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Projections in Hindsight for the Building Sector: Understanding Drivers for Future Policymaking

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ABSTRACT

Energy and emissions projections are essential for effective climate policymaking, yet their alignment with actual developments is rarely evaluated. This study retrospectively assesses carbon dioxide emissions projections for the buildings sector in Belgium and the Netherlands between 2000 and 2020. Using a mixed-methods approach, it combines decomposition analysis with a review of policy and socio-economic contexts to compare 43 national scenarios against historical data.

Emissions were decomposed into four drivers, weather, socio-economic activity, energy intensity, and emission intensity, to identify causes of deviations. Projections in both countries consistently overestimated emissions and energy use when compared to historical data, with 2020 deviations averaging +22% for Belgium and +15% for the Netherlands in residential buildings, and +29% and over in the service sector. Energy intensity was the most uncertain and typically overestimated driver, reflecting conservative assumptions on efficiency gains. Emission intensity trends were more accurately captured, while socio-economic and heating degree day assumptions varied in precision. Scenarios with higher policy ambition showed notably smaller deviations. All scenarios assumed continuous activity growth, excluding potential disruptions, such as economic crises, and projected rapid recoveries thus resulting in deviations as compared to historical data.

This comparative assessment demonstrates the value of systematic hindsight analysis to improve projection methodologies and policy design. It highlights the need for more ambitious scenarios that move beyond prevailing concerns, draw on past policy impact assessments to improve modelling of energy intensity and behavioural change, and incorporate dynamic assumptions on economic, demographic, and weather-related uncertainties.

Keywords

Retrospective analysis, energy scenarios, historical analysis, decomposition analysis, building sector

Acronyms

BE	Belgium
CO_2	Carbon dioxide
EU	European Union

FEC	Final energy consumption
GHG	Greenhouse gas
HDD	Heating degree days
IDA	Index decomposition analysis
LMDI	Logarithmic mean divisia index
NL	The Netherlands
WAM	With additional measures
WEM	With existing measures

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Introduction

Over the past decades, numerous greenhouse gas (GHG) emission and energy projections have been reported for various scenarios to support climate and energy policymaking. The accuracy of the projections , however, has been an issue over decades (Bezdek & Wendling, 2002; Craig et al., 2002). Even if it is clear that perfect accuracy cannot be achieved when modelling socio-technical phenomena of the future under deep uncertainty, systematic and repeated projection errors can lead to situations where policy insights and decision recommendations drawn from the projections are not precise and carry bias from the modelling methods, with real world consequences (Morgan & Keith, 2008; Shen et al., 2023). To ensure that projections remain robust and effective in achieving long-term sustainability goals, it is essential to retrospectively compare them with historical developments, identify the main sources of deviation, and thereby gain insights into factors that can inform more effective future policy.

There are different ways to analyse the uncertainty and assess the accuracy of projections. Retrospective assessments can be categorised into qualitative assessments and quantitative assessments. Qualitative assessments reflect on energy models and scenarios in a general manner, analysing reasons for deviations between modelled scenarios and the real-world transition and giving suggestions on how to improve the models (Wen et al., 2022). An example of a qualitative retrospective analysis is the study conducted by Lopez, Pourjamal, and Breyer (2025), which compared different world energy outlook scenarios of the International Energy Agency (IEA) with historical developments to assess their performance. Quantitative assessments, on the other hand, provide more accurate information on how models and specific scenarios deviate from the real-world transition and make more in-depth analysis possible. A commonly used method is an in-depth analysis of accuracy indicators using error decomposition techniques (O'Neill & Desai, 2005; Wen et al., 2022; Winebrake & Sakva, 2006).

Such evaluations serve multiple purposes. First, they enable systematic assessment of the strengths and weaknesses of existing projection methodologies (Craig et al., 2002). Second, they provide crucial insights into the uncertainties and limitations inherent in projections (Tvinnereim, 2014). Third, they contribute to the refinement of projection models, enhancing their reliability for future policymaking and mitigation strategies (Trutnevyte et al., 2016). Despite these benefits, retrospective analyses of emissions and energy projections remain scarce in published research within the climate and energy domain. Most retrospective assessments have focused on the global level, especially the IEA's projections (Liao et al., 2016; Lopez et al., 2025), United States' projections, for which there has been a strong tradition (O'Neill & Desai, 2005; Winebrake & Sakva, 2006), and more recently also Chinese projections that are very complex due to the high uncertainty related to economic growth (Shen et al., 2023).

A barrier for retrospective assessments can be data availability. This is especially relevant if the performance of a range of projections is compared. Lack of explicit data, including major energy quantities, and inconsistent approaches and time horizons mean some projections have to be excluded from analysis. Since these models often have different structures and input variables, comparisons of the results are not straightforward (Ang & Goh, 2019). In this regard, decomposition analysis has emerged as a tool to facilitate comparisons in a harmonised way. It allows differences in emissions or energy consumption over time or between models to be broken down based on a set of accepted driving factors. Decomposition analysis has been used to assess the influence of economic growth, sectoral shifts, efficiency improvements, and technology changes on energy consumption and GHG emissions (Ang & Zhang, 2000). Decomposition analysis of past trends helps modellers to more accurately project future changes in energy use and GHG emissions (Hasanbeigi et al., 2013) and has been used to analyse how sectoral decarbonisation scenarios differ from system-wide scenarios in the European Union (EU) (Riemer et al., 2023).

This study evaluates deviations of carbon dioxide (CO_2) emission projections between 2000 and 2020, across available scenarios, against historical emission inventories. The aim is to identify the main factors contributing to these deviations and derive lessons to improve future projection practices. EU Member States have a long-standing tradition of developing long-term climate and energy projections due to reporting obligations under the relevant EU acquis. The availability of projections for the 2000-2020 period provides an opportunity to assess their accuracy in hindsight. The study focuses on CO_2 emission and energy projections for the buildings sector in Belgium and the Netherlands, with separate analysis for residential and service sector buildings. These two neighbouring countries share EU climate policy commitments but differ in governance structures, building stock, and energy efficiency measures. Differences in heating systems and emission trends further enhance the comparative analysis. The analysis is guided by the following research questions:

1. How do emission projections for the years 2000 to 2020 compare with reported emission inventories for the same period?
2. Which parameters and drivers are most critical in understanding uncertainties in the projection of scenarios?

Methods

This study used a mixed-methods approach to assess deviations between projected and historical CO_2 emissions in the buildings sector of Belgium and the Netherlands from 2000 to 2020. The methodology comprised three main steps:

1. data collection,
2. historical trend analysis using various sources of data, and
3. decomposition analysis of historical emission inventories and projections .

Data collection

Data collection involved identifying relevant scenarios and gathering their corresponding quantitative projection data and relevant qualitative information. Scenarios for Belgium and the Netherlands were selected based on the following predefined criteria, and are provided in Annex A of the supplementary information:

- The scenarios covered the period 2000–2020, either fully or partially.
- The data included sectoral direct CO_2 emissions and final energy consumption (FEC) for the residential and/or service sectors separately, and
- They were national projections, excluding regional or EU-wide scenarios to ensure comparability with available statistical data.

All types of scenarios were considered relevant for the study, including 'with existing measures' (WEM) and 'with additional measures' (WAM) scenarios. The identified scenarios originated from official national projection exercises, national climate strategies, and official reporting under the EU's climate and energy governance obligations[1].

The number of scenarios identified for Belgium (BE) and the Netherlands (NL) are presented in Figure 1. The search yielded a larger dataset for Belgium, particularly for WEM scenarios, while WAM scenarios remained limited for both countries. In total, 28 scenarios were identified for Belgium, compared to 15 for the Netherlands. All scenarios comprised projections for both the residential and service sectors. The figure also highlights the years included, either as historical or projection year (2000, 2005, 2010, 2015, and 2020). As an increasing number of scenarios became available over time, years 2015 and 2020 emerged as the most frequently projected years across the scenarios. Refer to Annex A for a full list of scenarios, and their characteristics, including the reference year used for projections.

[1] This includes reporting under the Greenhouse Gas Monitoring Mechanism Decision (280/2004/EC), the Greenhouse Gas Monitoring Mechanism Regulation (5252/2013/EU), and the Governance of the Energy Union and Climate Action Regulation (2018/1999/EU).

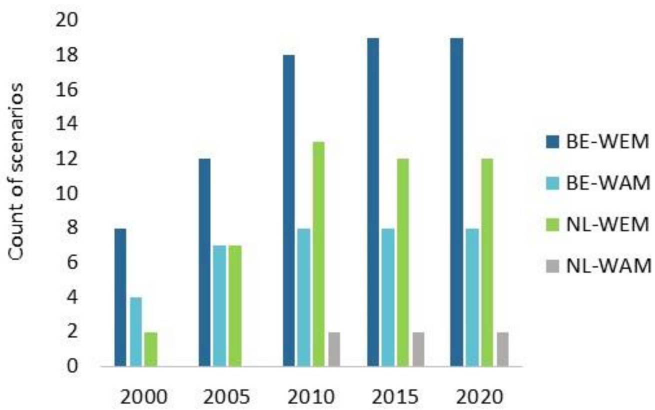

Figure 1. Number of relevant scenarios identified for Belgium (BE) and the Netherlands (NL), categorised by WEM and WAM, and the included years. *Source:* Authors' estimates based on relevant scenario references.

The data collection process of quantitative data (projections and historical data) followed a structured approach to ensure consistency and accuracy. All collected parameters (CO_2 emissions, FEC, population, and value added) were converted to the same units, and where projections were reported for irregular intervals, interpolation techniques were applied to obtain data points at five-year intervals for years ending with five or zero. For emissions and FEC data that included the broader tertiary sector, which accounted for the agricultural sector, adjustments were made. This was done by applying a five-year average ratio of the service sector to the tertiary sector based on historical data. The definitions of sectoral direct emissions were aligned across all scenarios and historical data, such that direct emissions excluded electricity consumption. The definition of FEC refers to all sources of energy including electricity use. Since electricity use is excluded from emissions but included in FEC, the two datasets are not fully consistent. In turn, any results that directly compare or combine these parameters should be interpreted with caution. Furthermore, the heating degree days (HDD) reported in the scenarios varied in terms of base outdoor temperature used for the calculation. For example, various studies use a base temperature of 15^{o}C (Belgium, 2009, 2011, 2015; Courcelle & Gusbin, 2001), meaning that only days with a daily mean air temperature equal or below 15^{o}C have an impact on heating needs. Other studies, take a base temperature of 16.5^{o}C (Devogelaer & Gusbin, 2006, 2011, 2014; Gusbin & Hoornaert, 2004), making the parameter not directly comparable between scenarios.

Analysis of historical trends of direct CO_2 emissions and key drivers

Using the gathered historical data, past trends in emissions and FEC were analysed to understand the historical context in which these trends occurred. They were examined in relation to the evolution of key underlying parameters, including: shares of fuel types, population, income per capita, household size, number of households, FEC per capita, emissions per unit of FEC, the share of apartments in the residential building stock, improvements in the energy ratings of buildings and implementation of climate and energy policy.

Decomposition analysis of CO_2 emissions

A retrospective decomposition analysis was conducted. This involved comparing the projected effect of main drivers in scenarios with the historical effect of the same drivers to identify deviations and potential causes. Similar to the approaches observed in literature (Ang & Goh, 2019), an index decomposition analysis (IDA) was applied in this study to systematically quantify the effects of drivers on emissions in the scenario.

IDA enables the isolation of key drivers of emissions or energy consumption, thus facilitating a structured comparison between historical data and projections. By disaggregating emissions into distinct components, the analysis aims to identify how the influence of these drivers in projections deviated from observed historical trends.

An additive logarithmic mean divisia index (LMDI), of type LDMI I, was applied, which typically captures activity, activity structure, and activity energy intensities on energy consumption (Ang, 2015). Due to the less complex mathematical formulation of additive LDMI I and its higher consistency in aggregation (Ang, 2004, 2015), this approach was preferred over LDMI II. The mathematical formulation for this methodology was defined in a way to disaggregate the total change in CO_2 emissions for five-year intervals in four key effects: activity, weather-adjusted energy intensity, emission intensity, and weather. The mathematical formulation of this IDA is provided in Annex B.

This approach required consistency in the variables used across historical data and projections. The selection of contributing factors was constrained by the availability of data reported in projections, as well in historical statistics. To ensure comparability between scenarios with historical data, the effects included in the analysis were based on the most commonly available variables in both datasets. While a more detailed disaggregation of energy intensity, such as insulation levels, heating system types, and energy prices, would have provided deeper insights, these variables were not consistently reported in scenarios. Similarly, historical data on these aspects were limited, further restricting the scope of disaggregation.

In the adopted IDA, the activity effect was represented by socio-economic drivers, specifically population for the residential buildings and service sector value added for the service sector buildings. While other parameters, such as the number of households (for the residential sector) or the average building area (for both sectors), would have been preferable, their limited availability in the reported scenarios prevented their use. It is further acknowledged that service sector value added does not fully capture the activity driving public sector building emissions. Nevertheless, given the constraints in data availability, value added was considered the most suitable common parameter to represent the activity driver for the service sector.

The energy intensity effect reflected variations in FEC per unit of activity, encompassing efficiency improvements and demand-side changes. The emission intensity effect is defined as direct CO_2 emissions per unit of FEC. The lack of data availability, did not allow the emission intensity estimates to include emissions from electricity use, or exclude electricity from FEC. Therefore, based on this approach, the improvements in the emission intensity effect captures a shift in energy mix to lower-carbon fuels (including shifts to electricity use), and/or an overall increase in electricity consumption. Due to the application of this approach, the two effects cannot be distinguished, resulting in a limitation in the results.

The HDD were reported in all relevant scenarios, with various scenarios for the Netherlands considering changing HDD over the future years. Due to this, and to the important link between weather conditions and energy demand (Kaufmann et al., 2013), the weather effect was isolated in the decomposition analysis, expressed as the HDD in a specific year relative to the average HDD in a reference period 1980-2000[2].

Results

Residential sector projections

Figure 2 and Figure 3 illustrate the decomposition of historical CO_2 emission changes in the residential buildings in Belgium and the Netherlands during the period 2000-2020. The bars in these two figures represent the decomposed emissions based on historical GHG inventory, indicating the estimated contribution of each driver to the five-year emission changes. The lines correspond to the decomposition of projections over the five-year periods. Figure 4 depicts the historical CO_2 emission trend over the same period, along with projected emissions.

The emissions from the residential sector buildings declined over the period 2000-2020, at an average rate of 2.1% in Belgium and 1.7% in the Netherlands. The period between 2007 and 2014 was characterised by fluctuations in buildings emissions in both countries. The decomposition analysis sheds light on the drivers behind these fluctuations. Improvements in energy intensity (FEC per capita) and emission

[2] The relative HDD effect was adjusted using the elasticity of energy demand to account for weather-dependent end-uses, primarily space and water heating. The applied elasticity values were 0.60 for the residential sector and 0.46 for the service sector, based on findings from an analysis of HDD conducted in 2018 as part of the Energy Balance for the Belgian Flemish region under the authority of the Flemish Energy Agency.

intensity (emissions per unit of FEC) significantly contributed to emission reductions in the residential sector throughout the period, but population growth offset a share of these improvements. Changes in the relative HDD also influenced emissions considerably. The relative low temperatures in 2010, which led to relatively high HDD when compared to both the reference period (1980-2000) and 2005, resulted in a strong positive effect in emissions, followed by relatively milder heating seasons that resulted in negative effects.

From 2000 to 2020, population in Belgium and the Netherlands grew by an average of 0.6% and 0.4% per year, respectively (Eurostat, 2025c).

Improvements in energy intensity significantly reduced emissions in both countries. The share of apartments increased from 20% in 2001 to 30% by 2020, and apartments generally have better EPC labels than single-family houses (Flemish Region, 2020; Wallonie Service Public, 2020). This contributed to a smaller floor area per inhabitant over the period (Statbel, 2024), which played a role in the improvement in the per capita consumption. In the Netherlands, the shift towards apartments was minimal, as their share was already high prior to 2000 (CBS, 2023). In both countries, a declining number of occupants per dwelling (CBS, 2024b; Statbel, 2024b) offset part of per capita consumption gains. Energy intensity improved significantly from 2010 to 2015, peaking in 2015. However, in both Belgium and the Netherlands, 2020 saw lower energy intensity gains, resulting in minimal or no energy and emission savings. The pandemic likely contributed (e.g., due to school closures and remote working), resulting in an increase in per capita energy demand in the residential sector.

Overall, emissions savings from improvements in emission intensity followed a similar trend to energy intensity but at a smaller scale. Since these estimates are based on the sectoral direct emissions (excluding electricity consumption) and FEC values that include electricity consumption, both the shifts from fossil-based fuels to electricity and an overall increase in electricity consumption, contributed towards a reduction in the sectoral emission intensity. Due to the application of this approach, the two effects cannot be distinguished. Belgium registered an increase in emission intensity in 2005, while the Netherlands experienced it in 2010. Between 2005 and 2010, Belgium replaced a share of gas and oil with electricity (Eurostat, 2025a). In the Netherlands, the improvement registered in 2015 was driven by a stronger shift from natural gas to electricity and bioenergy (Eurostat, 2025a). By 2020, electricity shares remained stable in both countries, while bioenergy, heat pumps, and solar energy grew modestly, further reducing emissions (Eurostat, 2025a).

Both countries implemented policies targeting energy efficiency and renewable energy in buildings. In Belgium, energy performance regulations drove efficiency and decarbonisation, supported by fiscal and financial incentives promoting efficiency and, in some cases, renewable energy integration (Belgium, 2007, 2011, 2014, 2017; Departement Omgeving, 2013; Vlaamse Regering, 2003). In the Netherlands, major energy and climate programmes (2008 More with Less, 2008 Spring Agreement, 2013 Energy Agreement, and 2016 Energy Agenda) were aimed to reduce heating demand and promote sustainable alternatives (the Netherlands, 2007, 2011, 2014, 2017). These policies combined regulations, voluntary agreements, financial incentives, and information measure. The cumulative impact of better insulation and efficient heating (CE Delft, 2023) contributed to improvements in energy and emission intensity particularly between the period 2010-2015, as shown in Figure 3.

To understand the deviations in the decomposition of emission projections from historical data, the analysis first examines deviations in emission levels. Figure 4 shows annual CO_2 emissions trends for Belgium and the Netherlands, as reported in the GHG inventory and projections. The shaded grey area highlights the extent of variation between scenario outcomes.

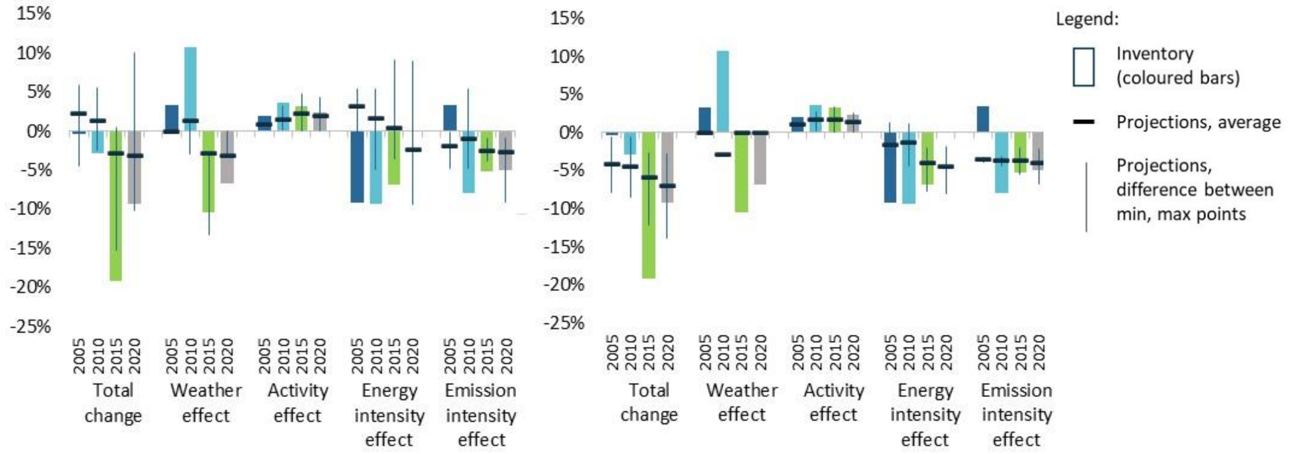

Figure 2. Decomposition of historical emission changes over five-year periods, for the Belgian residential buildings compared to the WEM (left) and WAM (right) emission projections. Source: Authors' estimates based on UNFCCC (n.d.) and projection scenario references.

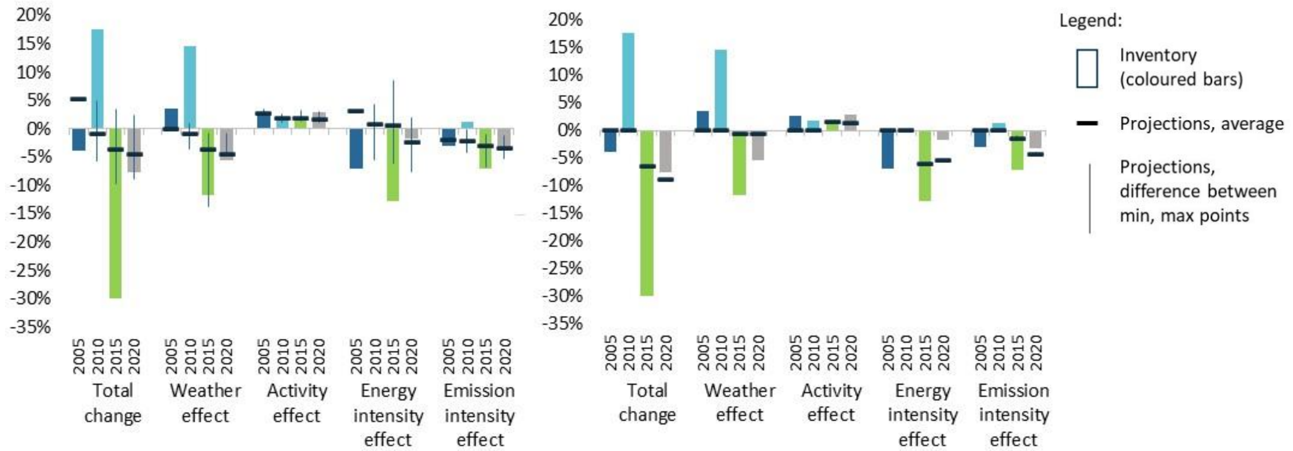

Figure 3. Decomposition of historical emission changes over five-year periods, for the Dutch residential buildings compared to the projections of WEM (left) and WAM (right) scenarios. *Source:* Authors' estimates based on UNFCCC (n.d.) and projection scenario references.

Note: The bars represent the decomposed emissions based on historical GHG inventory, indicating the estimated contribution of each driver to the five-year emission changes. The lines correspond to the decomposition of projections over five-year periods. Vertical black lines denote the range of variation between the minimum and maximum effects across scenarios, and the horizontal lines signify the average value of the decomposed projected effects.

Compared to the historical emission trend, in years 2000 and 2005 emission projections were, on average, predominantly underestimated, with deviations relatively low. In contrast, deviations of projections from historical data in 2015 and 2020 were generally overestimated, and more pronounced. Deviations increased from an average of -1% in 2005 to +22% in 2020 in the Belgian scenarios, and from -2% in 2005 to +15% in 2020 in the Dutch scenarios.

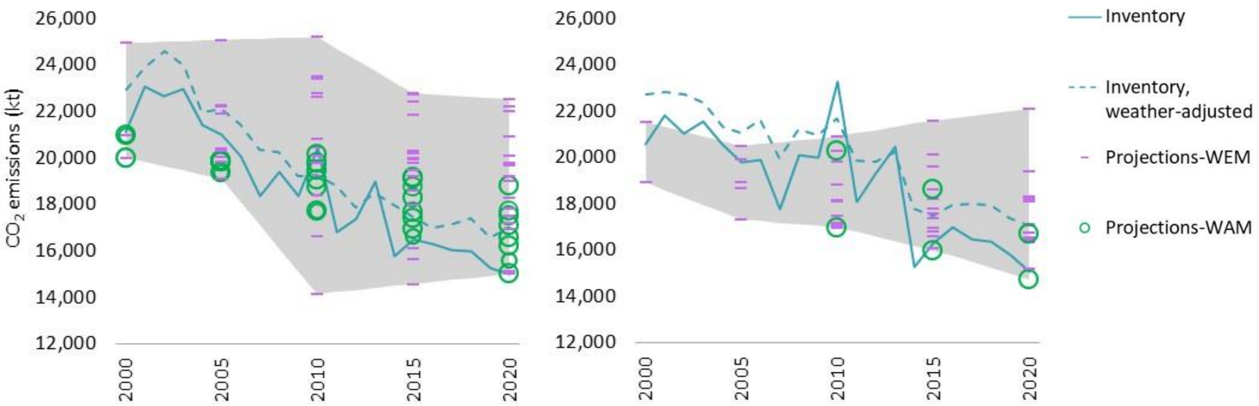

Figure 4. Deviations between the historical emission trend and projections of WEM and WAM scenarios for the residential buildings for Belgium (left) and the Netherlands (right). *Source:* Authors' estimates based on UNFCCC (n.d.) and projection scenario references.

In the decomposition analysis, shown by Figure 2 and Figure 3, the decomposed effects of the key indicators vary significantly between the scenarios, represented by the increasing height of the vertical line over time. This is particularly evident for Belgium. This is primarily influenced by significant deviations in the projections of energy intensity effects. Compared to the historical 2020 energy intensity value, the Belgian scenarios deviated from this parameter by an average of +27%, while the Dutch scenarios showed an average deviation of +15%. The energy intensity parameter was significantly overestimated in nearly all scenarios for 2015 and 2020, with deviations of at least +10%. Additionally, FEC itself was predominantly overestimated, with deviation magnitudes comparable to those seen in emission projections.

The decomposition analysis shows that reductions in emissions due to energy intensity effects on average were underestimated in the scenarios for all years up to 2015. However, in 2020, projections of energy intensity effect on average were overestimated, meaning scenarios projected a greater five-year improvement than what actually materialised. Despite the projected improvement in the final five-year period, FEC and energy intensity parameters remained overestimated in 2020 due to the low energy efficiency ambition accounted for in the previous years.

In contrast to energy intensity, the trend of emission intensity and its impact on emission changes were projected with greater accuracy, particularly in the WAM scenarios. Compared to the historical 2020 emissions intensity value, projections, on average deviated from this parameter by 0% for both the Belgian and the Dutch scenarios. Variance In projections across scenarios was low, except for two Belgian scenarios with deviations at -10% and +23%. WAM scenarios assumed a slightly higher share in renewable energy than their WEM counterparts, resulting in the relatively lower deviations.

Regarding demographic activity and its projected effects on emissions, deviations between projections and historical data were small, but not negligible, across all scenarios. In nearly all scenarios, population size was typically underestimated. 2020 deviations from actual figures ranged from -10% to +3%, at an average of -4% for Belgium, and from -3% to +3%, at an average -1% for the Netherlands. For both countries, changes in population size were projected to contribute to increases in emissions throughout the entire period, with variations between scenarios being relatively minimal. The impact of demographic changes on emissions was, on average, expected to be slightly lower than what actually materialised.

Overall, HDD values were consistently underestimated for all years in projections for Belgium. While this resulted in relatively low deviations between projected and historical HDD, the projections nonetheless underestimated HDD on average. Consequently, the effects of weather on emissions were generally underestimated. For the Netherlands, HDD projections in HDD were overestimated in scenarios that considered changing HDD values across the years, while those with constant HDD values were underestimated similarly to Belgian scenarios.

Service sector projections

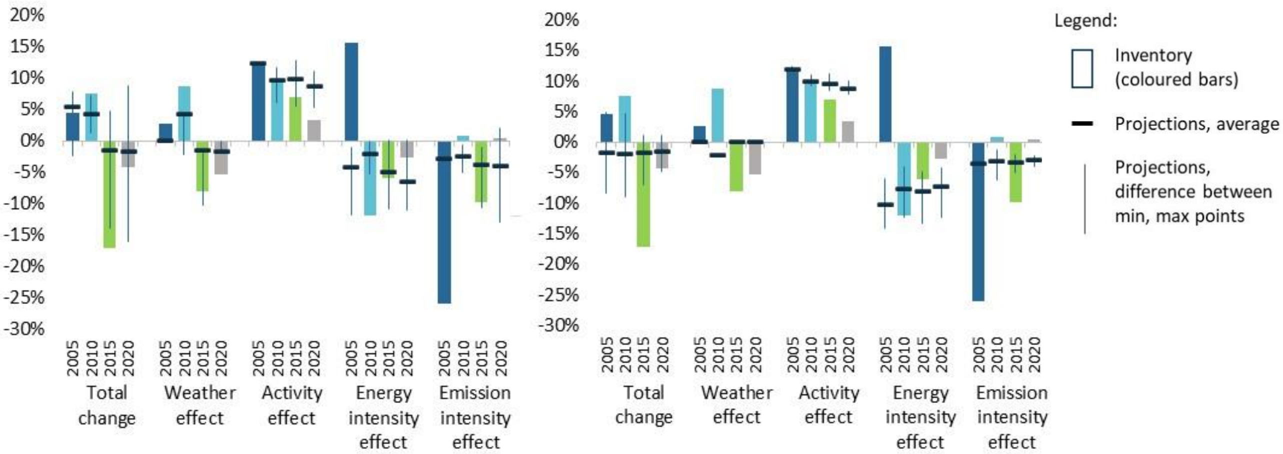

Figure 5. Decomposition of historical emission changes for the Belgian service sector buildings compared to the projections of WEM (left) and WAM (right) scenarios. *Source:* Authors' estimates based on UNFCCC (n.d.) and projection scenario references.

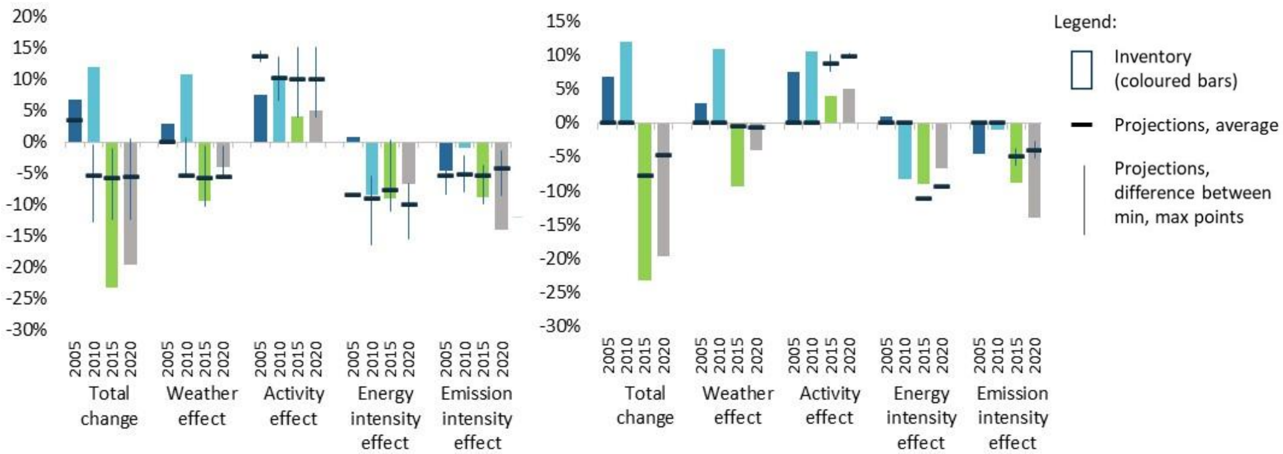

Figure 6. Decomposition of historical emission changes for the Dutch service sector buildings compared to the projections of WEM (left) and WAM (right) scenarios. *Source:* Authors' estimates based on UNFCCC (n.d.) and projection scenario references.

Figure 7. Deviations between the historical emission trend and projections of WEM and WAM scenarios for the service sector buildings for Belgium (left) and the Netherlands (right). *Source:* Authors' estimates based on UNFCCC (n.d.) and projection scenario references.

Figure 5 and Figure 6 illustrate the decomposition of historical CO_2 emission changes in the service sector buildings in Belgium and the Netherlands. Figure 7 provides the historical trend of annual CO_2 emissions for Belgium and the Netherlands, compared to projections.

Between 2000 and 2020, emissions from the service sector declined at a slower rate than in the residential sector, with notable fluctuations. Based on the decomposition of historical data, weather effects had a smaller impact on emissions, compared to the residential sector, as space and water heating accounted for a smaller share of total energy consumption. However, the cold winter of 2010 still led to a temporary increase in emissions. The primary driver of emission increases in the service sector was economic activity, measured by value added, which generally increased over the period.

On average, the economic activity grew during this period in both countries, except during the 2009 (global financial crisis) and 2020 (global pandemic) recessions (Eurostat, 2025b).

While energy intensity improvements offset some of the impact of economic growth, their effect varied significantly across different years, especially for Belgium. In Belgium, the service sector's value added grew at an annual rate of 1.8%, while the Netherlands saw a 1.4% annual increase (Eurostat, 2025b).

The energy intensity (FEC per unit of value added) improved after 2005, and further improvements continued to contribute towards emission savings. FEC in the Dutch service sector remained relatively stable, peaking in 2010 before declining towards 2020 (Eurostat, 2025a). In Belgium, however, FEC increased at an average rate of 0.9% per year (Eurostat, 2025a). Energy intensity, measured as FEC per unit of value added, declined by 1.4% annually in the Netherlands and by 0.9% annually in Belgium.

While FEC trends differed between the two countries, both experienced a steady decline in emission intensity. This was primarily driven by a shift away from fossil fuels towards a higher share of electricity used in service sector buildings in Belgium and the Netherlands. However, the adoption of heat pumps and solar energy remained minimal in the service sector, with bioenergy accounting for a relatively small share of the transition.

The policy landscape in the service sector in both countries was similar to that in the residential buildings, however, less policies and measures, in terms of number were aimed at service sector buildings and they were also introduced later.

Compared to the residential sector, service sector projections exhibited greater overestimations in emissions and energy consumption, particularly for 2015 and 2020. The overestimation for emissions level compared to historical data (without weather adjustment) ranged from -11% to +78%, at an average of +29%, for the Belgian scenario, and +20% to +60%, at an average of +39% for the Dutch scenarios.

The main sources of deviation were overly optimistic assumptions about economic growth and challenges in capturing the full effects of energy efficiency measures. Scenarios assumed steady growth in value added, which led to higher projected energy demand and emissions. In reality, economic growth was lower than anticipated, and efficiency improvements further reduced energy consumption.

Discussion

The retrospective assessment revealed that projections for both residential and service sector buildings in Belgium and the Netherlands consistently overestimated CO_2 emissions and energy consumption, particularly in the years 2015 and 2020. The deviations were significantly larger in the service sector than in the residential sector, a trend consistent across both WEM and WAM scenarios.

While deviations in 2020 were partly influenced by the exceptional circumstances of the COVID-19 pandemic, it is recognised that such events cannot realistically be foreseen in long-term scenario design. No projection framework can anticipate specific disruptions such as pandemics, wars, or sudden energy price shocks. Nevertheless, these events highlight the importance of developing scenarios that are resilient to a wide range of potential shocks and uncertainties, rather than relying solely on deterministic assumptions of uninterrupted economic and demographic growth.

While inherent unpredictability contributes to these discrepancies, the persistence of substantial deviations even in recent scenarios indicates that the ambition level, particularly regarding energy efficiency improvements and low-carbon investments, was generally conservative.

The scenario's publication year did not directly influence deviations, as recent scenarios still showed deviations above +10%. This suggests that low-carbon investments and energy saving measures were overall underrepresented in most scenarios. It must be noted that the number of considered policies and measures in the scenarios increased over time. The Belgian WEM scenarios considered policies and measures that have been adopted up to a cut-off date (usually a year prior conducting the study), while the WAM scenarios were mostly target-driven, defined by the Kyoto Protocol targets and later by the EU energy and climate framework. The Dutch scenarios explicitly defined lists of policies and measures, with the number expanding significantly over time, from eight measures in the earliest study (Ybema et al., 2002), to 41 in the most recent study (Hekkenberg, M. & Verdonk, M., 2014). In the two Dutch WAM scenarios, the list of policies and measures is identical to their WEM counterparts, but are more impactful, for example due to more stringent regulations. The predominant focus of scenarios in both countries was towards energy efficiency and savings, and to a much lesser extent on promotion of renewable energy use.

As expected, WAM scenarios exhibited smaller deviations than WEM scenarios, suggesting that the explicit inclusion of additional measures and higher ambition levels improved projection accuracy.

Heating degree days and energy intensity parameters emerged as main sources of uncertainty in the decomposition analysis. This aligns with literature showing that building energy use projections are highly sensitive to assumptions, including those related to simulation models, data on building characteristics, weather patterns, and the unpredictability of occupant behaviour (Koosha and Shahsavari, 2019; Tian et al., 2018; Wang, Mathew, and Pang, 2012).

The considerable variations in energy intensity across different scenarios suggest persistent challenges in accurately capturing the impacts of measures aimed at increasing energy savings on overall emission trends. Furthermore, the consistent overestimation of energy intensity in projections potentially highlights a conservative ambition of scenarios towards energy intensity improvements. The high deviations in the energy intensity parameter towards the end of the assessed period even in the latest scenarios, could partly be explained by the fact that such scenarios consider policies and measures implemented by year 2014. This meant that none of the WEM scenarios for both countries took account of impacts of key measures implemented between 2015 and 2020. For Belgium, this meant that the further tightening of regulatory requirements on energy performance of new builds and renovations was not accounted for, along with other regulations and information instruments. Key financial subsidies introduced in the Netherlands after 2014 were also not accounted for in the scenarios. This in part explains the deviations in projections for energy intensity and historical data. For example, a sudden drop in historical residential emissions for the Netherlands was observed from 2014 onwards. This contrasts with the projections for 2015, in which emissions were overestimated when compared to the historical data. During the years 2014 to 2016, historical energy savings in the residential buildings increased significantly, in good part due to increased insulation (Niessink et al., 2024), driven by key energy saving measures which intensified during that period (Kruit et al., 2022). The deviations in the 2015 energy intensity level between scenario projections and historical data may be due to measures which were adopted in 2014 and later, not being (fully) captured in the Dutch scenarios.

Emission intensity was generally projected with greater accuracy, reflecting its steady historical decline driven by gradual fuel switching and modest adoption of renewable technologies. The historical improvement in emission intensity of buildings has been steady and moderate over the evaluated period in Belgium and the Netherlands, resulting in relatively low uncertainty. Although progress was made in this aspect, reflected in the increasing share of electricity, the historical contributions of heat pumps and solar energy sources remained marginal throughout the assessed timeframe. Scenarios generally adopted a conservative approach with regard to the emission intensity parameter. By 2020, none of the scenarios considered substantial structural changes in energy mix. As a result, the gradual historical trend in emission intensity was captured more accurately by projections. This conservative approach may have been influenced by prevailing concerns about the pace of renewable energy deployment, leading to scenarios that reflected low policy ambition for the decarbonisation of the building sector.

Projections of demographic and economic activity tended to underestimate population growth and overestimate service sector value added. As demographic parameters tend to change gradually over time, their projections are relatively more predictable, yet uncertainty remains (Ahn et al., 2005). For the service sector, scenarios adopted an overly optimistic perspective regarding the sector's growth resulting in the overestimation of the sector's value added particularly in 2015 and 2020, and in turn overestimated its effect on emissions, especially in the Dutch scenarios. The consistent assumption of uninterrupted economic growth overlooked disruptive events, such as the 2008 financial crisis, and its slower than expected recovery, and the 2020 pandemic, which had measurable impacts on actual emissions trends.

Assumptions regarding heating degree days varied across scenarios. Belgian scenarios typically assumed constant HDD values until 2020, whereas several Dutch scenarios incorporated changing HDD based on predictive climate modelling. Methodological differences also arose from the assumed base heating temperature, which refers to the threshold at which heating is considered necessary. These differences led to variation in projected energy demand even under identical weather conditions, highlighting the substantial uncertainty not only in future climatic and weather patterns, but also in their impact on energy demand due to changes in the building stock, such as improved insulation.

Conclusions

This comparative assessment of CO_2 emissions projections for the Belgian and Dutch building sectors between 2000 and 2020 reveals that most scenarios systematically overestimated both emissions and energy use, particularly in the service sector. These discrepancies largely stemmed from conservative assumptions regarding efficiency improvements, overly optimistic socio-economic development, insufficient integration of evolving policy measures implemented after baseline years, and expected higher heating degree days. Energy intensity emerged as a key uncertain parameter and consistently overestimated driver, underscoring the need for more refined modelling approaches that incorporate behavioural changes, detailed building stock data, and comprehensive representation of past and projected policy impacts. By contrast, emission intensity was generally projected with greater accuracy due to its steady historical decline, although scenarios often underestimated the potential for structural changes in the energy mix. Higher-ambition WAM scenarios demonstrated closer alignment with historical trends, highlighting the importance of incorporating robust policy frameworks and ambitious efficiency targets into future projections. Weather conditions impacting on energy demand is another key uncertainty reflected by differences in projections of HDD values and in HDD calculation method across scenarios, highlighting the need for better modelling of the impact of climate change on HDD (and cooling degree days).

To some extent, scenarios were shaped by prevailing concerns at the time, particularly in relation to the potential deployment rate of low-emission technology. Both WEM and WAM scenarios lacked policy ambition and growth in the deployment of renewable energy in both Belgian and Dutch scenarios. As Trutnevyte et al. (2016) point out, past scenarios often relied on parametric assumptions influenced by short-term issues, neglecting structural uncertainties. A broader approach is needed to acknowledge that energy transitions are driven by institutional, technological, and socio-economic changes beyond narrow model parameters (Trutnevyte et al., 2016). This highlights the need to refine assumptions about energy efficiency improvements, especially in light of technological innovations and policy interventions. Continual updates to projection models, informed by ex-post policy and measures evaluations and monitored data, can enhance accuracy.

To create more resilient and insightful scenarios, multiple policy scenarios should be developed to account for a wider range of uncertainties impacting the energy and emissions parameters. Scenario development should also incorporate more dynamic modelling of economic variables and weather conditions, informed by retrospective analyses. Unforeseen or short-lived events amplified deviations between projections and historical data, stressing the importance of uncertainty analysis that reflect observed historical deviations. Furthermore, many analysed scenario studies relied heavily on earlier frameworks, reinforcing assumptions and limiting adaptability of scenarios. Future scenarios should be developed in response to emerging trends, such as shifts in societal behaviour including remote working, and new technological advancements.

Finally, retrospective analysis, as well as ex-ante and ex-post policy assessments, could be instrumental in informing future scenarios. These assessments provide insights into how past assumptions have aligned with actual developments and help improve methodologies for scenario selection and design. Systematic evaluation of past energy transitions and policy impacts can enhance projection accuracy and support better anticipation of structural shifts, policy effectiveness, and behavioural change. This makes scenario-based decision-making more adaptive and resilient amid evolving energy challenges.

The study is subject to several limitations. First, the estimation of emission intensity could not distinguish between reductions from fuel switching to electricity and increases in electricity consumption, limiting the interpretation of results. Second, limited documentation of scenario assumptions constrained the depth of analysis, necessitating a focus on broad patterns rather than detailed case-specific insights. Third, the decomposition model relied on variables commonly reported across scenarios, which excluded potentially important factors such as insulation levels, heating system types, floor area, and energy prices. Finally, the scope of the analysis was limited to the building sector in Belgium and the Netherlands, which may reduce the generalisability of findings to other sectors or regions.

Future research should address these limitations by developing decomposition models that separately account for direct emissions and electricity consumption, enabling clearer attribution of changes in emission intensity. Enhanced transparency in scenario documentation and open access to datasets would also facilitate replication and deeper analysis. Finally, applying similar retrospective decomposition analyses to other sectors and countries would help assess the generalisability of observed patterns and strengthen the evidence base for scenario design and policymaking.

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Annex A – List of projection scenarios

Table 1. List of scenarios for Belgium and their main characteristics.

Author(s) and year of publication	Scenario name	Scenario Type (WEM or WAM)	Sector: Residential	Sector: Services	Reference year	Included year[1]: 2000	2005	2010	2015	2020
Courcelle & Gusbin (2001)	Baseline	WEM	✓	✓	1998					
Courcelle & Gusbin (2001)	Higher fuel price variant	WEM	✓	✓	1998					
Courcelle & Gusbin (2001)	Macro economic variant	WEM	✓	✓	1998					
Courcelle & Gusbin (2001)	Permanent Kyoto	WAM	✓	✓	1998					
Courcelle & Gusbin (2001)	Growing Kyoto	WAM	✓	✓	1998					
ECONOTEC Consultants (2002)	SSTC	WEM	✓	✓	1997					
European Commission & Directorate-General for Energy and Transport (2003)	Baseline	WEM	✓	✓	2000					
Gusbin & Hoornaert (2004)	Baseline	WEM	✓	✓	2000					
Devogelaer & Gusbin (2006)	Baseline	WEM	✓	✓	2004					
Devogelaer & Gusbin (2006)	Higher fuel price variant	WEM	✓	✓	2004					
Devogelaer & Gusbin (2006)	Bpk15	WAM	✓	✓	2004					
Devogelaer & Gusbin (2006)	Bpk30	WAM	✓	✓	2004					
European Commission et al. (2008)	Baseline	WEM	✓	✓	2005					
Belgium (2009)	WM	WEM	✓	✓	2006					
European Commission et al. (2010)	Baseline	WEM	✓	✓	2008					
European Commission et al. (2010)	Reference scenario	WEM	✓	✓	2008					
Devogelaer & Gusbin (2011)	Baseline	WEM	✓	✓	2009					
Devogelaer & Gusbin (2011)	Ref_20/20	WAM	✓	✓	2009					
Devogelaer & Gusbin (2011)	Ref_30/20_flex	WAM	✓	✓	2009					
Devogelaer & Gusbin (2011)	Ref_30/20_int	WAM	✓	✓	2009					
Belgium (2011)	WM	WEM	✓	✓	2008					
Belgium (2011)	WAM	WAM	✓	✓	2008					
Belgium (2013)	WEM	WEM	✓	✓	2010					
Devogelaer & Gusbin (2014)	Reference	WEM	✓	✓	2010					
European Commission et al. (2014)	Reference scenario	WEM	✓	✓	2010					
Belgium (2015)	WEM	WEM	✓	✓	2012					
European Commission et al. (2016)	Reference scenario	WEM	✓	✓	2013					
Gusbin & Devogelaer (2017)	Reference	WEM	✓	✓	2015					

Note:
[1] Indicating whether the year is included in the scenario as historical or projected data point:

Included

Not included

Table 2. List of scenarios for the Netherlands and their main characteristics.

Author(s) and year of publication	Scenario name	Scenario Type (WEM or WAM)	Sector		Reference year	Included year(s)[1]				
			Residential	Services		2000	2005	2010	2015	2020
Ybema et al. (2002)	Reference projection	WEM	✓	✓	2000					
European Commission & Directorate-General for Energy and Transport (2003)	Baseline	WEM	✓	✓	2000					
van Dril & Elzenga (2005)	Strong Europe	WEM	✓	✓	2002					
van Dril & Elzenga (2005)	Global Economy	WEM	✓	✓	2002					
European Commission et al. (2008)	Baseline	WEM	✓	✓	2006					
Daniels & van der Maas (2009)	UR-GE	WEM	✓	✓	2006					
Daniels & van der Maas (2009)	UR-GE(h)	WEM	✓	✓	2006					
Daniels & Kruitwagen (2010)	V	WEM	✓	✓	2008					
Daniels & Kruitwagen (2010)	VV	WAM	✓	✓	2008					
European Commission et al. (2010)	Baseline	WEM	✓	✓	2008					
European Commission et al. (2010)	Reference Scenario	WEM	✓	✓	2008					
Hekkenberg & Verdonk (2014)	V	WEM	✓	✓	2013					
Hekkenberg & Verdonk (2014)	VV	WAM	✓	✓	2013					
European Commission et al. (2014)	Reference Scenario	WEM	✓	✓	2010					
European Commission et al. (2016)	Reference Scenario	WEM	✓	✓	2013					

Note:
[1] Indicating whether the year is included in the scenario as historical or projected data point:
Included
Not included

Annex B – Decomposition analysis equations

The decomposition analysis employed a logarithmic mean divisia index (LMDI) method utilising an additive approach. The total change in CO_2 (ΔC) emissions for a time period between years t_1 and t_2 (Δt), was expressed as:

$$C_{t_2} - C_{t_1} = \Delta C = D_{RHDD} + D_Q + D_{Eint} + D_{Cint}$$
(Equation 1)

Where, for each country and sector:
C_{t_2} is CO_2 emissions in period t_2,
C_{t_1} is CO_2 emissions in period t_1,
ΔC is the absolute change in CO_2 emissions in Δt,
D_{RHDD} is absolute CO_2 emissions variation in Δt due to the relative HDD effect,
D_Q is absolute CO_2 emissions variation in Δt due to the activity effect,
D_{Eint} is absolute CO_2 emissions variation in Δt due to the energy intensity effect,
D_{Cint} is absolute CO_2 emissions variation in Δt due to the emission intensity effect.

The relative HDD ($RHDD$) is estimated as follows:

$$RHDD_t = \frac{HDD_t}{HDD_{ref}}$$
(Equation 2)

Where:
HDD_{ref} refers to the average HDD for the period 1980 to 2000.

The LDMI method incorporates a weighting factor for CO_2 emissions over a specified time period Δt, as estimated by the following equation:

$$W_{\Delta t} = \frac{C_{t_2} - C_{t_1}}{ln\, C_{t_2} - ln\, C_{t_1}}$$
(Equation 3)

The weighting factors were included in the equation 1 to estimate the isolated effects as follows.

1. $D_{RHDD} = \Delta C_{Wth} = C_{Wth,t_2} - C_{Wth,t_1} = W_{\Delta t} \cdot ln\left(\frac{{RHDD_{t_2}}^e}{{RHDD_{t_1}}^e}\right)$
   (Equation 4)

   Where:
   e is weather elasticity of energy demand.

2. $D_Q = \Delta C_Q = C_{Q,t_2} - C_{Q,t_1} = ln\left(\frac{Q_{t_2}}{Q_{t_1}}\right)$
   (Equation 5)

3. $D_{Eint} = \Delta C_{Eint} = C_{Eint,t_2} - C_{Eint,t_1} = ln\left(\frac{Eint'_{t_2}}{Eint'_{t_1}}\right)$
   (Equation 6)

   And $Eint'_t = Eint_t / {RHDD_t}^e$
   (Equation 7)

4. $D_{Cint} = \Delta C_{Cint} = C_{Cint,t_2} - C_{Cint,t_1} = \ln\left(\frac{Cint_{t_2}}{Cint_{t_1}}\right)$
   (Equation 8)