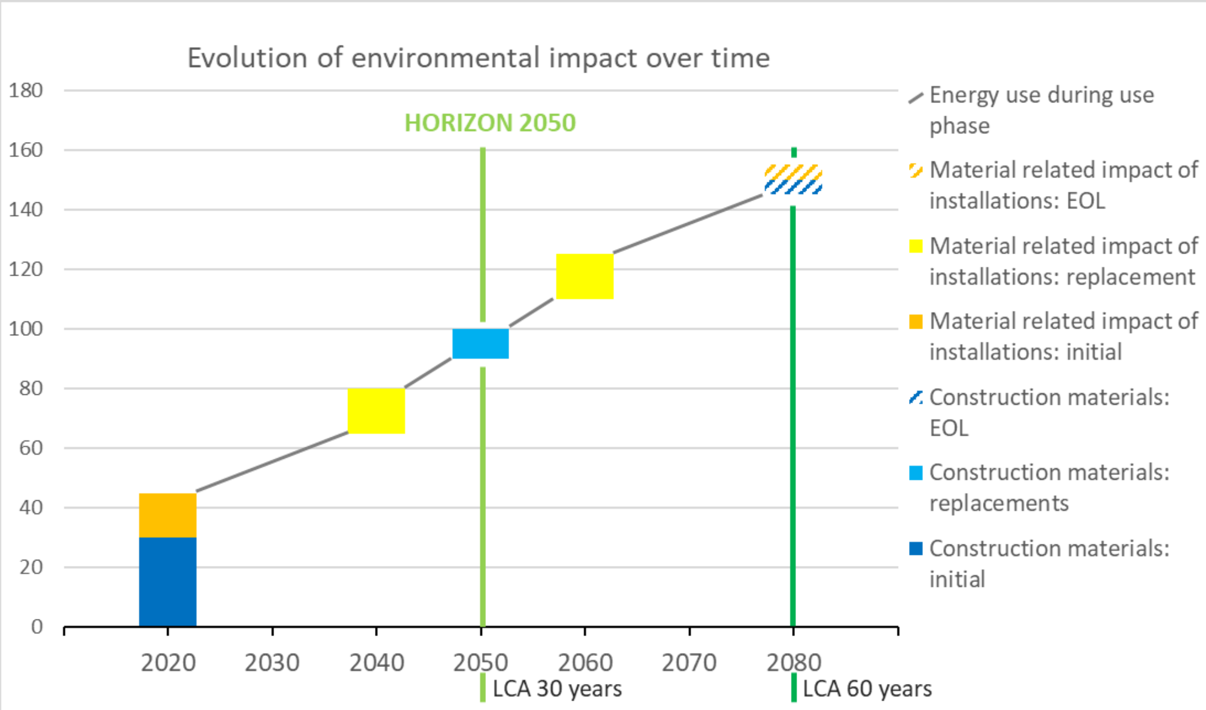


Figure 2. Conceptual representation of the different impacts over time, in relation to the RSP (reference study period).

4.2.2 Renovation

For the renovated buildings, only the life cycle/embodied impact (production, transport, installation, replacements and EOL) of the newly added construction materials and technical installations is assessed. The impact of the existing construction materials and technical installations within the building (that are not removed or changed during renovation), as well as of construction materials and technical installations that are removed and demolished during renovation, is not considered, because this belongs to the former life cycle of the building.

4.2.3 Replacements (module B4)

Replacements of construction materials and technical installations (module B4) are considered during the reference study period of 30 years. This means that all construction materials and technical installations with a service life below 30 years will be replaced. Table 2 provides an overview of the service life for all technical installations that are replaced (all construction materials considered for the study have a service life of at least 30 years, and therefore none are replaced).

It is important to note that for the “reference situation” of the renovation cases, no replacements are considered, only operational energy use. In reality, however, technical installations from existing buildings are likely to be replaced somewhere within the considered horizon of 30 years. Therefore, for the reference situation the material related impact of installations is slightly underestimated (because no replacement of the old boiler is considered), and the operational energy use is overestimated (new condensing gas boilers are up to 30% more energy efficient than old boilers[2]).

Table 2. Service life of technical installations replaced within 30 years.

Technical installation	Service life (years)
Heat pump air-water	15
Condensing gas boiler	20
Expansion vessel	20
Circulation pump	20
Hydro collector	20
Central heating control (thermostat, thermostatic valves, sensors)	15
Radiators	20
Sanitary hot water storage vessel	20
PV inverter	15
Ventilation unit	15
Ventilation control unit (sensors)	15
Ventilation grid	15
Window ventilator	15
Air filters	1

4.2.4 Operational energy use (module B6)

In order to assess the environmental impact of the operational energy use of the building (module B6), the annual energy that is used to meet the different needs associated with the building is calculated using the EPB methodology for residential buildings in Flanders (2015). The following building-related annual energy uses are determined:

- energy for heating,
- energy for domestic hot water (SWW) supply,
- energy for ventilation and auxiliaries, and
- energy for air-conditioning (cooling).

[2] http://document.environnement.brussels/opac_css/elecfile/IF%20Energie%20CH01%20part%20FR

For the reference situation of the renovation cases (=continuing to use the building in in its original state), the energy use for heating calculated using the EPB methodology is a worst-case scenario. Indeed, for buildings with a poor energy performance, it is known that the actual energy consumption is likely to be lower than what is predicted by EPB (typically factor 0.5), because in that situation people will tend to accept lower thermal comfort.

For determination of the environmental impact of electricity use, an electricity mix representative of the Belgian market (= national production + imports) for the year 2014 is used (latest mix available in Ecoinvent v3.4). This mix is kept constant for the entire reference study period.

In case of scenarios including rooftop photovoltaic panels, the electricity produced by the panels is calculated. Since certain scenarios are gas-based, it is assumed for all scenarios that the produced electricity is entirely exported to the Belgian electricity grid. As a result, a “benefit” or “avoided impact” can be specified for the scenarios using PV: this “avoided impact” corresponds to the impact of a corresponding amount of energy sold on the Belgian market. According to the European standard NBN EN 15978, the environmental benefits resulting from the exported energy must be reported in module D [8]. The avoided impact from a corresponding amount of electricity sold on the Belgian market is indicated in module D as a negative value. The material related impact of the PV installation is declared in modules A1-A3 (production).

Nevertheless, in order to also allow for the evaluation of the direct use of electricity produced by photovoltaic panels within the building (even for scenarios without electricity use for heating and domestic hot water supply), the non-building related energy use of home appliances is also included in this study. This electricity use is set at 3000 kWh/year for each building type (mean value used for a family with 4 persons in Flanders). The environmental benefits of using electricity produced by PV panels directly within the building shows when subtracting the avoided impact of electricity produced by PV panels (reported in module D) from the impact of the non-building related energy of home appliances.

5 SCENARIOS FOR DIFFERENT LEVELS OF AMBITION

Based on the different national and regional climate plans (policies and measures to reduce emissions of greenhouse gases) (see also chapter 2) and on current and future regulation for buildings in Flanders, different ambition levels and renovation scenarios were defined for the different renovation and new construction cases evaluated in this study.

5.1 SCENARIOS FOR THE RENOVATION CASES

Table 3 gives an overview of the ambition levels and corresponding renovation scenarios defined for the renovation case studies.

Table 3. Overview of scenarios for the renovation case studies.

Ambition level	Renovation scenarios and measures
Minimal renovation	The building is renovated by application of three specific renovation measures. (1) Replacement of the heating installation (2) Insulation of one element of the building envelope to U=0,24W/m².K (3) Insulation of a second element of the building envelope to U=0,24W/m².K *OR* Replacement of the windows Depending on the reference case, different options are selected for the last measure.
Renovation to E60	The building is renovated to achieve level E60. Minimum two alternative scenarios are evaluated: **E60mat** (1) Focus on insulation of the building envelope, including replacement of windows (2) Basic replacement of heating installation **E60inst** (1) Insulation of the building envelope according to minimal regulatory requirements * (2) Focus on installations (heating, ventilation, PV)
Renovation to E30	The building is renovated to achieve level E30. Minimum two alternative scenarios are evaluated: **E30gas** (1) Focus on insulation of the building envelope, including replacement of windows (2) Heat production using a combi condensing gas boiler **E30HP** (1) Insulation of building envelope according to minimal regulatory requirements * (2) Heat production using an air-water heat pump Whenever needed, PV panels are added to reach the desired ambition level.
* U=0.24 W/m².K for building envelope; U=1.5 W/m².K and Ug=1.0 W/m².K for windows	

5.2 SCENARIOS FOR THE NEW CONSTRUCTION CASE

Table 4 gives an overview of the ambition levels and scenarios for the new construction.

Table 4. Overview of scenarios for the new construction case study.

Ambition level	Scenarios and measures
E30 minimal	The building is conceived according to the minimal legal requirements for new construction (E30). Two scenarios are evaluated considering different technical installations. In both cases, a certain amount of PV panels is added in order to reach E30. **Min E30gas** (1) Insulation of building envelope following current legislation* (2) Heat production using a combi condensing gas boiler **Min E30HP** (1) Insulation of building envelope following current legislation* (2) Heat production using an air-water heat pump
E30/E25 passive	The building is aiming for the passive standard by focussing on higher insulation levels of the building envelope. Two scenarios are evaluated considering different technical installations: **Passive E30gas** (1) Deep insulation to U=0.13W/m².K for building envelope and triple glazing (2) Heating production using a combi condensing gas boiler **Passive E30HP** (1) Deep insulation to U=0.13W/m².K for building envelope and triple glazing (2) Heating production using an air-water heat pump In both cases, the minimum requirement (E30) can be achieved without PV panels
E0 passive	The building is conceived exactly as Passive E30HP, but PV panels are added in order to reach E0
* U=0.24 W/m².K for building envelope; U=1.5 W/m².K and Ug=1.0 W/m².K for windows	

6 DESCRIPTION OF CASES AND SCENARIOS

Within this study, three renovation cases and one new construction case taken from [5,6] are evaluated:

(1) Terraced house, mansion (1920) – renovation
(2) Apartment building (1970) – renovation
(3) Detached house, fermette (1985) – renovation
(4) Semidetached house (2020) – new construction

In the following paragraphs, a short description is given of the reference buildings (base cases), and the various measures taken to reach the defined ambition levels and underlying scenarios .

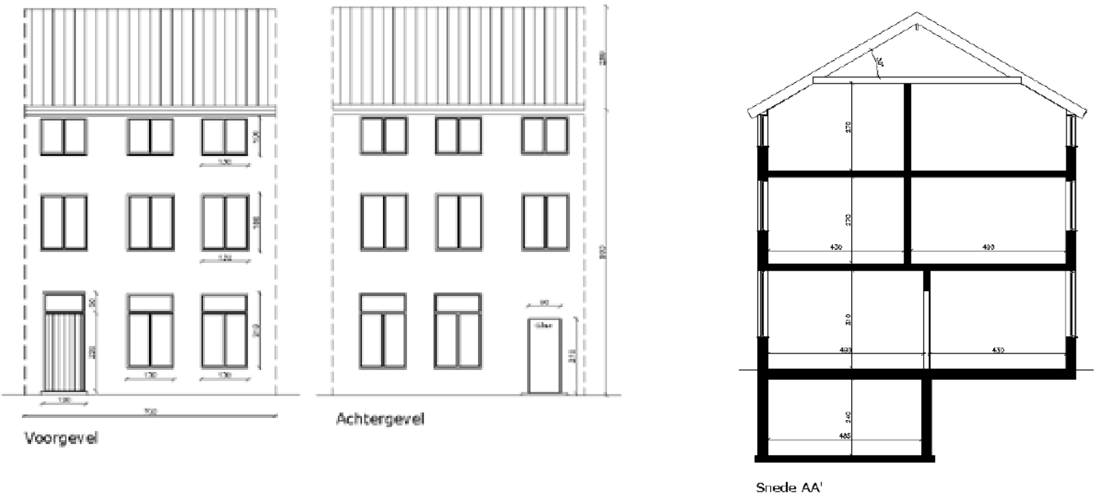
6.1 TERRACED HOUSE, MANSION (1920) – RENOVATION

6.1.1 Description of the building

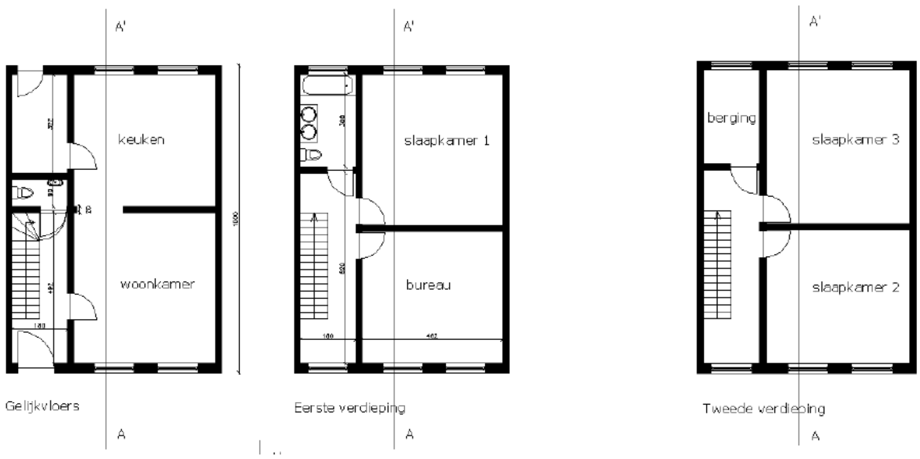
The considered terraced house was built in 1920. It consists of three floors, a cellar and an attic. Figure 3 gives an overview of the façades, a cross section and the floor plans. Table 5 provides an overview of the characteristics of the house, as it was built in 1920 (reference situation). More details on this dwelling are given in the VEA study (2013) [6].

Table 5. Overview of the characteristics of the terraced house (mansion), as it was built in 1920.

Terraced house (mansion, 1920)	
Protected volume	631.4 m³
Floor area	210 m²
Pitched roof	Non-insulated wooden roof
External walls	Non-insulated brick wall (30 cm)
Floor above cellar	Non-insulated concrete floor
Floor on ground	Ceramic tiles on sand bed
External windows	Wooden profiles with single glazing
Heating	Local heating with gas fires
Sanitary hot water	Local gas geyser
Ventilation	System A
Renewable energy	None



Façades (front and rear) and cross section of the dwelling



Floor plans (ground, first floor, second floor)

Figure 3. Visualisation of the terraced house [6]

6.1.2 Renovation scenarios

Different renovation scenarios, allowing to reach the different ambition levels (minimal, E60 and E30), have been determined for this terraced house.

Table 6 summarizes the energetic characteristics of this dwelling prior to renovation and describes the various renovation scenarios. It also includes the corresponding operational energy use and a short description of the renovation measures in terms of construction materials and technical installations considered.

Table 6. Terraced house: Overview of renovation measures related to the different scenarios, including overview of materialisation and energy performance.

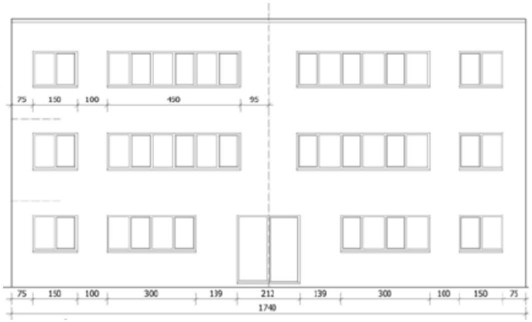
	Reference	Renovation scenarios							Materialisation of the renovation measure
		Min. (E100)	**E60inst_gas**	**E60inst_HP**	**E60_mat**	**E30_HP**	**E30gas_ U=0,24**	**E30gas_ U=0,16**	
U-Roof (W/m²K)	1,7 (no insulation)	0,24	0,24	0,24	0,24	0,24	0,24	0,16	New roof insulated with glass wool between the structure
U-façade (street side) (W/m²K)	1,7	1,7	1,7	1,7	0,24	0,24	0,24	0,16	Insulation from the inside: glued PUR +gypsum plasterboard panel
U-façade (back) (W/m²K)	1,7	1,7	1,7	1,7	0,24	0,24	0,24	0,16	ETICS system with EPS
U-window (W/m²K)	2.36/5.8	1.6/1.1	1.6/1.1	1.6/1.1	1.6/1.1	1.6/1.1	1.6/1.1	1.6/1.0 (g=0.5)	Double glazing with aluminium profile
U-Floor above cellar (W/m²K)	0,85	0,85	0,85	0,85	0,85	0,24	0,24	0,16	PUR boards glued on the ceiling of the cellar
Ventilation system	/	/	C3	C3	C3	C3	C3	D with heat recovery	Ventilation unit and ducts
Heating system	Local gas fires	Combi condensing gas boiler		Air-water heat pump (COP3.5, high temperature radiators) + storage tank for SWW	Combi-condensing gas boiler	Air-water heat pump (COP3.8, low temperature radiators (SPF=3.0)) + storage tank for SWW	Combi condensing gas boiler		New installation + distribution pipes and radiators adapted to energy demand
Sanitary warm water (SWW) production	Local gas geyser								
PV (kWp)	None	None	4	2.5	None	2.5	3.9	2	Mono-SI panels mounted on the roof
E-level	202	100	60	60	59	30	30	30	
K-level	132	74	74	74	45	39	39	32	
Final energy use for heating (kWh/y/m2)	267 (gas)	116 (gas)	90 (gas)	23 (elec)	48,9 (gas)	12,7 (elec)	40,1 (gas)	29,1 (gas)	
Final energy use for SWW (kWh/y/m2)	18,9 (gas)	18,9 (gas)	18,9 (gas)	6,7 (elec)	18,9 (gas)	6,7 (elec)	18,9	18,9	
Final energy use for auxiliaries (kWh/y/m2)	0	2,6	3,5	2,6	3,5	2,6	3,5	4,4	

	Reference	Renovation scenarios							Materialisation of the renovation measure
		Min. (E100)	E60inst_gas	E60inst_HP	E60_mat	E30_HP	E30gas_ U=0,24	E30gas_ U=0,16	
Final energy use for cooling (kWh/y/m2)	0	0,35	0,7	0,7	2,4	3,2	3,2	0,3	
Final energy use for non-building related energy (kWh/y)	3000	3000	3000	3000	3000	3000	3000	3000	
Electricity produced by PV (kWh/y)	0	0	2913	1821	0	1821	2840	1457	Avoided impact from corresponding amount of electricity sold on the Belgian market

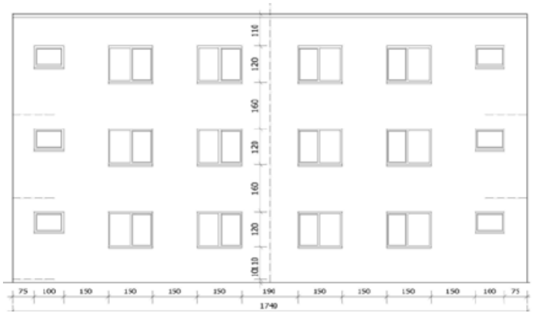
6.2 APARTMENT BUILDING – RENOVATION

6.2.1 Description of the building

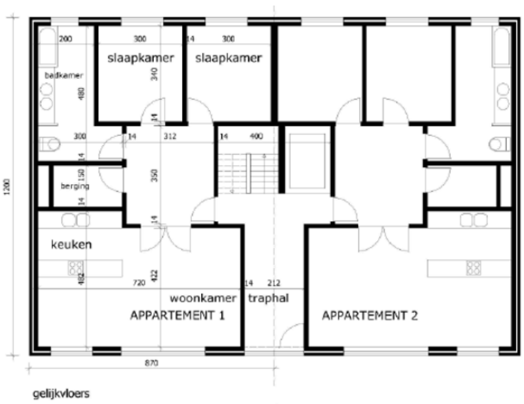
The considered apartment building was built in 1970 and consists of six individual flats with a similar floor surface, located on three floors. Figure 4 gives an overview of the front façade and the rear side of the building, as well as a floor plan of the three floors with the six individual flats. In order to simplify the calculations on building level and to be able to evaluate the impact of renovation measures on all parts of the building envelope (i.e. roof, floors, windows and external walls), a fictitious mean flat was considered.



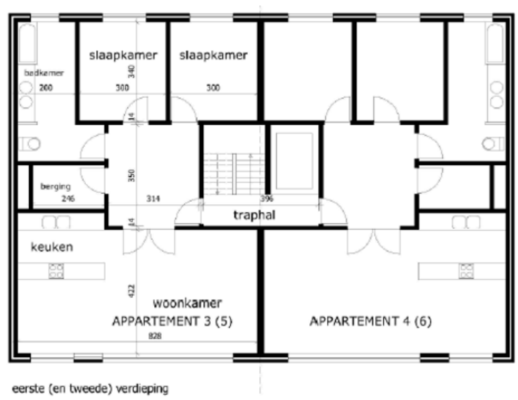
Front façade



Back façade



Plan of the first floor



Plan of the second and third floor

Figure 4. Visualisation of the multi-family dwelling or apartment building. Images from [6]

Table 7 provides an overview of the characteristics of the reference flat, as it was built in 1970. More details on this apartment building are given in the VEA study (2013) [6].

Table 7. Overview of the characteristics of the mean flat within the apartment building, as it was built in 1970.

Multi-family dwelling – mean flat (apartment building, 1970)	
Protected volume	292,20 m^3
Floor area	97,40 m^2
Flat roof	Slightly insulated concrete roof with EPS insulation, bitumen roof finishing and gravel ballast
External walls	Non-insulated cavity wall
Floor above cellar	Non-insulated concrete floor with ceramic tiles
External windows	Aluminium window frames with double glazing
Heating	Collective central heating system with oil boiler
Sanitary hot water	Electrical boiler
Ventilation	System A
Renewable energy	None

6.2.2 Renovation scenarios

Different renovation scenarios, allowing to reach the different ambition levels (minimal, E60 and E30), have been determined for this apartment building.

Table 8 summarizes the energetic characteristics of the mean flat prior to renovation and gives an overview of the energetic characteristics of the various renovation scenarios. It also includes the corresponding operational energy use and a short description of the renovation measures in terms of materials considered.

Table 8. Apartment building: Overview of renovation measures related to the different scenarios, including overview of materialisation and energy performance.

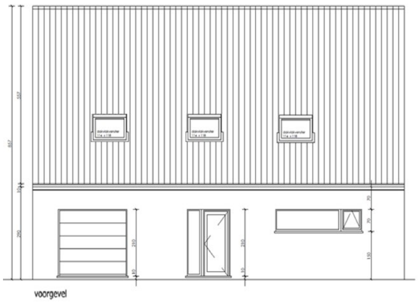
	Reference	Renovation scenarios					Materialisation of renovation measure* *The renovation measure is only applied when the U-value is displayed in bold
		Minimum (E90)	**E60mat**	**E60inst**	**E30gas**	**E30HP**	
Flat roof (U-value, W/m².K)	0,85	0,24	0,24	0,24	0,16	0,24	Additional PUR insulation board upon existing roof finishing, new bitumen roof finishing, new gravel ballast
External walls (U-value, W/m².K)	1,7	0,55		0,55			Filling up cavity with sprayed PUR insulation
			0,24		0,16	0,24	ETICS system with EPS insulation and external plaster
Floor above cellar (U-value, W/m².K)	0,85	0,85	0,85	0,85	0,1	0,2	PUR insulation board glued under cellar floor
External windows (U-value for profiles and glass, W/m².K)	4,19/2,7	4,19/2,7	1,4/1,0	4,19/2,7		1,4/1,0	Replacement by windows with aluminium frames and double glazing
					1,4/0,6		Replacement by windows with aluminium frames and triple glazing
Ventilation system	System A	System A (system C not feasible without replacement windows)	System C3	System A (system C not feasible without replacement windows)	System C3	System C3	Installation of ventilation system C3 with demand control (ventilation unit, grids, ducts, sensors)
Heating system	Collective central heating system with oil boiler	Combi condensing gas boiler (25 kW production)	Combi condensing gas boiler (25 kW production)	Combi condensing gas boiler (25 kW production)	Combi condensing gas boiler (25 kW production) Combi with gas boiler	Air-water heat pump COP 3.8 (3,5 kW production, SPF 3,64) with hot water storage vessel	New installation of heating system with reuse of existing HT radiators
Sanitary warm water (SWW) production	Electrical boiler						
PV panels (kWp)	None	None	None	1,2	None	None	Mounting of multi-Si PV panels on flat roof
E-level	197	94	58	59	30	31	
K-level	115	69	55	69	20	35	
Final energy use for heating (kWh/m².y)	280 (oil)	125,6 (gas)	63,9 (gas)	88,8 (gas)	18,3 (gas)	9,8 (elec)	

	Reference	Renovation scenarios					Materialisation of renovation measure* *The renovation measure is only applied when the U-value is displayed in bold
		Minimum (E90)	E60mat	E60inst	E30gas	E30HP	
Final energy use for SWW production (kWh/m².y)	15,3 (elec)	21,4 (gas)	21,4 (gas)	21,4 (gas)	21,4 (gas)	7,6 (elec)	
Final energy use for auxiliaries (kWh/m².y)	2,6 (elec)	2,6 (elec)	3,8 (elec)	3,8 (elec)	3,8 (elec)	2,9 (elec)	
Final energy use for cooling (kWh/y/m²)	0	0	0	0	0	0	
Final energy use for non-building related energy (kWh/y)	3000	3000	3000	3000	3000	3000	
Electricity produced by PV panels (kWh/y)	0	0	0	874	0	0	Avoided impact from corresponding amount of electricity sold on the Belgian market

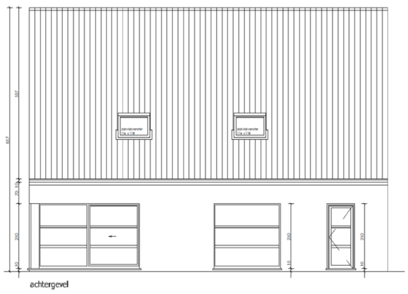
6.3 DETACHED HOUSE – RENOVATION

6.3.1 Description of the building

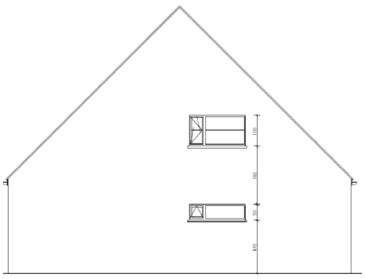
The considered detached house was built in 1985. Figure 5 gives an overview of the four façades of the dwelling, as well as a cross section and the floor plans.

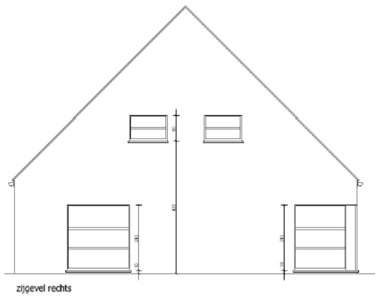


Front façade (N side)

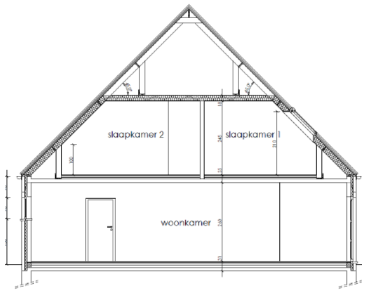


Back facade (S side)

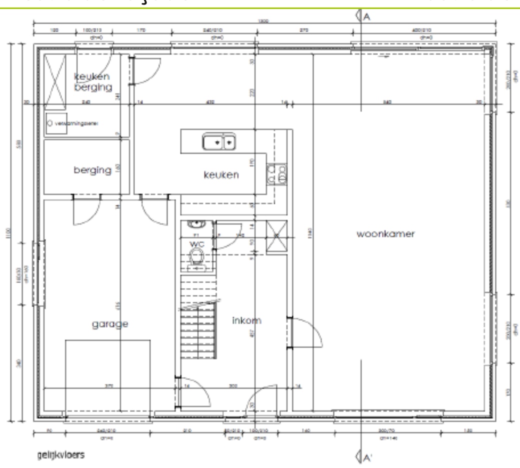

West-side façade



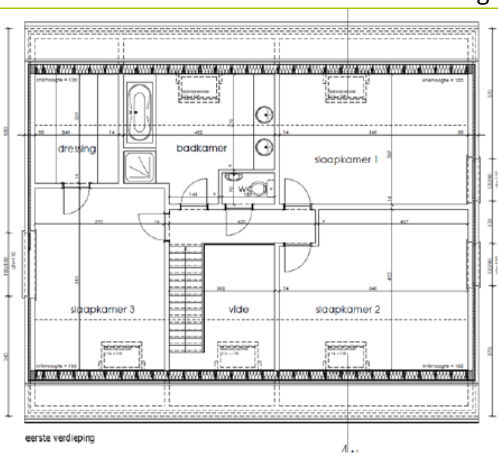
East-side façade



cross section of the dwelling



plan of the ground floor of the dwelling



plan of the first floor of the dwelling

Figure 5. Visualisation of the detached house (fermette, 1985). [6]

Table 9 provides an overview of the characteristics of the reference house, as it was built in 1985. More details on this dwelling are available in the VEA study [6].

Table 9. Overview of the characteristics of the detached house, as it was built in 1985.

Detached house (fermette, 1985)	
Protected volume	720,7 m^3
Floor area	247 m^2
Pitched roof / attic floor	Wooden structure with insulation in between
External walls	Insulated cavity wall
Floor on ground	Concrete floor with insulating screed and ceramic tiles
External windows	Wooden window frames with double glazing
Heating	Central heating system with oil boiler
Sanitary hot water	Boiler
Ventilation	System A
Renewable energy	None

6.3.2 Renovation scenarios

Different renovation scenarios, allowing to reach the different ambition levels (minimal, E60 and E30), have been determined for this detached house.

Table 10 summarizes the energetic characteristics of the dwelling prior to renovation and gives an overview of the energetic characteristics of the various renovation scenarios. It also includes the corresponding operational energy use and a short description of the renovation measures in terms of materials considered.

Table 10. Detached house (fermette): Overview of renovation measures related to the different scenarios, including overview of materialisation and energy performance.

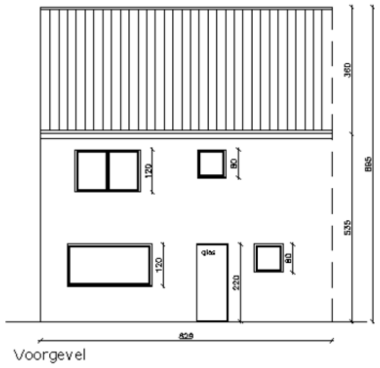
	Reference	Renovation scenario					Materialisation of renovation measure* *The renovation measure is only applied when the U-value is displayed in bold
		Minimum (E90)	E60mat	E60inst	E30gas	E30HP	
Pitched roof / attic floor (U-value, W/m^2.K)	0,6	0,24	0,24	0,24	0,13	0,24	Additional mineral wool insulation between wooden structure and gypsum plasterboard as internal finishing
External walls (U-value, W/m^2.K)	0,6	0,6	0,24	0,6	0,13	0,6	ETICS system with EPS insulation and external plaster on all four walls
Floor on ground (U-value, W/m^2.K)	0,5	0,5	0,5	0,5	0,24	0,5	Replacement of ceramic tiles and insulating screed by PUR insulation board, new insulating screed and new ceramic tiles
External windows (U-value for profiles and glass, W/m^2.K)	2,36/2,9	1,4/1,0	1,4/1,0	1,4/1,0		1,4/1,0	Replacement by windows with aluminium frames and double glazing
					1,4/0,6		Replacement by windows with aluminium frames and triple glazing
Ventilation system	System A	System A	System C3	System C3	System C3	System C3	Installation of ventilation system C3 with demand control (ventilation unit, grids, ducts, sensors)
Heating system	Central heating system with oil boiler	Combi condensing gas boiler (25 kW production)	Combi condensing gas boiler (25 kW production, SPF 0,97)	Combi condensing gas boiler (25 kW production)	Combi condensing gas boiler (25 kW production, SPF 0,98) + shower heat recovery	Air-water heat pump COP 3.8 (16 kW production, SPF 3,5) with hot water storage vessel + shower heat recovery	New installation with reuse of existing HT radiators (or use as LT radiators)
Sanitary warm water (SWW) production	Boiler						
PV panels (kWp)	None	None	None	3	1,5	4	Mounting of mono-Si PV panels on pitched roof
E-level	123	86	56	60	30	29	
K-level	75	54	41	54	25	52	
Final energy use for heating (kWh/m^2.y)	170,3 (oil)	113,3 (gas)	60,2 (gas)	89,1 (gas)	35 (gas)	23,3 (electricity)	
Final energy use for SWW production (kWh/m^2.y)	23,4 (oil)	21,1 (gas)	21,1 (gas)	21,1 (gas)	13,1 (gas)	4,7 (electricity)	

	Reference	Renovation scenario					Materialisation of renovation measure* *The renovation measure is only applied when the U-value is displayed in bold
		Minimum (E90)	E60mat	E60inst	E30gas	E30HP	
Final energy use for auxiliaries (kWh/m².y)	2,47 (electricity)	2,5 (electricity)	3,4 (electricity)	3,4 (electricity)	3,4 (electricity)	2,5 (electricity)	
Final energy use for cooling (kWh/y/m2)	79,04	2,47	81,51	22,23	296,4	27,17	
Final energy use for non-building related energy (kWh/y)	3000	3000	3000	3000	3000	3000	
Electricity produced by PV panels (kWh/y)	0	0	0	2176	1088	2901	Avoided impact from corresponding amount of electricity sold on the Belgian market

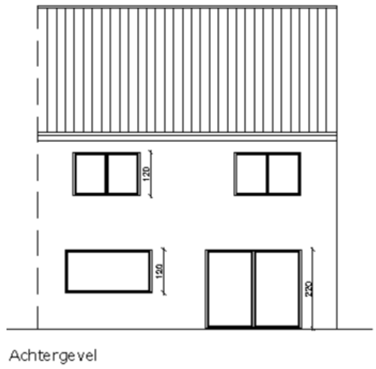
6.4 SEMIDETACHED DWELLING – NEW CONSTRUCTION

6.4.1 Description of the building

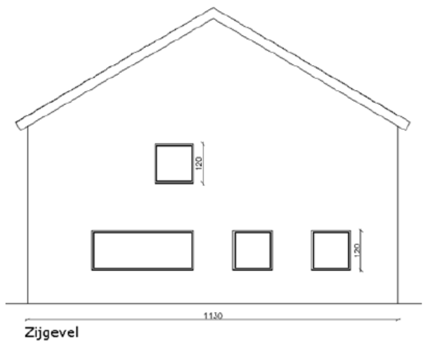
The considered semidetached house is supposed to be newly built in 2020. Figure 6 gives an overview of the four façades of the dwelling, as well as a cross section and a floor plan of the ground floor and the first floor.



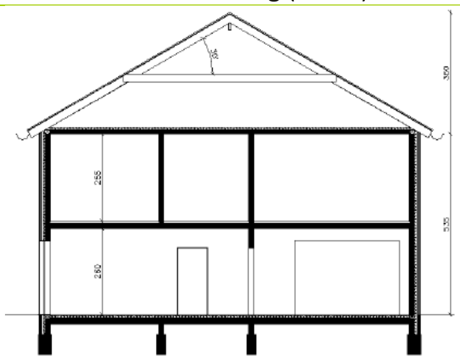
front façade of the dwelling (N side)



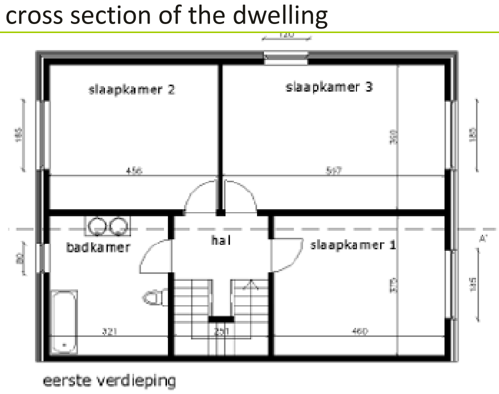
rear side of the dwelling (S side)



side façade of the dwelling (E side)


cross section of the dwelling

plan of the ground floor of the dwelling



plan of the first floor of the dwelling

Figure 6. Visualisation of the semidetached dwelling (2020). Images from [5].

Table 11 provides an overview of the composition of the different components of the house. More details on this dwelling are given in the VEA study [5].

Table 11. Overview of the composition of the different components of the semidetached dwelling (2020).

Semidetached dwelling (2020)	
Protected volume	548 m³
Floor area	187,36 m²
Pitched roof	Non-insulated roof with ceramic roof tiles, PE subroof and wooden rafters and purlins
Attic floor	PUR insulation boards, PE vapour barrier, hollow core slabs with concrete pressure layer, gypsum plaster
Storey floor	Ceramic floor tiles or laminate floor finishing, cement-based screed, mineral wool acoustic insulation, hollow core slabs with concrete pressure layer, gypsum plaster
Floor on ground	Ceramic floor tiles, cement-based screed, PUR insulation boards, in situ reinforced concrete floor slab
External walls	Cavity wall with facing bricks, PUR insulation boards, clay brickwork, gypsum plaster
Party wall	Cavity wall with mineral wool insulation, clay brickwork and gypsum plaster
Internal walls	Clay brickwork with gypsum plaster on both sides
Foundations	In situ reinforced concrete sole foundation
External windows and doors	Aluminium frames with double or triple glazing*
Internal doors	Wooden doors
Staircase	Wooden steps with wooden railing
Heating	Central heating system with combi condensing gas boiler or air-water heat pump*
Sanitary hot water	Combi with gas boiler or with heat pump*
Ventilation	System C3 with demand control or system D with heat recovery*
Renewable energy	Mono-Si PV panels mounted on pitched roof

* The choice for a specific option is related to the chosen scenario.

6.4.2 Scenarios

Different scenarios, allowing to reach the different ambition levels (E30 minimal, E30/E25 passive and E0), have been determined for this semidetached newly built house.

Table 12 summarizes the energetic characteristics of the various scenarios, as well as the corresponding operational energy use.

Table 12. Energy performance characteristics of the newly built semidetached dwelling (2020) following various scenarios.

	Minimal E30 gas	**Minimal E30 HP**	**Passive E30 gas**	**Passive E25 HP**	**Passive E0 HP**
Attic floor (U-value, W/m².K)	0,24	0,24	0,13	0,13	0,13
External walls (U-value, W/m².K)	0,24	0,24	0,13	0,13	0,13
Party wall (U-value, W/m².K)	0,6	0,6	0,6	0,6	0,6
Floor on ground (U-value, W/m².K)	0,24	0,24	0,13	0,13	0,13
External windows (U-value for profiles and glass, W/m².K)	1,4/1,0	1,4/1,0	1,4/0,6	1,4/0,6	1,4/0,6
Ventilation system	System C3	System C3	System Dwtw3	System Dwtw3	System Dwtw3
Heating system	Combi condensing gas boiler (25 kW production, SPF 0,94) + HT radiators	Air-water heat pump COP 3.8 (5,6 kW production, SPF 3,67) + LT radiators	Combi condensing gas boiler (25 kW production, SPF 0,94) + HT radiators	Air-water heat pump COP 3.8 (3,7 kW production, SPF 3,67) + LT radiators	Air-water heat pump COP 3.8 (3,7 kW production, SPF 3,67) + LT radiators
Sanitary warm water (SWW) production	Combi with gas boiler	Heat pump boiler with hot water storage vessel	Combi with gas boiler + shower heat recovery	Heat pump boiler with hot water storage vessel	Heat pump boiler with hot water storage vessel
PV panels (kWp)	2,5	0,5	None	None	4,2
E-level	30	30	29	25	-1
K-level	30	30	20	20	20
Final energy use for heating (kWh/m².y)	40,1 (gas)	10,3 (electricity)	16,1 (gas)	4,1 (electricity)	4,1 (electricity)
Final energy use for SWW production (kWh/m².y)	21,5 (gas)	7,7 (electricity)	17,5 (gas)	7,7 (electricity)	7,7 (electricity)

	Minimal E30 gas	Minimal E30 HP	Passive E30 gas	Passive E25 HP	Passive E0 HP
Final energy use for auxiliaries (kWh/m².y)	3,45 (electricity)	2,57 (electricity)	4,35 (electricity)	3,47 (electricity)	3,47 (electricity)
Final energy use for cooling (kWh/y/m2)	106,8	106,8	91,8	91,8	91,8
Final energy use for non-building related energy (kWh/y)	3000	3000	3000	3000	3000
Electricity produced by PV panels (kWh/y)	1796	359	0	0	3017

7 RESULTS ENVIRONMENTAL IMPACT

In this section the results of the LCA-studies of the individual cases are presented and discussed. For each case two major figures with results are presented: the CO2 emissions and the monetised global environmental impact generated by the building over a period of 30 years (from 2020 to 2050). Specific attention in the discussion goes to the relation between the material related impact (i.e. construction materials and technical installations) and the impact related to operational energy use.

For the graphical representation of the results following conventions are systematically used:

- The impact related to the construction materials (MAT) is represented in blue,
- The material related impact of technical installations (INST) is represented in yellow,
- The impact related to the operational energy use (heating, cooling, sanitary hot water production, auxiliaries (AUX), non-building related energy use) is represented in black and grey tones.
- The end-of-life impact of the materials is marked with hatched bars because in practice this impact will only take place after 2050.

Moreover, the electricity produced by the PV panels is represented as a benefit (avoided impact from electricity produced according to the Belgian electricity mix) and is therefore shown as a negative result in the figure (ELECTRICITY PRODUCED). This way of presenting the data implies that all the produced electricity is exported to the grid. The black horizontal bar provides a second way of looking at it. This bar represents the total impact in case the produced electricity would be used by the building itself instead of being exported. Indeed, in the latter case the produced energy would reduce the impact related to the electricity consumption of the building (e.g. non-building related electricity use (plug-in appliances) or impact from heating with a heat-pump).

For the renovation cases, the reference scenario represents the building's impact in its original state (no renovation action). Consequently, it shows only an impact related to the energy use over 30 years predicted by EPB calculations. As mentioned previously (4.2.3, 4.2.4), this represents a worst-case scenario and the actual impact of the reference case will probably be lower.

In addition to the case-specific results, this section also presents the results from the scaling up to the building stock and a sensitivity analysis on the considered electricity mix.

7.1 TERRACED HOUSE – RENOVATION

The CO_2 emissions and the global monetised environmental impact generated by the terraced house over a period of 30 years for various renovation scenarios are represented respectively in Figure 7 and Figure 8.).

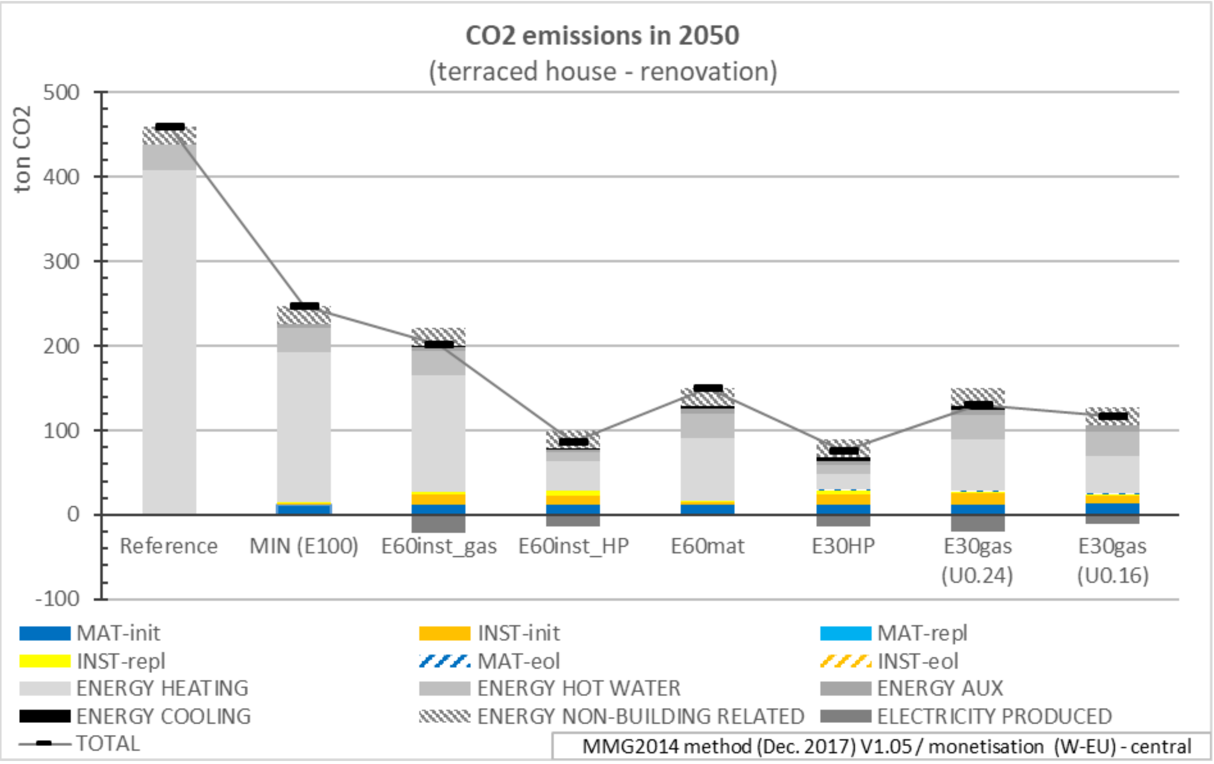


Figure 7. Terraced house: CO2 emissions generated over 30 years for different renovation scenarios

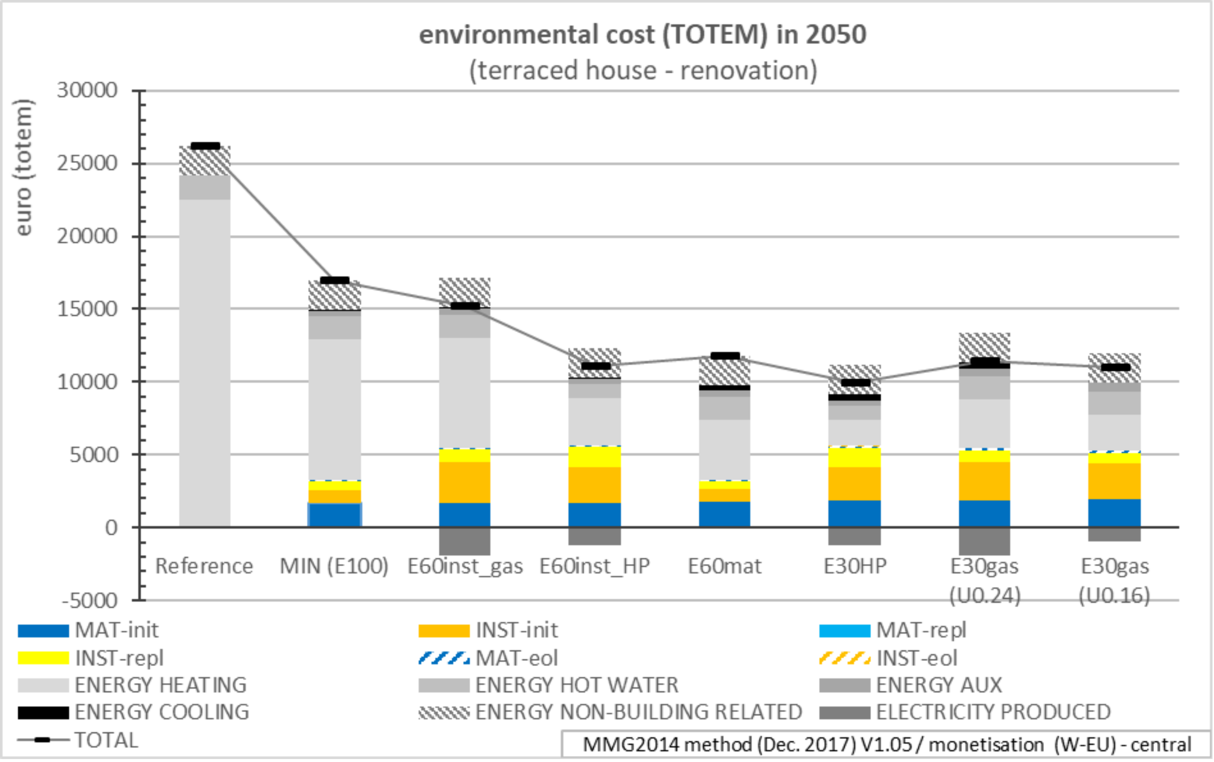


Figure 8. Terraced house: Environmental impact (expressed in Euros) generated over 30 years for different renovation scenarios

Based on Figure 7 the following general conclusions can be drawn:

- At higher E-levels, the material related impact (from construction materials (MAT) and installations (INST)) used for the renovation is very small compared to the impact from energy use.
- All renovation scenarios result in important reductions in CO_2 emissions related to the operational energy use. However, there is only a small CO2-increase of the material related impact compared to the reference case (no renovation). Therefore, significant reductions in CO_2 emissions can be achieved by energetic renovation.
- The CO_2 emissions tend to decrease with decreasing E-levels (see downward trend to the right). However, the results for the different E60 scenarios show that the CO_2 emissions of scenarios with a same E-level can vary significantly.
- From a CO_2 perspective, it is more interesting to increase the insulation level of the building than to install PV panels (E60inst_gas > E60mat, E30gas_U=0.24 > E30gas_U=0.16). Indeed, as the Belgian electricity mix is relatively CO_2 efficient, the benefit gained by the installation of the PV-panels (in terms of avoided electricity production with the Belgian electricity mix) is only slightly higher than the impact caused by the production of the PV panels themselves (INST_init). On the contrary, the additional $C0_2$-impact caused by additional insulation is very small compared to the savings in terms of heating (e.g. MAT-init $_{E60mat}$-MAT-init$_{min(E100)}$ << ENERGY-heating$_{min.(E100)}$-ENERGY-heating$_{E60mat}$).

- The use of a heat pump leads to significant savings in impact from energy use for heating whereas it only leads to a limited additional impact from installations. Therefore, for a given E-level, the renovation scenario with the lowest CO_2 emissions is the one with a heat-pump instead of a gas boiler.
- E60 renovation with a heat pump (E60inst_HP) performs better than the E30 renovation scenarios with gas (E30gas). Therefore, E-level is not always a good indicator for environmental performance.
- The scenario with ambition level E30 and the use of a heat pump (E30HP) leads to the lowest CO_2 emissions over 30 years.

Compared to the reference building (no renovation) a reduction of 46% of CO_2 emissions over 30 years can be achieved with minimal renovation and a reduction of 83% with renovation to E30 with a heat pump. As mentioned above, the actual energy use for the reference scenario will probably be lower, which implies that this is an overestimation of the possible reductions. Nevertheless, in comparison to the MIN scenario, a reduction of 18% in CO_2-emission is still noted for the E60 renovation with gas (E60inst_gas), and of 69% for the E30 renovation with a heat pump (E30 HP).

The conclusions drawn from the global (monetised) environmental impact (Figure 8) are similar to the ones drawn from the CO_2 emissions (Figure 7). The main differences are the following:

- The relative contribution of construction materials and installations to the total impact is higher based on the monetised (TOTEM) score than based solely on CO_2. Therefore, the achieved reduction in impact compared to the reference case is slightly smaller based on the Totem score.
- The net benefit from the PV-panels is smaller for the monetised impact than for the CO_2 emissions. This is related to the fact that the PV-panels contribute significantly to the environmental impact of the technical installations.
- For a given E-level, the scenario with a heat pump and the scenario with more insulation but heating with a condensing gas boiler lead to similar results (e.g. E60inst_HP ≈ E60mat). There are mainly two reasons why for a given E-level the difference between the alternative with heat pump and the one with more insulation is smaller based on the global environmental impact than based on CO_2 only. Firstly, the alternatives with heat pumps include more PV panels and PV panels are less interesting based on the monetised score than based on CO_2. Secondly, the relative impact of electricity (compared to gas) is higher based on the global impact than based on CO_2.

In general, the difference between the various scenarios is relatively smaller based on the monetised score than based on CO_2. For the TOTEM-results a reduction of 35% and 62% of the impact is achieved respectively for the minimal renovation scenario and the E30 scenario with heat pump, both compared to the reference situation. A comparison to the minimal scenario, leads to a 41% impact reduction for the E30 scenario with heat pump.

7.2 APARTMENT BUILDING – RENOVATION

The CO_2 emissions and the global monetised environmental impact (TOTEM score) generated by the apartment building over a period of 30 years for various renovation scenarios are represented respectively in Figure 9 and Figure 10. It should be noted that these results represent the impact for a fictitious mean single apartment (as described in §1.1). The impact for the (renovation of the) complete apartment building should thus be multiplied with the number of apartment units.

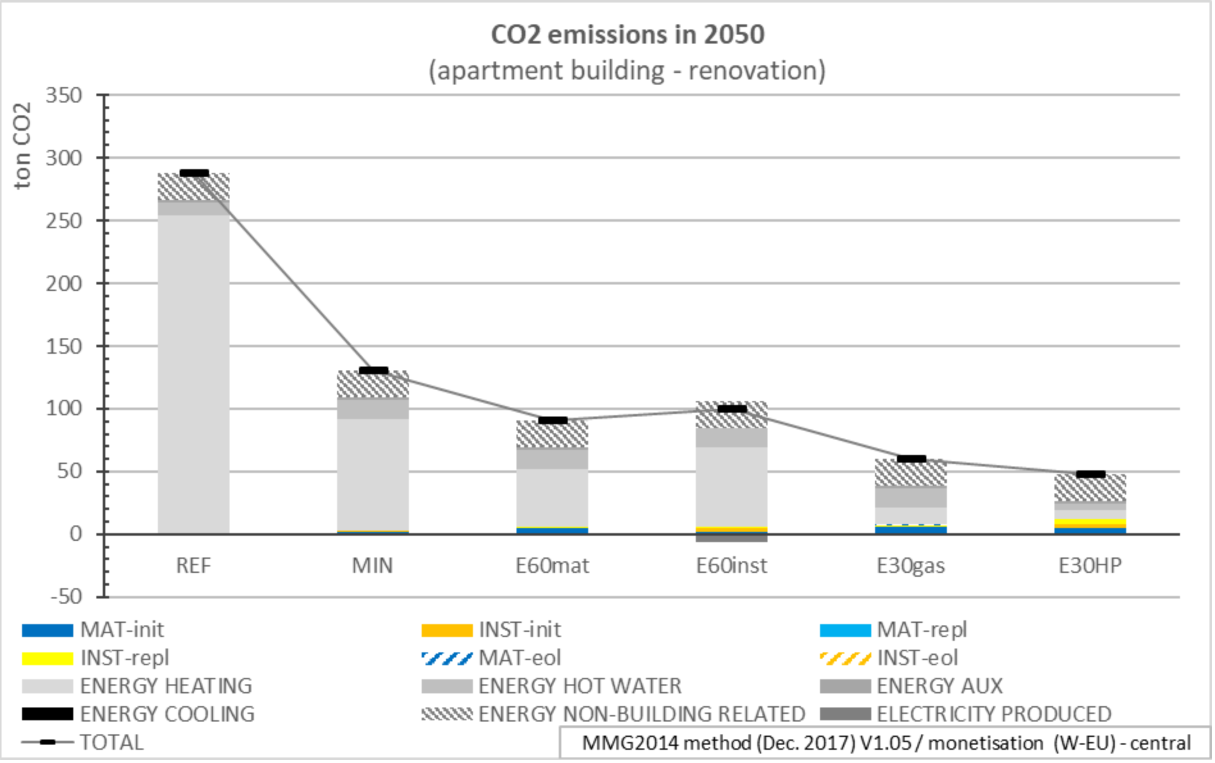


Figure 9. Apartment (1 unit): CO2 emissions generated over 30 years for different renovation scenarios

As for the terraced house, the results show that both the CO_2 emissions and the monetised global impact, generally decrease with decreasing E-levels.

For the apartment building the material related impact (i.e. from construction materials (MAT) and installations (INST)) becomes even less important compared to the energy use. This can be clarified by the fact that the amount of envelope per unit floor area is smaller for an apartment building than for a single family house. Given the limited impact of materials to be added for a renovation, significant reductions in CO_2 emissions and environmental impact can be achieved through energetic retrofitting.

Given the relatively low operational energy use at E30, the difference between the scenario with a gas boiler (E30gas) and the one with a heat pump (E30HP) is rather small. In terms of CO_2 emissions (Figure 9), the alternative with a gas boiler has a slightly higher impact than the one with a heat pump (E30gas > E30HP).

Considering the global environmental impact (Figure 10), the alternative with a heat pump has a higher impact because of the increased material related impact of technical installations (INST).

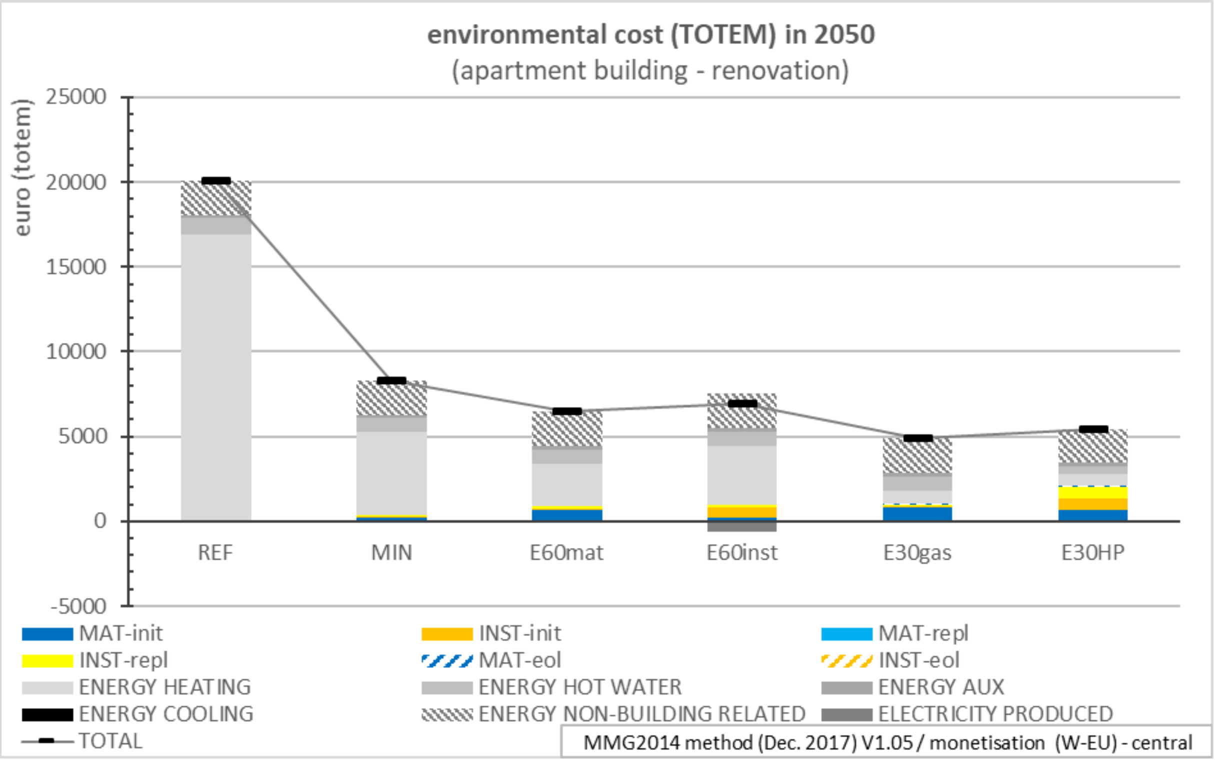


Figure 10. Apartment (1 unit): Environmental impact (expressed in Euros) generated over 30 years for different renovation scenarios

7.3 DETACHED HOUSE – RENOVATION

The CO_2 emissions and the global environmental impact caused by the apartment building over a period of 30 years for various renovation scenarios are represented respectively in Figure 11 and Figure 12. Similar findings as for the other cases can be found:

- The life cycle impact (both CO_2 and global monetised environmental impact) generally decreases as the E-level becomes lower.
- Nevertheless, significant differences in impact exist for different scenarios within a given E-level (e.g. E60inst > E60mat).
- The contribution of materials (i.e. construction materials (MAT) and technical installations (INST)) to the overall impact is small compared to the impact related to the energy use, especially for the lower ambition levels (MIN and E60).

For the scenarios focusing on the insulation of the building envelope (E60mat and E30gas) the type of renovation action can significantly influence the results. Certain energetic retrofitting actions require a limited amount of additional materials (e.g. insulation of the roof with mineral wool from the inside and addition of an ETICS with EPS on the façades). Other retrofit actions might require additional (non-insulating) materials, which can have a significant impact. For example, for the scenario E30gas, the insulation of the floor requires the removal of the existing floor and the installation of new screed and ceramic floor tiles. This explains why the global monetised score related to the construction materials (MAT) of E30 gas is significantly higher than for the other scenarios (Figure 12).

Finally, as stated before, the installation of PV has a significant (positive) effect on the E-level of a building, but not necessarily on its environmental performance.

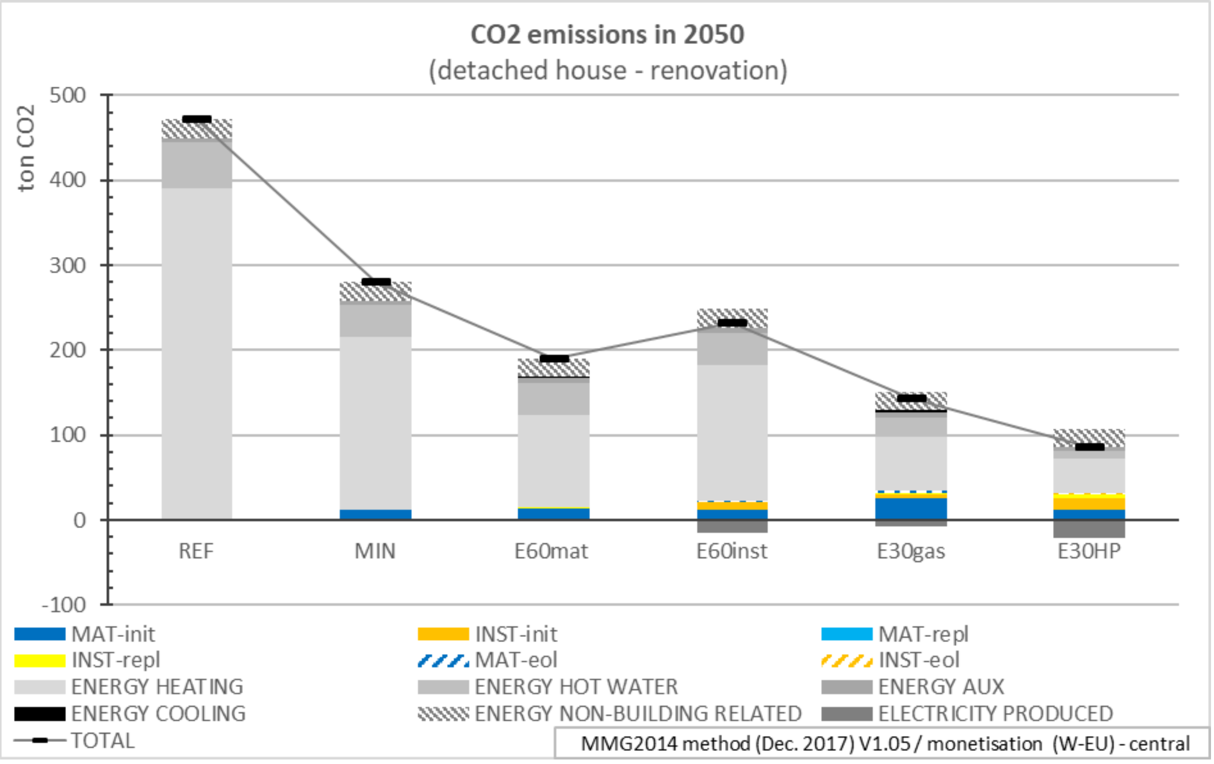


Figure 11. Detached house: CO2 emissions generated over 30 years for different renovation scenarios

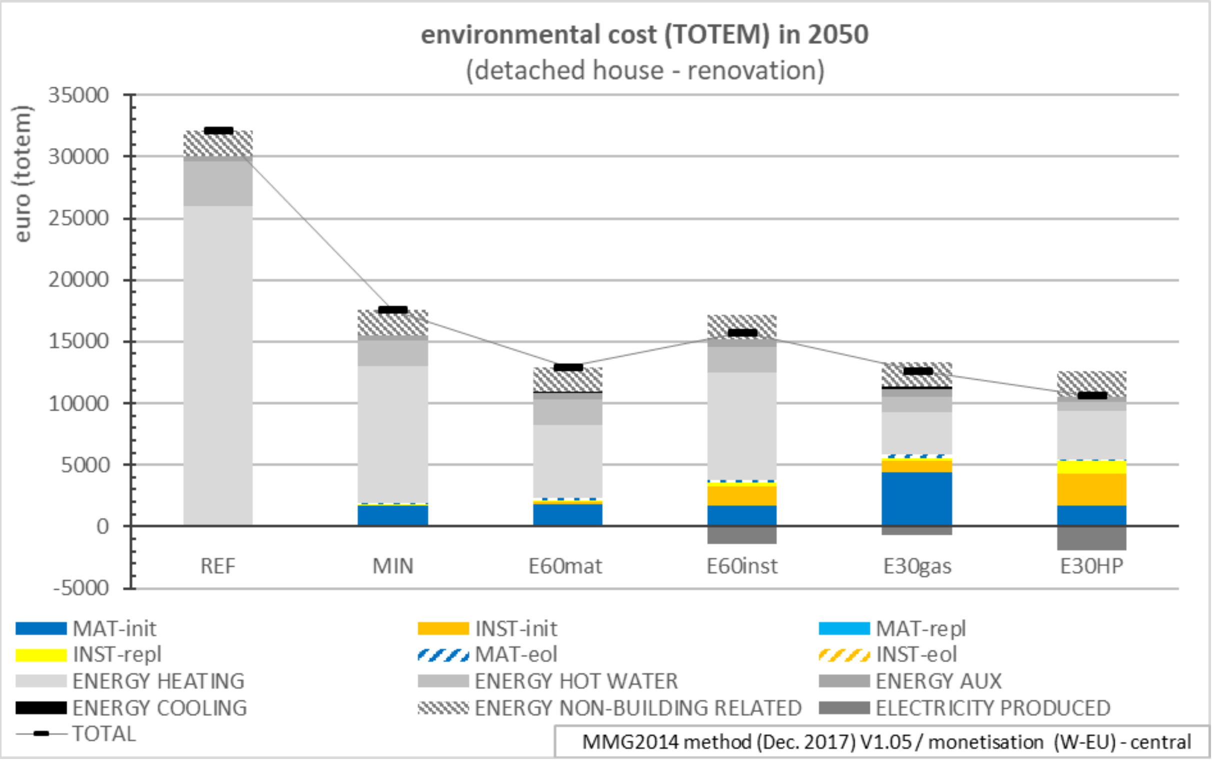


Figure 12. Detached house: Environmental impact (expressed in Euros) generated over 30 years for different renovation scenarios

7.4 SEMIDETACHED HOUSE – NEWLY BUILT

The CO_2 emissions and the monetised global environmental impact generated by the newly built semidetached house over a period of 30 years for various renovation scenarios are represented respectively in Figure 13 and Figure 14.

Based on Figure 13 the following general conclusions can be drawn:

- The CO_2 emissions related to the construction materials MAT) do not vary much amongst the considered scenarios. However, unlike the renovation cases, for the new built house the embodied CO_2 of construction materials (MAT) is equal to or larger than the emissions related to the operational energy use over 30 years.
- The CO_2 emissions related to the material use of the technical installations (INST) are small compared to those related to the construction materials (MAT). For the scenarios using PV-panels (Min E30gas, Passive E0) the emissions related to technical installations are higher than for the scenarios without PV panels; however, they are still small in comparison to emissions related to the construction materials (MAT).
- The main difference between the different scenarios is related to the energy use for heating and hot water. From a CO_2 perspective, it is more interesting to use a heat pump than using a condensing gas boiler (MIN E30gas > MIN E30HP, PAS E30gas > PAS E25HP).

- From a CO_2 perspective, it is more interesting to increase the insulation level of the building than to install PV solar panels (MIN E30gas > PAS E30gas), especially when using a condensing gas boiler.
- When using a heat pump, the benefit of adding additional insulation becomes small for the highly insulated scenarios (MIN E30HP ≈ passive E25HP). Indeed, given the limited energy use for heating and hot water, the additional gains to be made are limited. Nevertheless, this effect will become larger when considering a longer study period.
- The scenario aiming towards E0, using a heat pump and an increased number of solar panels, shows only slightly lower CO_2 emissions then the Passive E25HP scenario. This corresponds to the previous findings that the benefit associated with the installation of PV-panels is only slightly higher than the impact caused by the production of the panels.

It should be noted that for new construction the actual lifetime is estimated to be longer than the 30 years considered in this study. For a reference study period (RSP) of 60 years, some additional emissions related to the replacements of technical installation and certain materials will occur, but more importantly the operational energy use will increase according to the increased lifetime. The relative importance of embodied CO2 of construction materials (MAT) will be smaller based on an RSP of 60 years than based on an RSP of 30 years. However, in all cases its contribution remains significant.

The main differences observed between the results based on CO2 only (Figure 13) and the total monetised impact (Figure 14) are the following:

- The relative contribution of the construction materials (MAT) and installations (INST) to the life cycle impact of the building is higher based on the global monetised score (TOTEM) than based solely on CO_2
- Seen the relatively high contribution of construction materials (MAT) to the global monetised score (TOTEM) and its small variation across the scenarios, the difference between the life cycle impact of the scenarios is less significant based on the TOTEM score than based solely on CO2.

In both cases (CO2 and global monetised impact), the relative important contribution of the construction materials (MAT) to the life cycle impact of the case study indicate that the optimisation potential through material selection can be high for new low energy buildings.

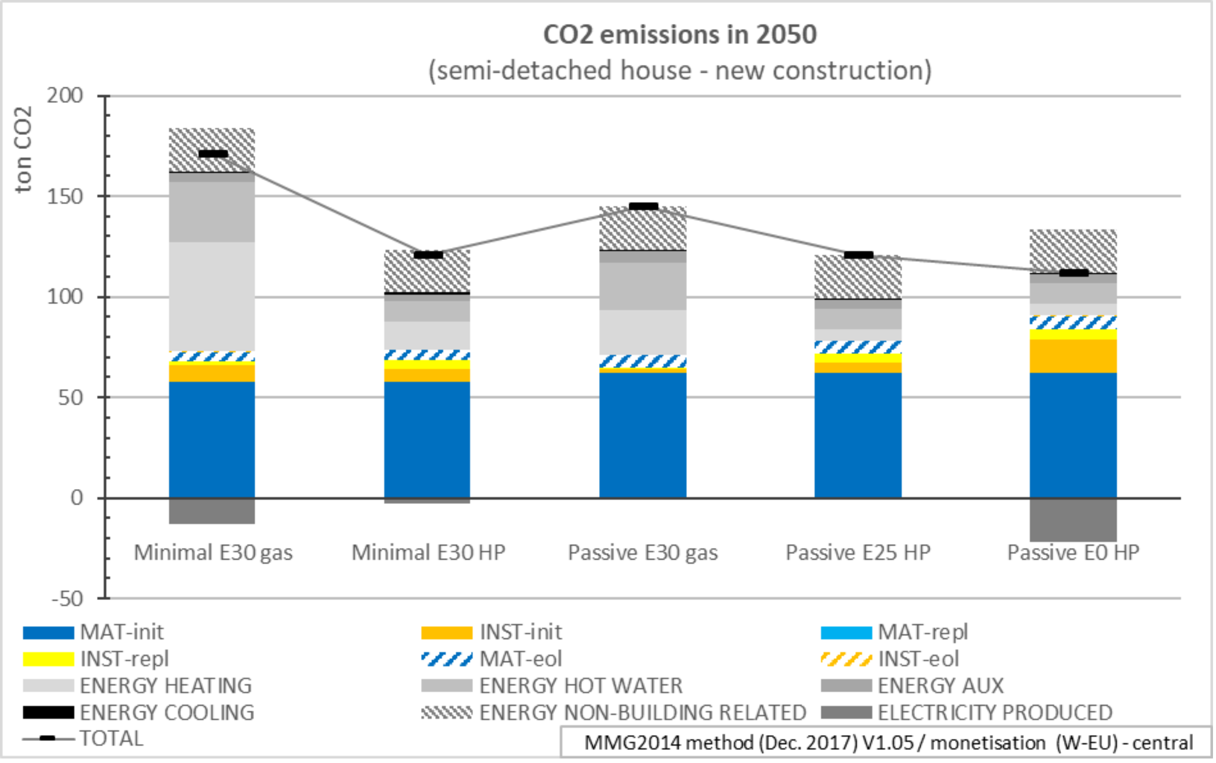


Figure 13. Semidetached house: CO_2 emissions generated over 30 years for different construction scenarios

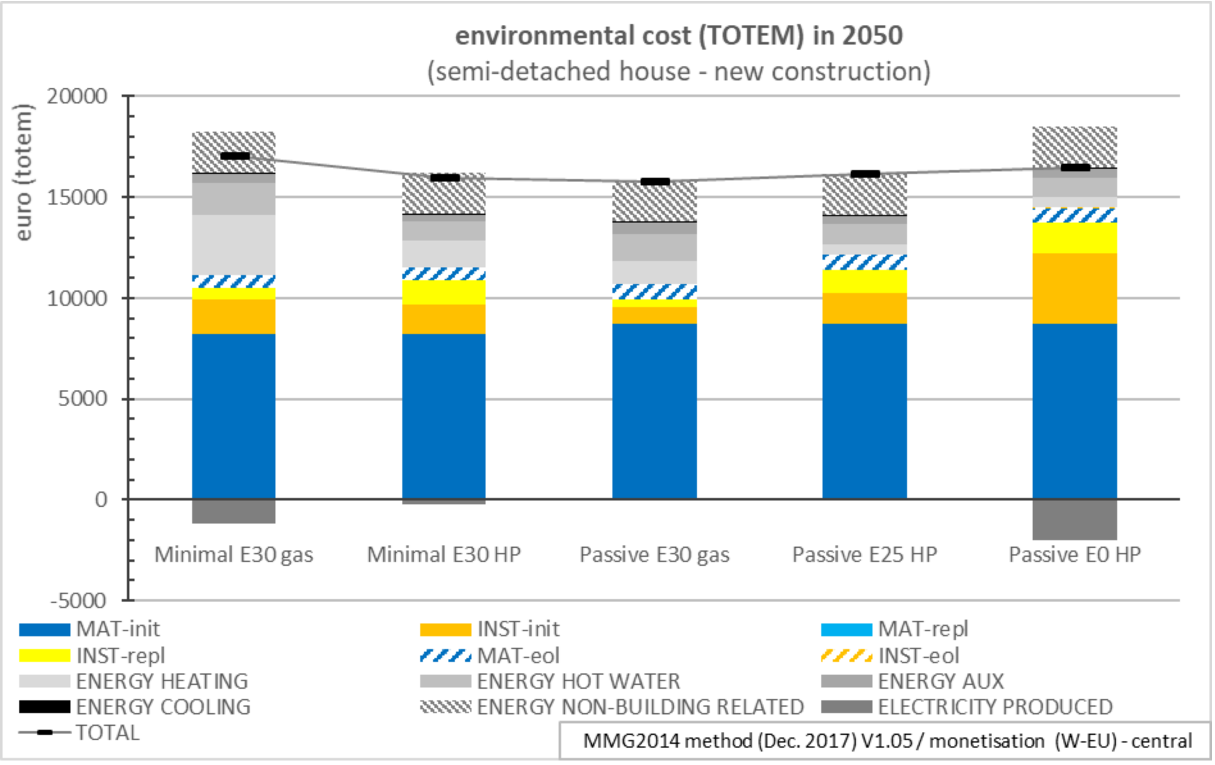


Figure 14. Semidetached house: Environmental impact (expressed in Euros) generated over 30 years for different construction scenarios

7.5 SENSITIVITY ANALYSIS ELECTRICITY MIX

The results from the individual renovation cases indicate that for existing buildings the highest environmental gains are to be made in the reduction of the operational energy use. However, critical voices state that there is a limit to pushing the energy performance of a building to the extremes as the embodied impact of construction materials and installations becomes relatively more important for very energy efficient buildings. Especially with the electrification of our building stock, changes in the Belgian electricity mix might have an influence on the results. In order to evaluate these influences, a sensitivity analysis is performed considering the changes expected in the Belgian electricity mix with the intended closure of the nuclear energy plants in Belgium.

7.5.1 Impact of the Belgian electricity mix

All previously presented results considered the Belgian electricity consumption mix representative of 2014-2015, which is composed of about 72% Belgian electricity production mix and 28% imports (mostly from France and the Netherlands). For the sensitivity analysis, only the Belgian production mix is changed. The composition of the future Belgian production mix (Aandeel 2030) is presented in Table 13, aside the current mix (Aandeel 2015). The share and the composition of the imports in the Belgian consumption mix are assumed to remain unchanged.

Table 13 Composition of the Belgian electricity production mix used in the sensitivity analysis – the mix of 2014-2015 ('aandeel 2015') used from 2020 to 2030 and the future mix used ('aandeel -2030') from 2030 to 2050 [11]

Technologie	Aandeel - 2015	Aandeel - 2030
Steenkool	3,7%	0,5%
Waterkracht - pumped storage	2,2%	2,2%
Waterkracht - run-of-river	0,5%	0,5%
Aardgas - combined cycle power plant	13,1%	28,9%
Aardgas - conventionele centrale	3,0%	6,7%
Nucleair - pressure water reactor	56,3%	0,0%
Olie	0,0%	0,0%
Wind - onshore	4,9%	8,8%
Wind - offshore	3,2%	13,2%
Biogas - WKK - gasmotor	0,5%	8,4%
Aardgas - WKK - combined cycle power power plant – 400 MWel	3,0%	6,6%
Aardgas – WKK-conventionele centrale – 100 MWel	7,0%	15,5%
Olie - WKK	0,0%	0,0%
Houtsnippers - WKK – 6.667 kW - state-of-the-art 2014	2,6%	2,6%
Zon-PV [55]	0,0%	6,0%
Totaal	**100,0%**	**100,0%**

In the future mix an important part of the electricity from nuclear power plants is replaced by electricity from gas power stations (Table 13). As a result, the impact/MJ electricity from the 2030 Belgian consumption mix is about 40% higher in terms of CO_2 emissions and about 50% higher in terms of monetised environmental impact than the current consumption mix (representative of 2015). Indeed, as can be seen from Figure 15 and Figure 16, the impact per MJ electricity is significantly higher, both in terms of CO_2 and monetised impact, when it is produced by a gas power station than when it is produced by a nuclear power plant.

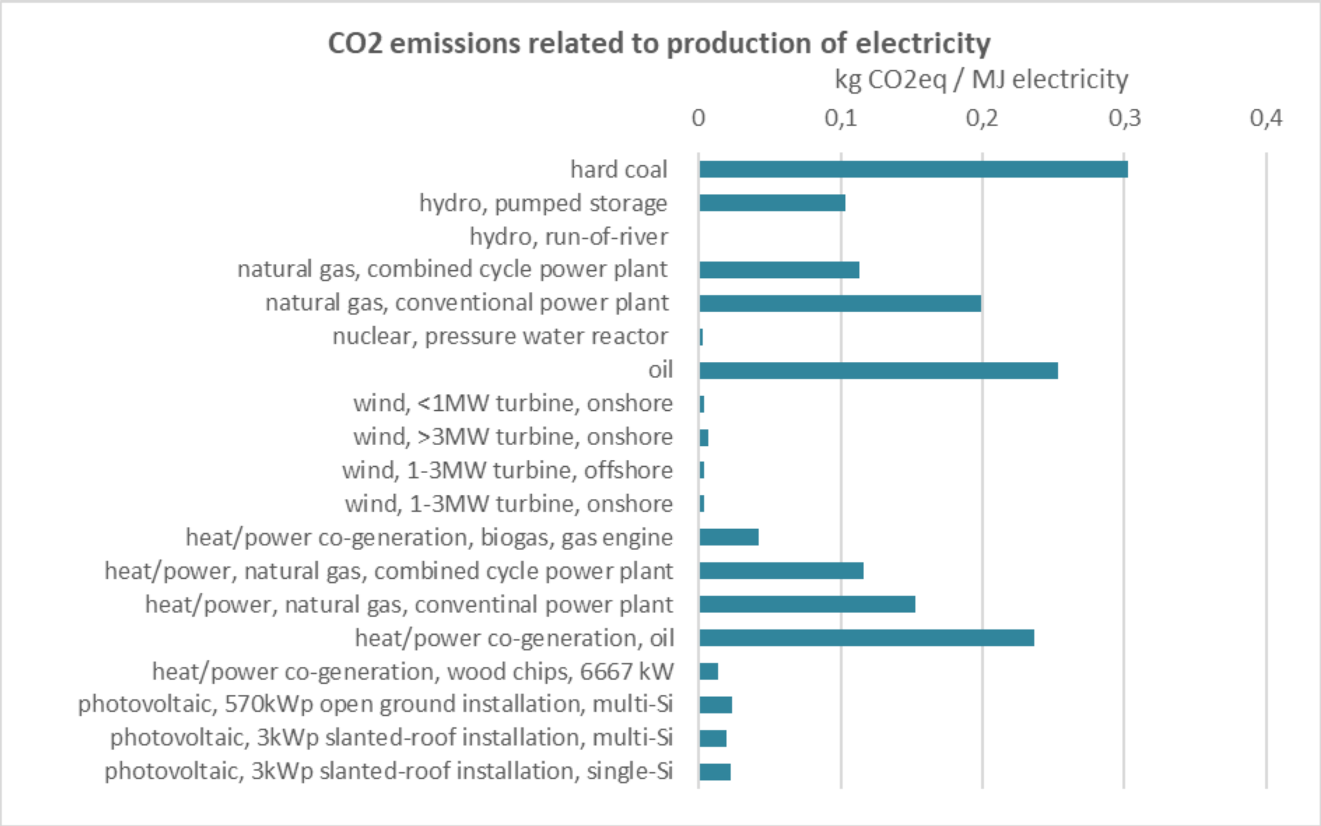


Figure 15. CO2 emissions related to the production of 1 MJ electricity produced by different power plants.

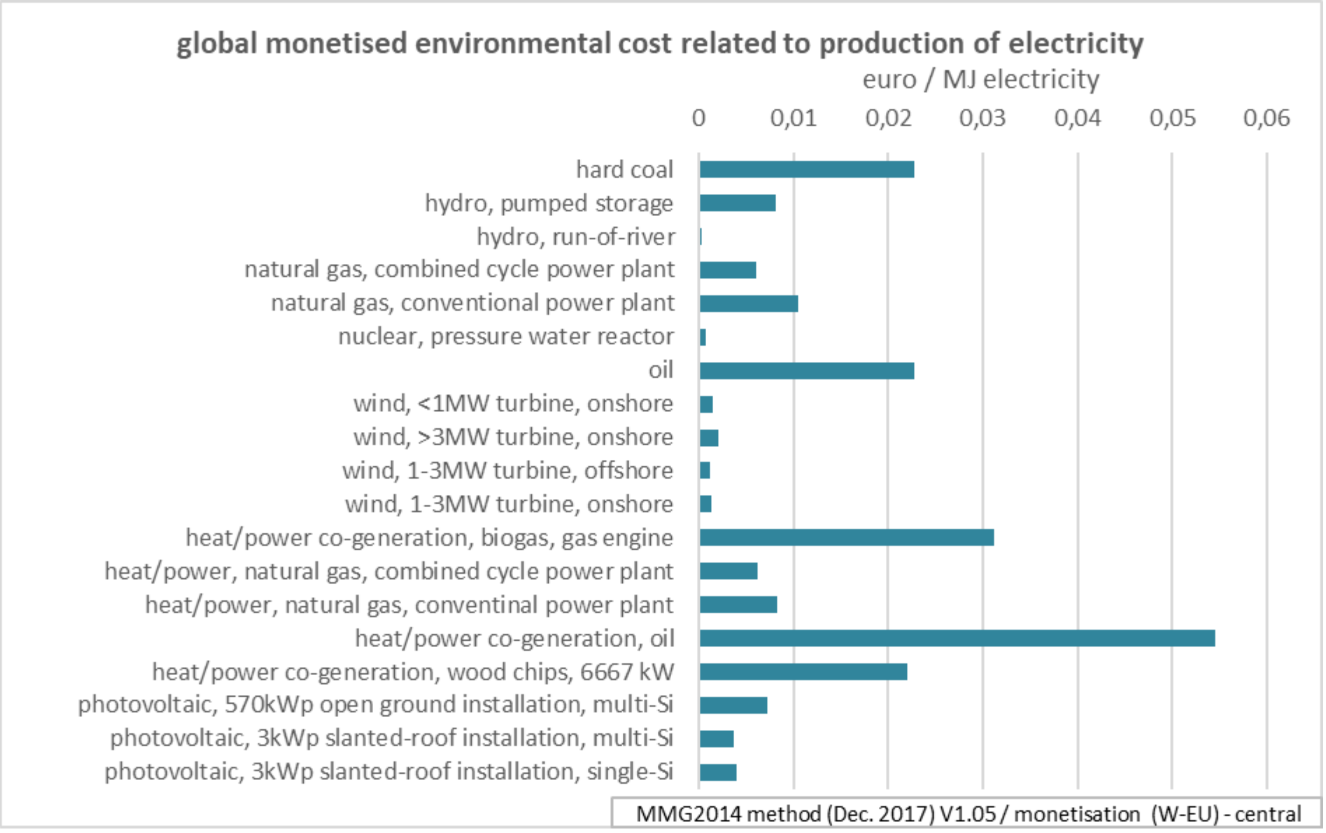


Figure 16. Monetised global environmental impact related to the production of 1 MJ electricity produced by different power plants.

7.5.2 Effect of a changing electricity mix on the renovation of the terraced house

The results in the paragraphs above showed that solar panels lead only to small net benefits in terms of CO_2 emissions and monetised environmental impact and that heat pumps appear to be an interesting option from an environmental point of view. However, one can question whether these conclusions remain valid if we move to a less carbon efficient electricity mix, as expected with the intended closure of the nuclear energy plants in Belgium. Therefore, as a sensitivity analysis, the results from the renovation of the terraced house (see §0) were recalculated assuming that the Belgian electricity mix would change in 2030, that is 10 years after the renovation took place.

Figure 17 and Figure 18 present the results from the renovation of the terraced house using the future electricity from 2030 onwards. As can be seen from those results, changing the electricity mix to the future mix after 10 years does not drastically change the conclusions of the analysis. The (net) benefit from PV panels becomes slightly larger because the avoided energy mix is slightly more polluting. And the impact from heating with a heat pump increases slightly because of the larger impact of the new electricity mix.

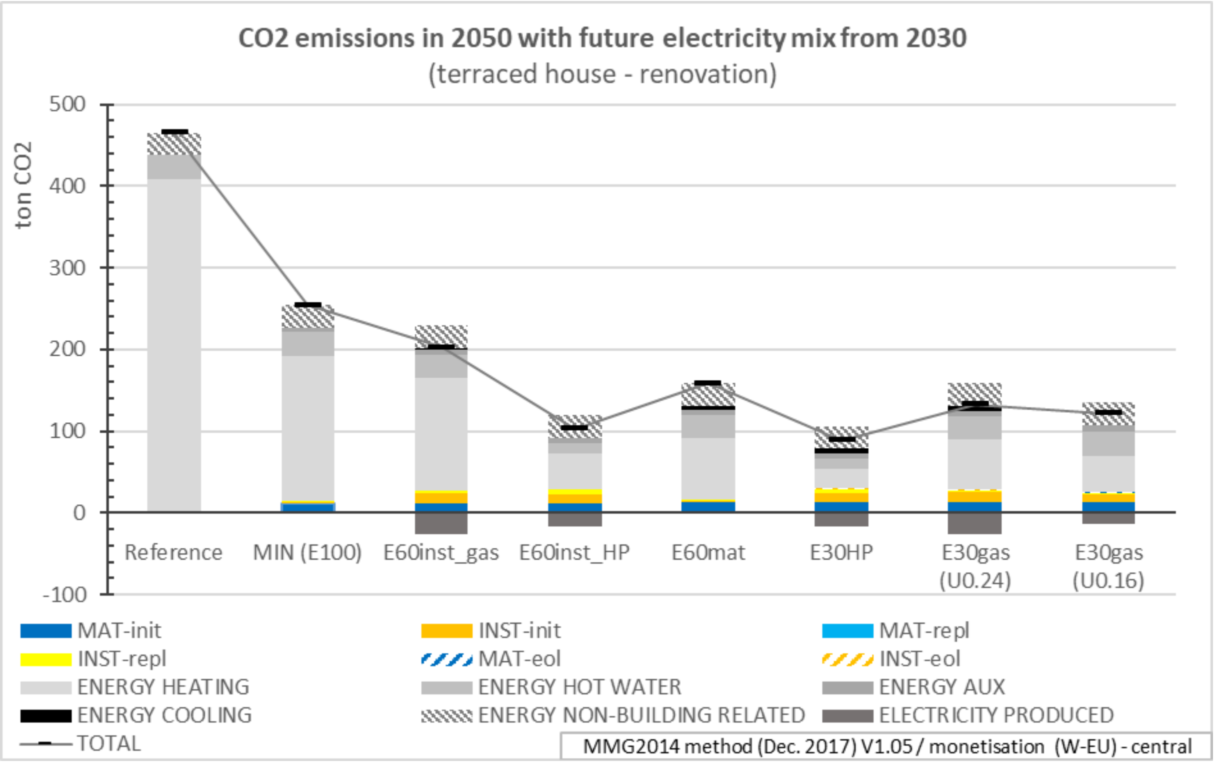


Figure 17. CO2 emissions generated by the terraced house over 30 years (from 2020 to 2050) for different renovation scenarios, with future electricity mix after 10 years

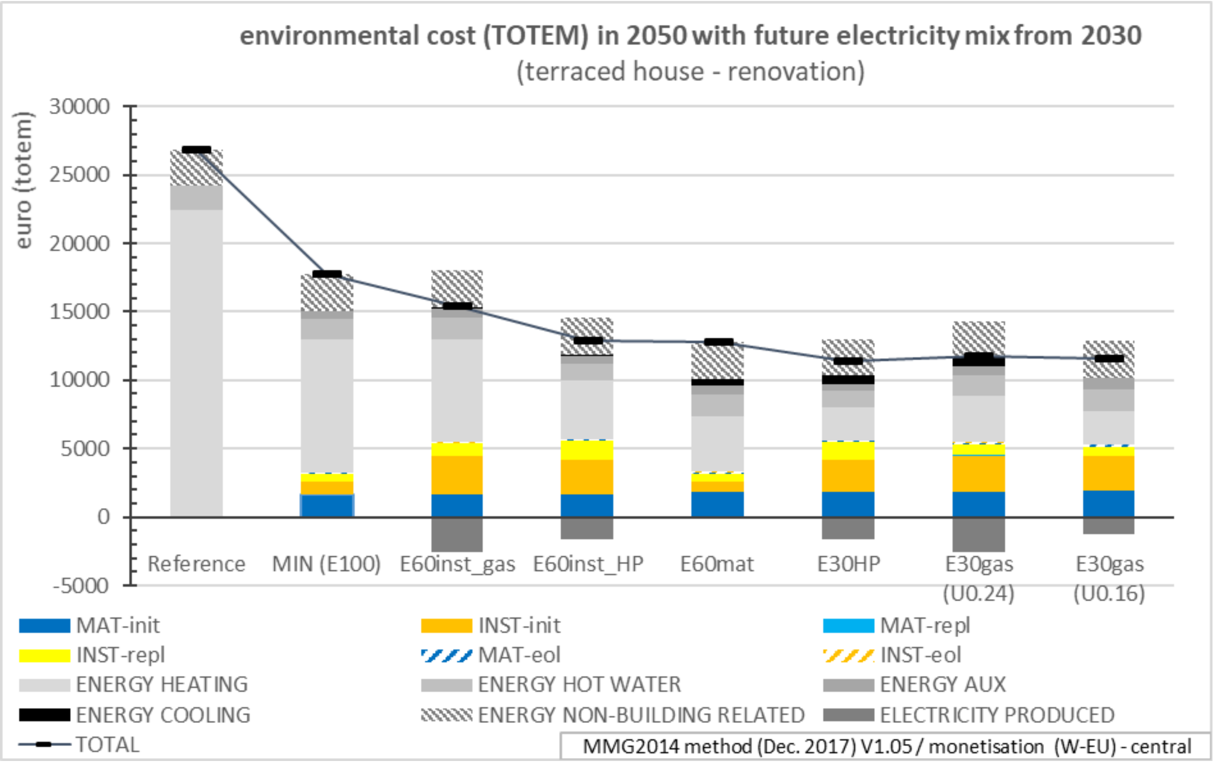


Figure 18. Monetised environmental impact generated by the terraced house over 30 years (from 2020 to 2050) for different renovation scenarios, with future electricity mix after 10 years

8 THE FLEMISH BUILDING STOCK AND SCALING UP

8.1 THE FLEMISH RESIDENTIAL BUILDING STOCK

Based on the information available from Statbel, the Belgian statistical office, there were 2.673.410 buildings in Flanders in 2018 [12]. These buildings can be further divided in terms of residential or non-residential buildings. Table 14 gives an overview of the number of residential buildings in Flanders in 2018 based on their typology. Further research on the distribution of the age of the houses within these typologies shows that the largest part of terraced houses (55%) dates from before 1945. For the detached houses, 44% was built after 1981 and a total of 64% after 1970. Most apartment buildings have been constructed from 1960 onwards (71%). These numbers clarify the choice for the older building for the two-façade case (1920) and the more recent building for the four-façade case (1985).

Table 14. Statistics on the residential housing stock in Flanders in 2018

Flemish housing stock 2018	Number of buildings
Terraced houses (Gesloten bebouwing)	650 421
Semidetached houses (Huizen in halfopen bebouwing)	582 778
Detached houses (Huizen in open bebouwing, hoeven en kastelen)	895 837
Apartment buildings (Buildings en flatgebouwen met appartementen)	127 983
TOTAAL	**2 257 019**

8.2 YEARLY CONSTRUCTION ACTIONS

Statbel also has information on the number of building permits delivered each year for renovation actions and new construction. In 2018, 17.132 building permits were delivered in Flanders for renovation and 21.933 for new construction.

8.2.1 Renovation

The number of renovations requiring a building permit was significantly higher in 2018 than in the previous years. According to the Vlaamse Confereratie Bouw, this rise can be explained by the introduction of the digital procedure for building permits in 2018. Taking the average of 2017 and 2018 leads to around 15.000 permits for renovations each year, which corresponds to the trend of the past 5-10 years.

Compared to the residential building stock, these numbers roughly lead to a renovation rate of 0.7% for Flanders. However, not all renovation actions are subject to the demand for a building permit. For some of the most basic energetic renovation actions, like insulating the roof or changing the heating installation, one does not require a building permit. Therefore, the actual renovation rate is higher and circulates probably around 1%. The main assumption for the **business-as-usual scenario** (BAU) for renovation in this study is that **each year 1% of the current building stock gets renovated**. This number is set as a fixed number and does not consider the expected changes in the building stock in the next years.

Based on recent studies by the Flemish Energy Agency (VEA) additional actions will be needed to reach the energy goals set for 2050. Tripling the renovation rate appears to be necessary in order to be able to reach these goals. In this study an **accelerated renovation speed of 3%** is set as one of the scenarios.

8.2.2 New construction

Also for new construction some assumptions have to be made. After all, part of the building permits for new construction concern building actions on a new terrain, whereas others concern the erection of a new building after demolition of an old building. The statistics show that the number of permits has significantly increased over the past years, but it is not clear whether this is related to the construction of additional buildings, or to demolition-and-new-construction.

Based on demographic evolutions, the number of households in Flanders is increasing each year. The data available at Statistiek Vlaanderen show that in the past 10 years (2008-2017) the number of households in Flanders increased on averaged with 21.700 per year. Predictions for the next 10 years lead to 17.100 additional households each year (on average) (See also Figure 19). This increase in households demands additional houses. This study assumes the **need for 20.000 additional houses each year** (in surplus to the current building stock) in order to meet the need related to the growing population in Flanders.

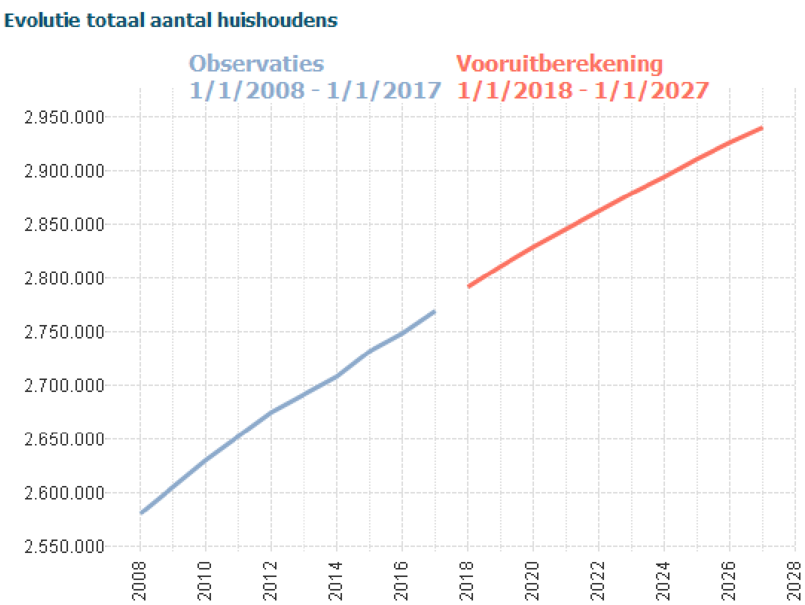


Figure 19. Evolution of the number of households based on the Flemish municipal demographic prognoses 2018-2035, according to Statistiek Vlaanderen [copyright figure from www.statistiekvlaanderen.be]

8.3 SCENARIOS FOR SCALING UP

The results from the individual cases are scaled up to the Flemish building stock based on their basic typology. The global monetised environmental impact and CO_2 emissions of the current building stock are thus determined by multiplying the number of dwellings within a certain typology (see Table 14) with the impact and emissions of the specific case results for this typology (see §7). Given the limited size of the study, no renovation case is available for the semidetached house. The impact of the semidetached house was set to the average impact of the terraced house and the detached house. The impact of the existing building stock anno 2019 is only related to the energy use of the buildings (before renovation).

The combination of the results for the different typologies in relation to the specified ambition levels is used to simulate the impact of the Flemish building stock in five renovation scenarios:

- S1 (MIN, 1%): Renovation rate 1%, with minimal renovation interventions
- S2 (E60, 1%): Renovation rate 1%, with medium-high ambition level E60 for all renovations
- S3 (E30, 1%): Renovation rate 1%, with extreme ambition level E30 for all renovations
- S4 (E60, 3%): Renovation rate 3%, with medium-high ambition level E60 for all renovations
- S5 (E30, 3%): Renovation rate 3%, with extreme ambition level E30 for all renovations

Based on the considered renovation rate, each year a fixed number of buildings are being renovated according to a specific ambition level. The impact related to the construction materials and the materials of the installations used for these renovations is consequently added to the impact related to the operational energy use for all buildings (renovated or not) in that year. Impacts related to replacements of technical installations are accounted for after 15 years, at the time they will occur.

This scaling up of results based on a single case for each typology contains a high uncertainty: some dwellings in the existing stock have already been renovated, or have a better or worst energy performance, the specified materials and renovation measures or approach might be different, the sizes of the houses and the comfort needs of the occupants differ, etc. Therefore, the conclusions based on this part should be interpreted with care.

8.4 SCALING UP OF CASE STUDY RESULTS TO FLEMISH BUILDING STOCK

8.4.1 Clarification of yearly emissions or impact – theoretical example

Before showing the results scaled up to the complete building stock, the figures below clarify which emissions or impact are represented when declaring a “yearly impact”. The example is given in Figure 20 and Figure 21 for the detached house and a renovation scenario towards E30gas.

The starting point in this example is a set of 100 detached houses in 2019 (not renovated). In line with the current renovation rate of 1%, from 2020 onwards one house gets renovated each year (according to scenario E30gas). As a result, in 2020 Figure 20 shows the CO_2 emissions related to the construction materials and materials of the installations used for the renovation of one house. In addition, the CO_2 emissions related to the energy use of 100 old houses shows (99 houses are not renovated yet, and the decreased energy use for the renovated house only starts showing in 2021). The CO_2 emissions related to the old buildings (red bars) decrease as more buildings get renovated over time. By 2050, 30 buildings have been renovated, thus 70 building are still consuming energy as in a non-renovated scenario. An increase in CO_2 emissions related to the energy use for the newly renovated dwelling starts in 2021 (orange bars) and increase as more buildings get renovated over time. Since the energy use for a renovated dwelling is lower than the energy use for an old building, overall the CO_2 emissions related to the energy use of the 100 dwellings (red + orange bars) is decreasing by 2050. As one building gets renovated each year, each year some CO_2 emissions emerge in relation to the renovation actions (construction materials and materials for technical installations). This is a punctual emission, since the impact is taking place at the moment of renovation. Starting from 2035 an additional impact related to the replacement of the technical installations occurs (but this impact is too small to be visible on the graph).

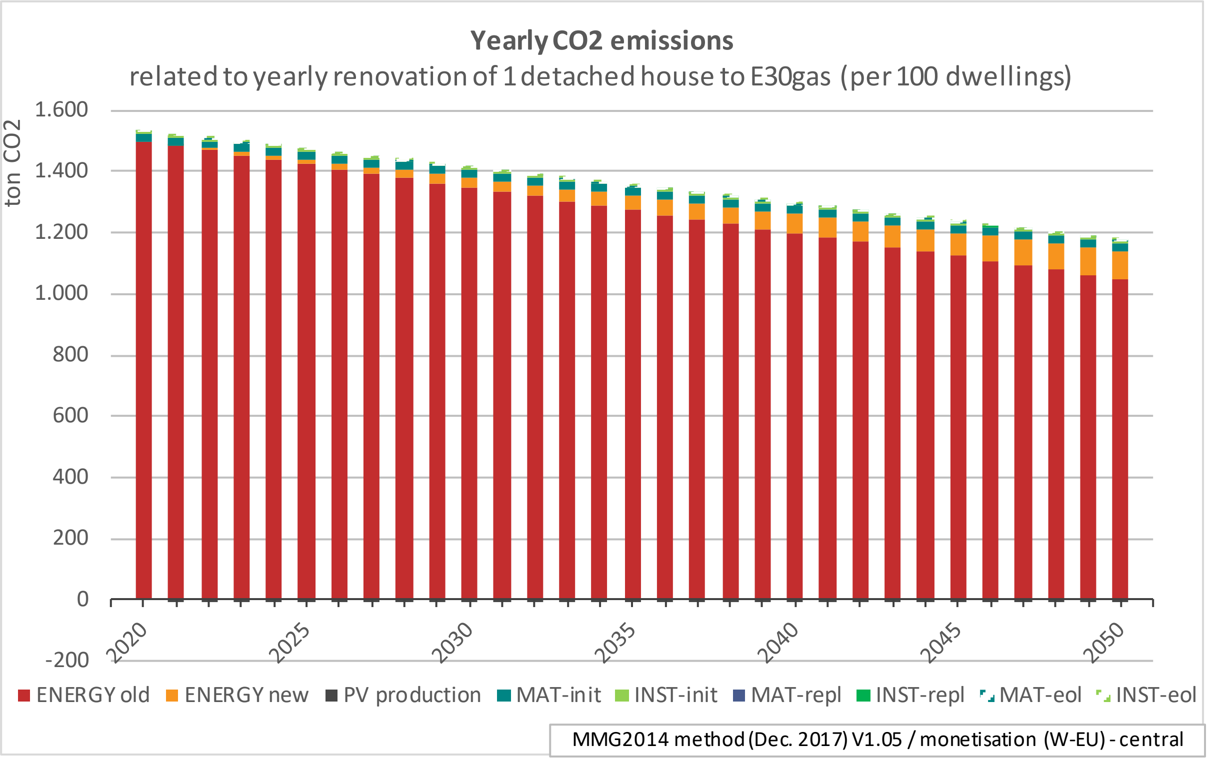


Figure 20. Yearly CO2 emissions related to a set of 100 detached buildings, considering the renovation of one house each year (1% renovation rate) according to the E30gas renovation scenario

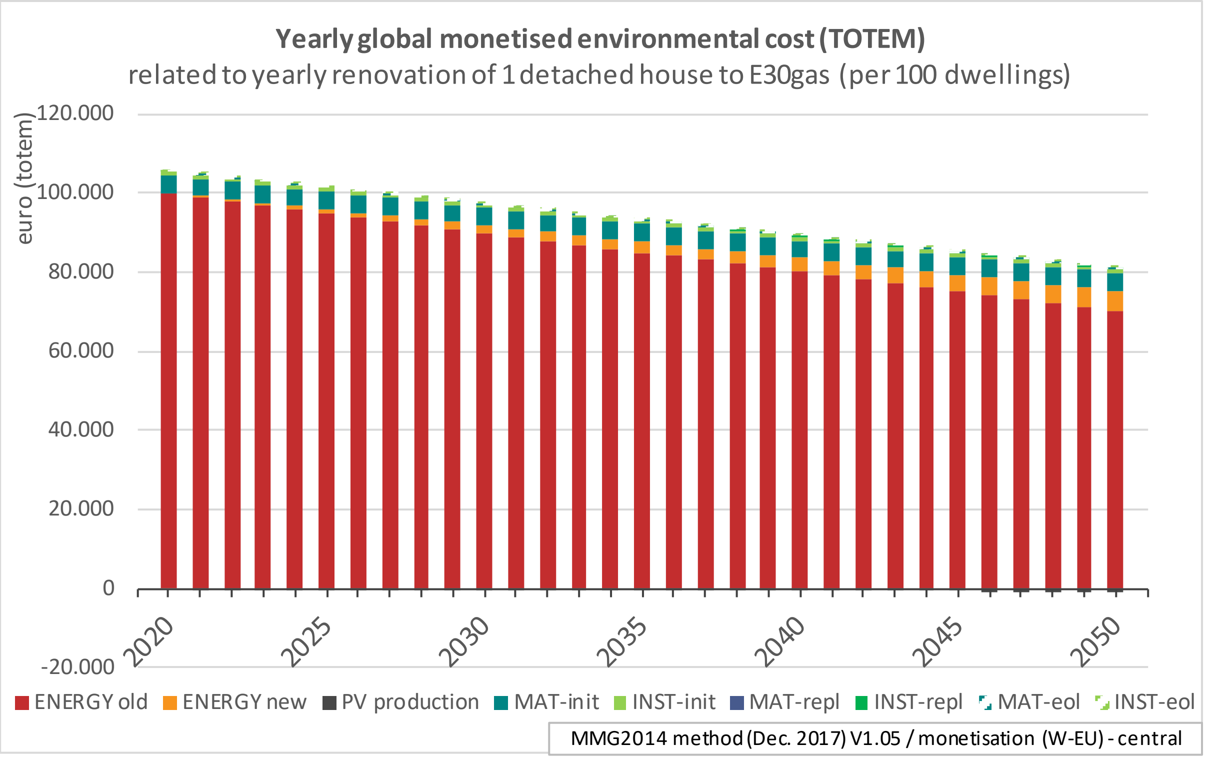


Figure 21. Yearly monetised global environmental impact related to a set of 100 detached buildings, considering the renovation of one house each year (1% renovation rate) according to the E30gas renovation scenario.

A similar approach is taken for the yearly global monetised environmental impact (see Figure 21). As could already be seen from the individual case results (see § 7.3) the relative importance of the materials and technical installations is larger based on the global monetised environmental impact than based on CO_2 emissions. Nevertheless, the initial increase in additional impact related to the material use, gets countered by the gains in terms of energy use.

8.4.2 Renovation of the existing housing stock

Figure 22 and Figure 23 respectively show the yearly CO_2 emissions and yearly monetised global environmental impact related to the Flemish building stock, for the time period 2020-2050, calculated based on the impact of the reference buildings and for different renovation scenarios. The impact related to the existing building stock anno 2019 is indicated with a dotted line. This number corresponds to the CO_2 emissions related to the yearly operational energy use as calculated for the reference buildings before renovation and multiplied by the number of buildings in the housing stock (see Figure 22). The coloured lines represent the different renovation scenarios (as described in §0). For example, for the first scenario S1 (MIN, 1%), each year 1% of the of the current building stock is being renovated according to a minimal renovation scenario. This implies that each year 6504 terraced houses, 5828 semidetached house, 8958 detached houses and 1280 apartment buildings (with on average 8 units per building) are being renovated. The CO_2 emissions associated to the materials (construction materials and materials for the installations) for these renovations are added to the emissions related to the energy use (cfr. principles described in §8.4.1). However, this breakdown between impact related to materials and energy is not visible in the results (for reasons of readability). These insights can be gained in the previous paragraph and in the description of the results for the individual cases.

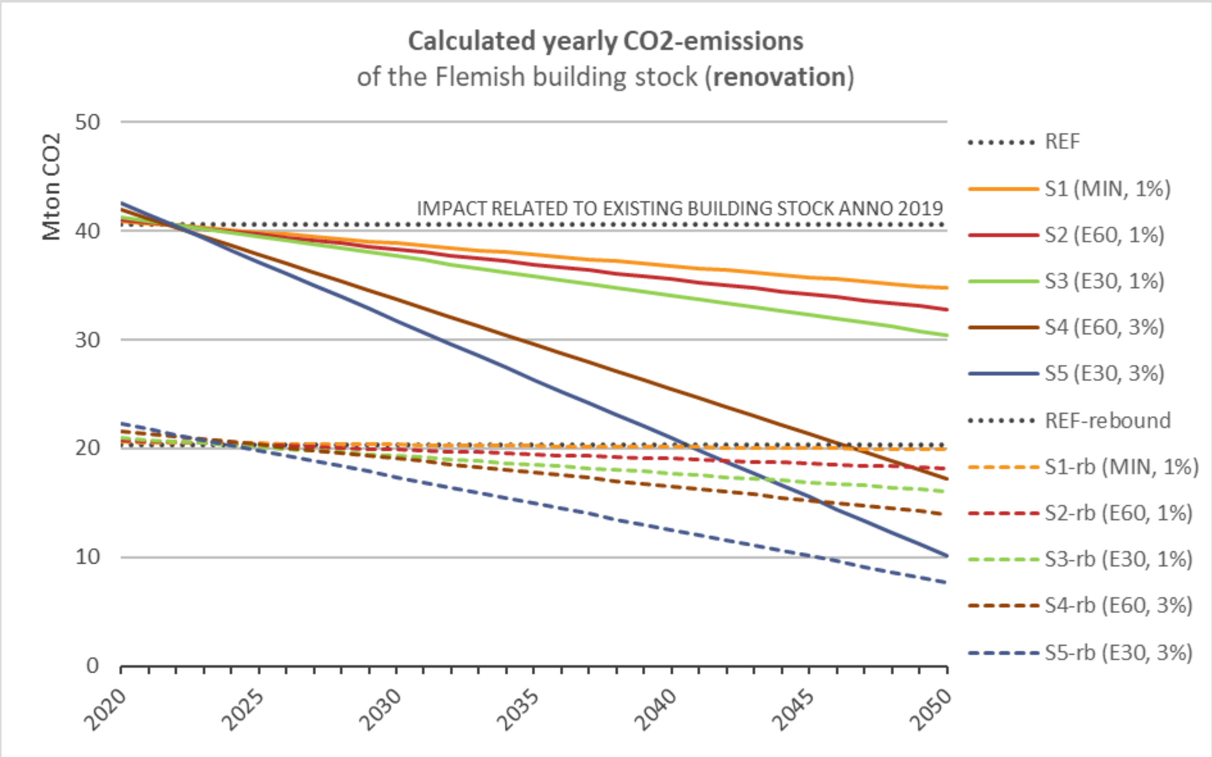


Figure 22. Calculated yearly CO2 emissions related to the Flemish building stock in case of different renovation scenarios.

Based on Figure 22, the following general conclusions can be drawn:

- For each scenario, an initial increase in total yearly CO_2 emissions can be seen, compared to the existing situation. This increase is caused by the emissions related to the materials used for the renovation (construction materials and materials of technical installations).
- However, for all scenarios a decrease in total yearly CO_2 emission can be noted within three years' time.
- Considering a renovation speed of 1%, the minimal scenario leads to a 15% decrease in yearly CO_2 emissions in 2050 compared to 2020. The scenario considering solely renovation towards E30 (so with a high ambition level for the energy performance), leads to a 25% decrease compared to 2020.
- Accelerating the renovation speed up to 3% of the building each year, could lead to a 75% decrease in CO_2 emissions in 2050 compared to 2020 when renovating all buildings towards E30.

However, an important note must be made concerning the considered energy use (and associated emissions) for the existing building stock. Research has shown that the energy use for non-insulated or poorly insulated buildings typically is lower than what is calculated in EPB/EPC. For high EPC-numbers (as is the case for most of the reference buildings), chances are that the actual energy use is a factor 0.5 lower than the calculated energy use. For the renovated houses, the actual operational energy use is expected to be situated around 90% of the calculated energy use. This correction factor (0.5 for reference and 0.9 for renovation) is taken into consideration and represented by means of dashed lines in Figure 22.

The results show that the gains to be made are significantly lower when considering this corrections factor related to the actual energy use. Renovation according to the minimal scenario for instance only leads to a 2% reduction in yearly CO_2 emissions in 2050. For higher levels of ambition, the results are less influenced: renovation towards E30 could lead to a 21% reduction in CO_2 emissions considering a renovation rate of 1% (and up to 60 reduction for a renovation rate of 3%). Also, it takes more time before an absolute decrease in yearly emissions can be noted compared to the reference situation.

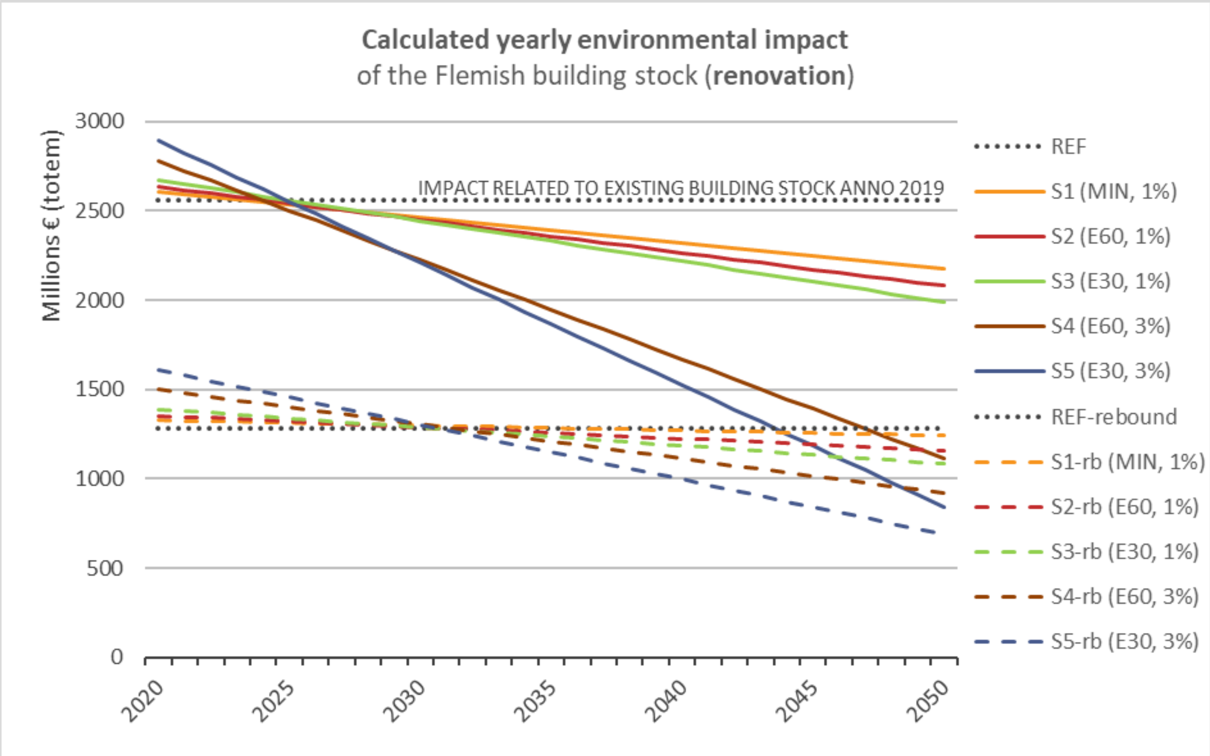


Figure 23. Calculated yearly monetised global environmental impact related to the Flemish building stock in case of different renovation scenarios.

The results and trends for the monetised global environmental impact (see Figure 23) are similar to those for the CO_2 emissions. The most important differences are stated below:

- The initial additional impact related to the renovation actions (embodied impact of construction materials and materials for installations) is larger for the global monetised environmental score. As a result, it takes around 5 to 7 years before an absolute decrease in yearly impact can be noted.

- The difference in (reduced) impact related to the different levels of ambition is rather limited. A 15% reduction in impact by 2050 can be achieved through a minimal renovation scenario, a 22% reduction through a deep renovation scenario (E30), both considering a renovation rate of 1%.
- Considering the rebound effect for the energy use, it takes about 10 years for all scenarios before the absolute yearly impact decreases in comparison with the 2019 situation. Considering a 1% renovation rate, the reduction in impact for the minimal scenario is limited to 3% in 2050 and to 15 % for the E30 renovation scenario.

8.4.3 Considering the need for additional new construction

As stated above, in relation to the demographic evolutions, a need for additional housing units continues to exist in the coming years. In addition to the results for the different scenarios above, Figure 24 and Figure 25 also consider the emissions and environmental impact associated with the construction of 20.000 additional houses (type semidetached) each year. Logically the possible reductions by 2050 will become smaller. For the CO_2 emissions, the results show a reduction of 9% and 19% by 2050 for respectively a renovation towards minimal renovation and deep renovation (E30) with a yearly renovation rate of 1%.

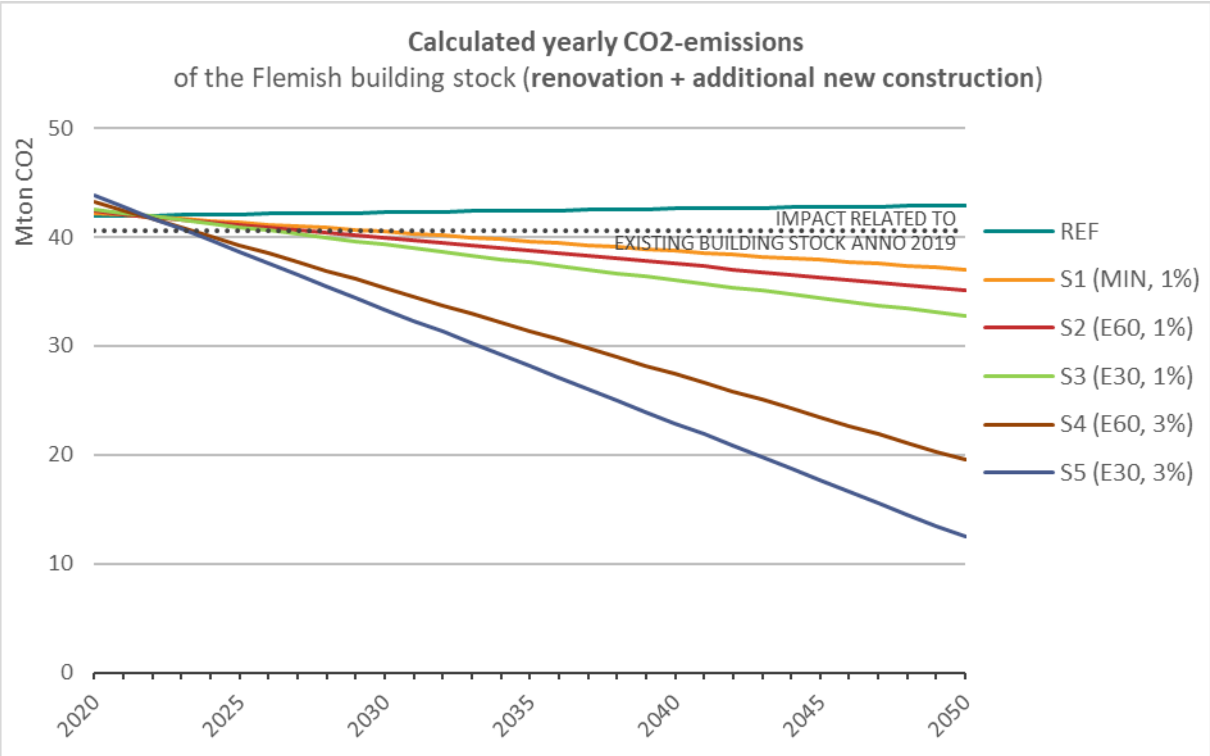


Figure 24. Calculated yearly CO2 emissions related to the Flemish building stock in case of different renovation scenarios, including additional new construction each year of 20.000 housing units.

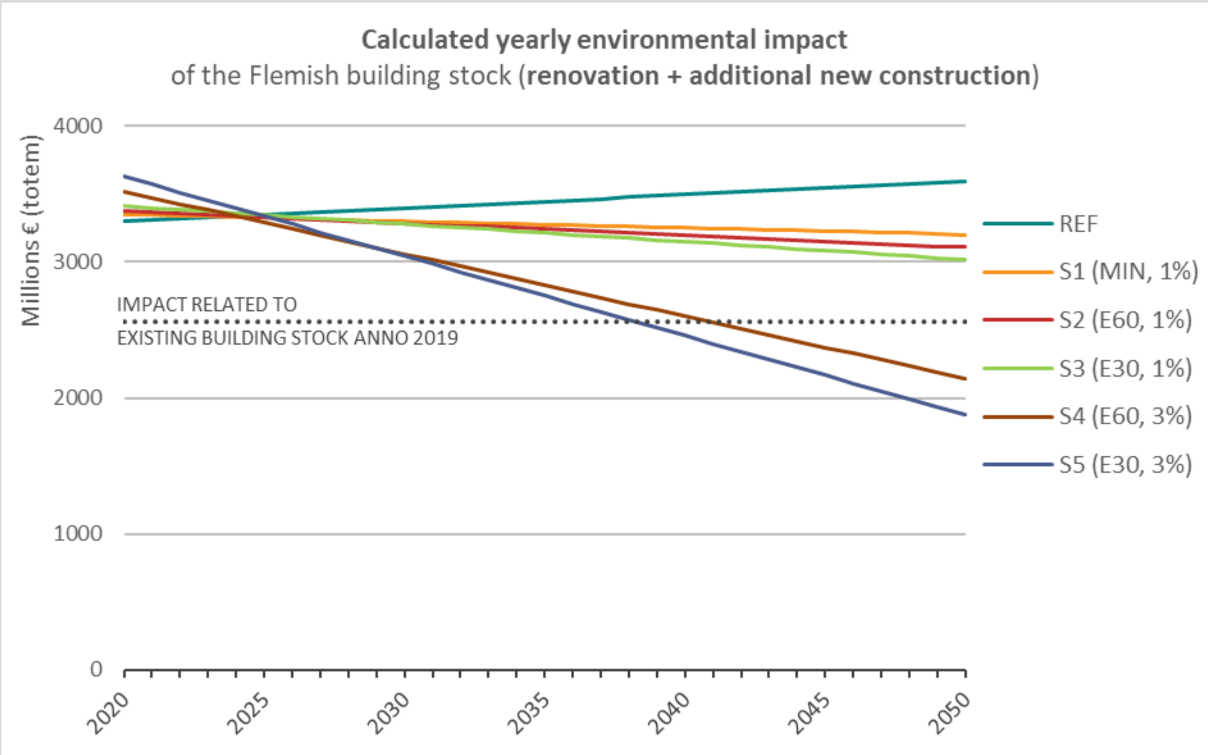


Figure 25. Calculated yearly monetised global environmental impact related to the Flemish building stock in case of different renovation scenarios, including additional new construction each year of 20.000 housing units.

However, for the monetised global environmental impact, the results are far more problematic. Given the high additional environmental impact associated with the newly constructed houses, all the advantages/gains by the renovation scenarios at 1% speed are undone: the environmental impact related to the newly constructed houses is higher than the environmental gains associated with renovation (see Figure 25). The materials used for the construction and technical installations of 20.000 semidetached houses have a global monetised environmental impact in the order of magnitude of 740 million euro.

In terms of global monetised environmental impact, it appears that reductions in the yearly impact can only be achieved for renovation speeds of 3%. If we were to consider the rebound effect in this case, even for the 3% renovation speeds no reductions in impact would be feasible.

These results confirm the earlier insights that the monetised global environmental impact becomes especially important in new construction.

9 CONCLUSIONS

9.1 IMPACT OF INDIVIDUAL CASE STUDIES

Based on the evaluation of the CO_2 emissions and monetised global environmental impact associated with the **renovation** of three reference buildings (considering a reference study period of 30 years), this study shows that:

- Significant environmental gains (expressed in $CO_{2\ (eq)}$ and global environmental cost) are achievable through energetic renovation; especially when the reference situation has a very poor energy performance. Indeed, the impact of the construction materials and the materials for technical installations used to improve the energy performance of buildings is relatively small in comparison to the resulting decrease in operational energy use.
- A lower E-level generally leads to a lower environmental impact (but not always, and the marginal environmental gain decreases as the E-value decreases)
- The environmental impact for a given E-level can vary significantly depending on the renovation strategy;
    - PV panels lead to smaller environmental gains than insulation (despite the 30 years horizon considered for the study)
    - The impact of insulation actions increases when additional materials must be replaced during the renovation process which do not contribute to the energy efficiency of the building (e.g. removing and replacing the floor finishing material and screed in order to insulate the floor)
    - These differences can be so significant that a worst case E30 renovation scenario can lead to a higher life cycle impact than a best case E60 renovation scenario

Based on the analysis of a newly built semi-detached house, the difference in environmental performance between various scenarios achieving an E-level of 30 or lower is rather limited. However, the results indicate that the relative contribution of embodied impact of materials and installations to the life cycle impact is rather high for highly energy efficient new buildings (i.e. because the operational energy use is low and the amount of materials is much higher than in the case of an energetic renovation). Therefore, the optimisation potential through material selection and circular design can be significant for new buildings.

Moreover, the renovation and new built case studies indicate that:

- the relative importance of construction materials and materials for technical installations (embodied impact) is higher (in comparison to the operational energy use) based on the monetised global environmental score (TOTEM) than based on global warming potential only. Therefore, although both indicators tend to point in the same direction, the conclusions concerning the most “interesting” scenario (with the lowest impact) can sometimes vary depending on the indicator considered;
- energy performance of building (EPB) regulations is a good tool to help improve the energy performance of buildings. However, the way in which this E-level is achieved, still leaves several opportunities in optimisation of the environmental impact. Therefore, LCA calculations (i.e. by use of TOTEM) nicely

complement EPB as they can help identify the most optimal combination in terms of selection of material and technical installations;

- the selection of technical installations within an optimisation process should be based on both the embodied impact of the materials used for the installations (production, transport, replacements, end-of-life) and their impact on the operational energy use. Both parameters shall be considered simultaneously.

Finally, a sensibility analysis shows that prognoses made by the Planbureau for changes in the Belgian electricity mix (when phasing out the nuclear power plants) hardly influences the conclusions concerning the PV panels or the heat-pumps. Indeed, although the foreseen electricity mix is slightly less favourable in terms of CO_2 and monetised global impact, thanks to their high efficiency heat pumps remain relatively interesting solutions and the installation of PV panels remains generally less interesting from an environmental point of view than insulation measures.

9.2 INFLUENCE OF DIFFERENT SCENARIOS ON THE YEARLY IMPACT OF THE FLEMISH BUILDING STOCK

A quick scaling up of the individual case results to the Flemish building stock shows that at the current renovation speed (1%), a maximum reduction of about 25% in yearly CO_2 emissions and 22% in yearly monetised environmental impact could be achieved (compared to 2020) when renovating towards an ambitious E30-level. Taking into consideration a rebound effect for the energy use related to the existing building stock limits these potential reductions to respectively 21% and 15%. This will not be enough to reach the climate goals. Therefore, it is necessary to increase the renovation speed. Indeed, at 3% renovation rate, much higher reductions can be achieved (e.g. including the rebound effect, renovation to E30 leads to about 60% reduction in terms of CO_2, and about 45% in terms of global monetised environmental impact compared to 2020). In all cases, considering the rebound effect, the yearly monetarised global impact decreases only after about 10 years (i.e. the embodied impact of renovation materials and installations initially increase the impact).

When accounting the need for about 20.000 additional houses each year in relation to the demographic evolutions, the results show that the potential reductions related to the building stock are even smaller – given that the building stock keeps growing. For the monetised global environmental impact, the embodied impact of the additional new construction is larger than the environmental gains that are made by renovating at a rate of 1%. Even considering a renovation rate of 3% and an ambition level for renovation of E30, gains in yearly global environmental impact are only observed after more than 15 years and the achieved reduction in yearly impact in 2050 is still limited to about 20% (compared to 2020).

10 LINK WITH STUDY 'POTENTIEELINSCHATTING'

In this study different scenarios are only defined based on the level of ambition in terms of energy performance (different E-levels) and on the use of different technical installations (e.g. condensing gas boiler, heat pump and/or photovoltaic panels). The evaluation of the CO_2 emissions and monetised global impact related to different renovation and new construction scenarios focused, amongst others, on the relative importance of the materials, technical installations and energy use in the total impact. Whereas insights are given in the optimisation in terms of energy use and technical installations, the selection of construction materials was fixed for this study.

Nevertheless, the CO_2 emissions and monetised environmental impact related to the construction materials used can also be reduced by optimising the choice of materials. As shown from the case study results, especially for new construction and high levels of energy ambitions, the emissions and impact related to the materials can be significant in comparison to those related to the energy use.

The study "TOTEM Potentieelinschatting" deals with the potential reduction in environmental impact that can be achieved by optimisation of the choices of materials. Results show that a 30% reduction in monetised environmental impact related to the materials is possible by choosing the materials with the lowest impact. Evidently, for renovation, this effect will be limited in comparison with the total environmental impact (including energy use). The study also evaluated the reduction potential through optimisation of the energy performance of buildings based on two of the previously discussed cases and scenarios (energetic renovation of the terraced house (6.1) and new construction of a semi-detached house (6.4)). However, as the objective of the study was different, the case studies were analysed based on a study period of 60 years instead of 30 years.

The paragraph below copies the general conclusions from the study. The complete report is available upon request at OVAM.

GENERAL CONCLUSIONS CONCERNING THE OPTIMIZATION POTENTIAL OF BUILDINGS - FROM STUDY 'POTENTIAL OF TOTEM FOR ENVIRONMENTAL IMPACT REDUCTION'

Both the results from literature and the performed case studies indicate that there can be high variations in environmental performance of buildings. Therefore, the optimization potential of buildings is significant.

The first case study (new apartment building-optimization strategy focusing on the material selection) shows that an optimization strategy based on material selection only (focusing only on materials contributing to at least 3% of the material impact) can lead to a reduction of about 30% of the material related impact (reduction of about +-17€/m2), or about 15% of the total impact (materials + energy use for HVAC). This reduction will however be very much influenced by the initial material selection and the freedom left to the designer. Moreover, the results confirm the findings from the literature study concerning the fact that finishing materials can be an important part of the optimization strategy. They are sometimes major contributors and usually many alternatives are possible. However, it is important to note that the optimization potential of finishing materials with a short service life may be overestimated. Indeed, the results assume that the choice made during design stage will be maintained throughout the service life of the building (e.g. the same type of paint will be used every 10 years). However, in reality the building owner may decide otherwise.

In line with the conclusions from the literature review, the renovation case study indicates that the highest reduction potential for old (poorly insulated) buildings lies in the improvement of the energy performance. The material related impact for an energetic renovation is usually relatively low, but the improvement potential in terms of energy use is high. For the renovation of the terraced house from 1920, a 50% reduction of the life cycle impact (almost 60€/m2) was achieved by optimizing the type of installations and insulation level compared to a strategy that would only fulfill the minimum requirements in terms of energetic renovation (replacement of windows and heating system and replacement and insulation of the roof). The results also show that EPB and TOTEM can be complementary tools. Indeed, although the E-value points in the right direction (lower E-levels lead to lower environmental impact), there is still room for optimization within a given E-value.

Based on the third case study (newly built family house – optimization strategy focusing on the energy performance), even for low energy buildings there is a potential for impact reduction through optimization of the insulation level and choice of installations. The extent of the optimization potential will depend on the performance of the starting point, but it can be of the same order of magnitude as the reduction potential through material selection.

Moreover, existing and present case studies, indicate that the impact of installations can be relatively high. As installations influence the impact related to the energy use of the building it must be ensured that the embodied impact of insulation materials, installations (modules A, B4, C) and operational energy use (B6) are considered together to allow for holistic optimization.

Finally, existing studies indicate that for new (low energy) buildings the reduction potential through optimized building design (lay-out, percentage of windows, height of ceilings, …) can be at least as important as the reduction potential through material selection or improvement of the energy performance of the building. Therefore, a geometric optimization should be the first step of any environmental optimization process.

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12 ANNEX 1 – MONETISED GLOBAL ENVIRONMENTAL INDICATOR

Table 15 gives an overview of the individual impact categories considered in the global monetised environmental score and the corresponding monetisation factors [10].

Table 15. Impact categories included in the monetised score and their corresponding monetisation factor

Impact category	Unit	Monetisation factor [€/unit]
Global warming	kg CO2 eq	0,05
Ozone depletion	kg CFC 11 eq	49,10
Acidification for soil and water	kg SO2 eq	0,43
Eutrophication	kg (PO4)3- eq	20
Photochemical ozone creation	kg Ethene eq	0,48
Depletion of abiotic resources - elements	kg Sb eq	1,56
Depletion of abiotic resources - fossil fuels	MJ, net calorific value	0
Human toxicity - cancer effects	CTUh	665.109
Human toxicity - non-cancer effects	CTUh	144.081
Particulate matter	kg PM2,5 eq	34
Ionising radiation - human health effects	kg U235 eq	9,70E-04
Ecotoxicity - freshwater	CTUe	3,70E-05
Water scarcity	m3 water eq	0,067
Land use: occupation - soil organic matter	kg C deficit	2,70E-06
Land use: occupation - biodiversity		
- urban	m^2yr	0,30
- argricultural	m^2yr	0,006
- forest	m^2yr	2,20E-04
Land use: transformation, soil organic matter	kg C deficit	2,70E-06