Understanding the development of Dutch residential energy use in the context of the Energy Efficiency Directive: combining top-down and bottom-up analysis

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ABSTRACT

A diverse set of policy instruments targets residential energy use, including building codes, energy performance standards, labels, energy taxes, and subsidies. While bottom-up evaluations suggest these instruments achieve energy savings, top-down evaluations do not always confirm the same results. This discrepancy arises because bottom-up evaluations often rely on assumption-based deemed savings, while top-down analyses may obscure savings due to structural dynamics that cannot be easily isolated.

To bridge this gap and better understand the impact of energy efficiency policies within broader energy consumption trends, this study analyses Dutch residential energy use from 2020 to 2023 within the framework of the EU Energy Efficiency Directive (EED). The EED caps total final energy use with an energy efficiency target (Article 4) while imposing an end-use energy savings obligation (Article 8), either by establishing an energy efficiency obligation scheme (Article 9) or by adopting alternative policy measures (Article 10).

Our analysis covers two years affected by COVID-19 (2020 and 2021) and two years of elevated energy prices (2022 and 2023). Using chained additive index decomposition analysis, we assess the Article 4 efficiency target top-down by quantifying key drivers: volume, structural, and efficiency effects. We then synthesize the results of 2020 and 2022 with the bottom-up figures reported under the Article 8 energy savings obligation, isolating the loss of energy savings due to the COVID-19 lockdowns and the energy savings from behavioural changes triggered by the energy price shock.

Our findings show that bottom-up and top-down evaluations complement each other. Bottom-up analysis helps disentangling efficiency effects in top-down evaluations, while top-down analysis contextualizes bottom-up policy impacts and can potentially be used for consistency checks. Combining these approaches can provide a clearer assessment of the contribution of (combined) energy efficiency policies to climate goals.

Keywords

Energy efficiency policy; bottom-up evaluation; top-down evaluation; EED.

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Introduction

In 2022, residential buildings accounted for 20% of global final energy consumption (IEA, Energy Statistics Data Browser). As fossil fuels still dominate residential energy use in many countries, improving energy efficiency and decarbonizing the residential fuel mix are essential to meeting climate goals. In the Netherlands, for example, the final energy consumption in residential buildings in 2023 was comprised of 62.3% natural gas, 23.8% electricity, 10.1% renewable energy, and 3.1% district heating (Statistics Netherlands).[1]

Figure 1a–d illustrates the trends in final gas and electricity consumption in Dutch households from the end of 2019 to 2023, including total consumption for all households and disaggregated data for single-family homes and multi-family homes (apartments).

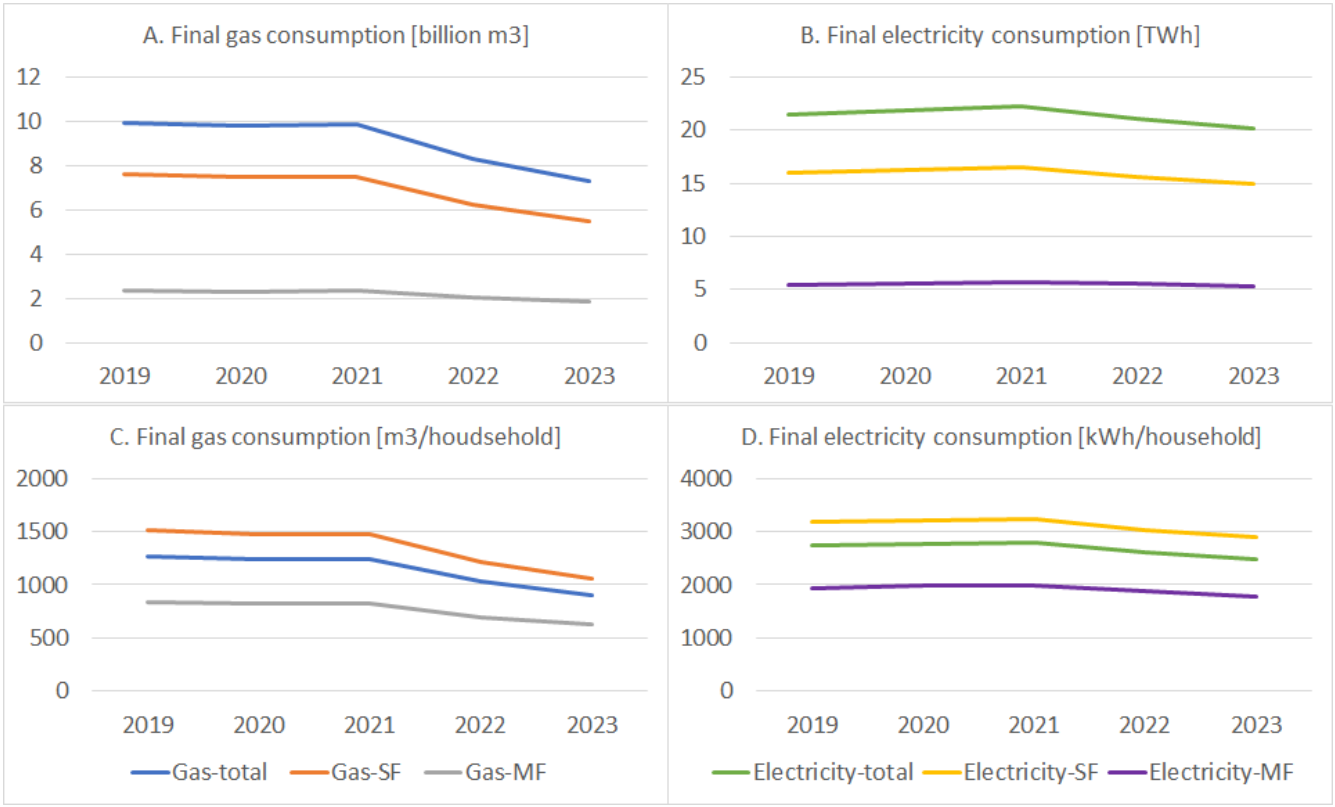

Figure 1. A) Final gas consumption in Dutch residential buildings; B) Final electricity consumption in Dutch residential buildings; C) Average gas consumption per household; D) Average electricity consumption per household; SF = single family home, MF = multi-family home. *Source:* Statistics Netherlands.

Total gas consumption, normalized for heating degree days by Statistics Netherlands, decreased by 26.2% between end of 2019 and 2023 for all households (Figure 1A). The reduction was 28.1% for single-family homes and 20.1% for multi-family homes. On a per-household basis, gas consumption declined by 29.0%, with

[1] In 2023, almost 40% of residential electricity consumption was (on a net-base) produced by domestic rooftop PV. Almost half of the domestic renewable energy use was ambient energy, used by heat pumps (this was less than 15% in 2019). The remaining renewable energy was mainly biomass and a small amount of solar heat. Both final energy consumption of biomass and solar heat have not changed much from 2020 to 2023. (Statistics Netherlands) Although, district heating (next to electric heat pumps) is seen as an important option in the Dutch heat transition, the overall contribution remains modest for the time being.

reductions of 30.0% in single-family homes and 24.8% in multi-family homes (Figure 1C). The percentage decline of total gas consumption is slightly lower because of the growth of the housing stock (see Table 1).

While electricity consumption also declined (Figure 1B), the reduction was more modest compared to gas.

Table 1. Net change in Dutch housing stock (number of dwellings).

Year	New construction	Other additions*	Demolition	Other removals**	Administrative correction by Statistics Netherlands	Net change in housing stock
2020	69,985	22,855	-10,245	-8,286	234	74,543
2021	71,221	25,411	-9,925	-8,409	952	79,250
2022	74,560	24,077	-10,559	-8,835	406	79,649
2023	73,638	20,750	-9,337	-6,555	323	78,819

* including housing unit splitting and building transformation

** including housing unit repurposing and merging housing units

Source: Statistics Netherlands.

In the years 2020, 2021, 2022, and 2023, residential energy consumption was influenced by two key factors: the COVID-19 pandemic (2020 and 2021) and elevated energy prices (2022 and 2023) (Figure 2). While lockdowns led to increased residential energy use in many countries (Li et al., 2023; Todeshi et al., 2022; Mohajeri et al., 2023; Krarti & Aldubyan, 2021), higher energy prices—driven by the Ukraine war—resulted in reduced consumption levels because of behavioural change (IEA, 2023; Zapata-Webborn, 2024).

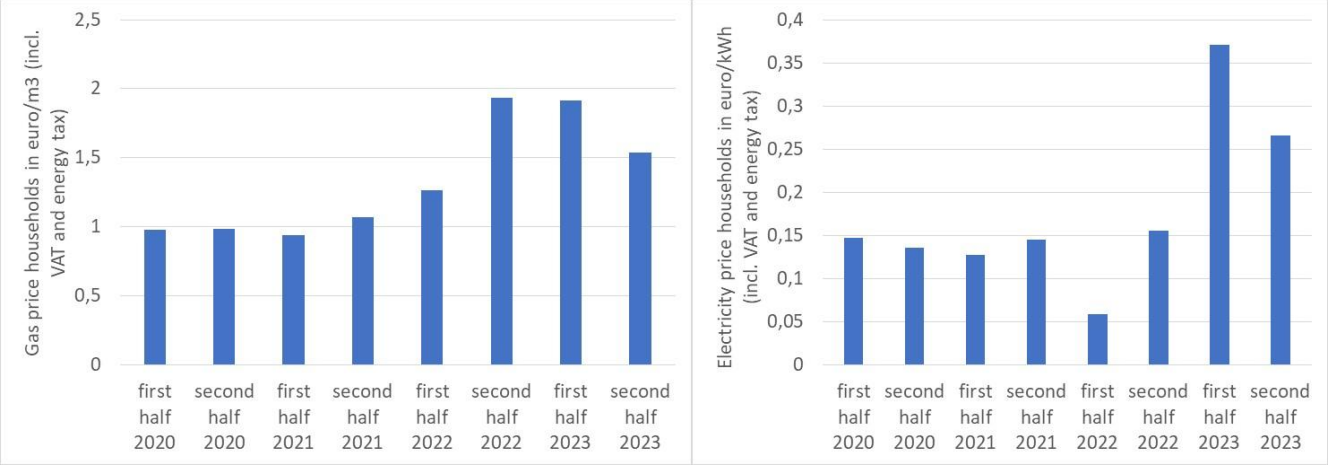

Figure 2. Development of Dutch consumer prices for gas and electricity. *Source*: Statistics Netherlands.

The impact of COVID-19 and rising energy prices has complicated the assessment of energy efficiency policies in this period, making it difficult to determine whether achieved reductions in energy consumption are sustained. These disruptions add to the impact of "normal" structural dynamics such as climate variability, demographic shifts, and changes in household density and floor area of new dwellings, all of which influence final energy use in the residential sector (Reuter et al., 2021).

The EU Energy Efficiency Directive (EED; European Parliament & Council, 2023) addresses final energy consumption in the residential sector (and other end-use sectors) through two key mechanisms: (1) an energy efficiency target, which sets a cap on total final energy consumption in 2030 (Article 4), and (2) an end-use energy

savings obligation, which mandates cumulative final energy savings over a specified period (Article 8).[2] Achieving the Article 4 efficiency target depends on a combination of volume, structural, and efficiency effects, including the impact of disruptions such as elevated energy prices. The savings obligation requires EU Member States to isolate the effects of national efficiency policies using verifiable monitoring data (RVO, 2024). Only savings that exceed those achieved through EU-level policies, such as the minimum energy performance standards in the Eco-design Regulation, contribute toward meeting this obligation (RVO, 2024). Member States can choose to fulfil their Article 8 obligation with an energy efficiency obligation scheme (Article 9) or with alternative policy measures (Article 10).

Discrepancies between bottom-up and top-down evaluations of energy savings are well-documented (e.g., Thomas et al., 2012). While bottom-up assessments capture the intended effects of policy measures, they often rely on deemed savings, which may only partially reflect actual savings. Conversely, top-down evaluations, based on aggregated energy consumption data, can obscure efficiency gains due to overlapping structural dynamics that are difficult to disentangle. Article 4.6 of Commission Recommendation (EU)2024/1590 (European Commission, 2024) encourages Member States to explain how the policy impact reported under Article 8 of the EED contributes to the achievement of the national energy efficiency target (Article 4). The European Commission proposes two levels of assessment: 1) Monitor the trends in final energy consumption (Article 4) and reported energy savings (Article 8) to see if they are consistent and on track of the current objectives; 2) Explain the changes or gaps observed. Such assessment may, e.g., lead to improving the accuracy of savings estimates under Article 8. Quoting the European Commission: *"The more inconsistencies found between the trends monitored for Article 4 and 8 of Directive (EU) 2023/1791 and/or the larger the gaps found between the trends monitored and the trajectories to meet the objectives of the current obligation period, the deeper the assessments mentioned above should go."* (European Commission, 2024, p.12)

One would expect the EED efficiency target and the savings obligation to work in tandem toward the same goal: improving energy efficiency, reducing energy consumption, and contributing to the broader climate objectives. However, during the first EED period (2014–2020), this alignment was not always evident across the EU. A 2022 European Commission report suggests that the two mechanisms were only partially aligned, as 25 EU Member States met their 2020 final energy consumption targets, while just 14 fulfilled their savings obligations (European Commission, 2022, p.9–13). The Netherlands, the case study country in this paper, complied both with the 2020 efficiency target and the 2020 savings obligation, the latter being complied with using EED Article 10 (alternative policy measures). However, this does not mean they were aligned. The Dutch efficiency target (final energy) was exceeded by 14.7% in 2020, while the savings obligation was overachieved by 39% (European Commission, 2022).[3] While the overachievement of the efficiency target was largely inflated by the effects of COVID-19[4], projections as early as 2017 had already indicated a significant surplus in meeting the savings obligation (ECN et al., 2017). Even without the impact of COVID-19, meeting the efficiency target proved challenging, whereas fulfilling the savings obligation appeared relatively easy.

The objective of this paper is to assess the more recent alignment of the efficiency target (Article 4) and the savings obligation (Article 8) by analysing final energy use of the Dutch residential sector. The following research questions will be addressed:

1) To what extent are the policy induced energy savings reported under Article 8 of the EED consistent with the trend in final energy consumption (Article 4)?
2) If not consistent: What explains the differences?
3) Can insight in the differences be used to assess the accuracy of savings estimates under Article 8?

[2] In the 2012 EED, Articles 3 and 7 (European Parliament & Council, 2012).

[3] Based on 672 PJ of cumulative savings achieved versus an obligation of 482 PJ, for all end-use sectors (Ministry of Economic Affairs and Climate, 2024). These figures include the savings in the residential sector.

[4] In 2019, an overachieved of 4.8% was projected (PBL et al., 2019).

Methods

We used a mixed-methods approach following three steps:

- Step 1: Top-down analysis Article 4
  - Step 1a: Chained decomposition of the change in number of private households 2019-2023
  - Step 1b: Chained decomposition of the final energy use by private households 2019-2023
- Step 2: Bottom-up analysis Article 8
- Step 3: Combining the top-down and bottom-up analysis

Step 1: Top-down analysis Article 4

Step 1a: Chained decomposition of the change in number of private households 2019-2023

As our data sources for the final energy use decomposition (see step 1b) did not allow to include household density in the analysis, we performed a separate decomposition analysis, using a different data set, to explain the change in the *number* of private households in three driving factors: population change (volume effect), the changing share between one-person and multi-person households (structure effect 1) and the change in the number of people living in multi-person households (structure effect 2). The decomposition identity used is:

$$\mathrm{HH} = \mathrm{POP} \times \sum \frac{\mathrm{POP_i}}{\mathrm{POP}} \times \frac{\mathrm{HH_i}}{\mathrm{POP_i}}$$

With: HH = number of private households; POP = the number of people living in private households[5]; Subscript i = one-person or multi-person

We applied chained (year-to-year) additive index decomposition analyses and calculated the effects with the following formulas (2019-2020 as an example, providing the effects for 2020):

$$\text{Volume effect} = \mathrm{LM} \times \ln \frac{\mathrm{POP}_{2020}}{\mathrm{POP}_{2019}}$$

$$\text{Structure effect 1} = \mathrm{LM} \times \ln \frac{\frac{\mathrm{POP_i}}{\mathrm{POP}}_{2020}}{\frac{\mathrm{POP_i}}{\mathrm{POP}}_{2019}}$$

$$\text{Structure effect 2} = \mathrm{LM} \times \ln \frac{\frac{\mathrm{HH_i}}{\mathrm{POP_i}}_{2020}}{\frac{\mathrm{HH_i}}{\mathrm{POP_i}}_{2019}}$$

With: $\mathrm{LM} = \log \text{mean} = (\mathrm{HH_i}_{2020} - \mathrm{HH_i}_{2019}) / \ln \frac{\mathrm{HH_i}_{2020}}{\mathrm{HH_i}_{2019}}$

We took all our data (2019-2023) from Statline, the freely accessible database of Statistics Netherlands (CBS).[6]

Step 1b: Chained decomposition of the final energy use by private households 2019-2023

This decomposition analysis explained the development of final residential energy use in four driving factors: change in the number of private households (volume effect), change in the share of construction periods

[5] This number is not the same as the Dutch population since "institutional households" are left out of the analysis. Institutional households refer to groups of people living together in non-private residential settings, where housing is provided as part of an institution or collective arrangement. These include, e.g., nursing homes, prisons, military barracks, monasteries, long-term care facilities. Private households include more than 98% of the Dutch population (StatLine, theme "Population" (subtheme "Population & Households")).

[6] Theme "Population" (subtheme "Population & Households").

(structure effect 1), change in the share of single versus multi-family dwellings in a construction period (structure effect 2), the amount of gas *or* electricity consumption per household (efficiency effect). For the decomposition of final residential energy use, we used the following decomposition identity:

$$FE = HH \times \sum \frac{HH_i}{HH} \times \frac{HH_{ij}}{HH_i} \times \frac{FE_{ijk}}{HH_{ij}}$$

With: FE = final energy use; HH = number of private households; Subscript i = construction period (1000-1946, 1946-1965, 1965-1975, 1975-1992, 1992-2006, 2006-2015, 2015-2023[7]); Subscript j = single *or* multi-family dwelling; Subscript k = gas *or* electricity[8]

Data on number, age and type of dwellings, final energy use and the fuel mix are sourced by Statistics Netherlands.[9]

The effects were calculated with the following formulas (2019-2020 as an example):

$$\text{Volume effect} = LM \times \ln \frac{HH_{2020}}{HH_{2019}}$$

$$\text{Structure effect 1} = LM \times \ln \frac{\frac{HH_i}{HH}_{2020}}{\frac{HH_i}{HH}_{2019}}$$

$$\text{Structure effect 2} = LM \times \ln \frac{\frac{HH_{ij}}{HH_i}_{2020}}{\frac{HH_{ij}}{HH_i}_{2019}}$$

$$\text{Efficiency effect} = LM \times \ln \frac{\frac{FE_{ijk}}{HH_{ij}}_{2020}}{\frac{FE_{ijk}}{HH_{ij}}_{2019}}$$

With: $LM = \log \text{mean} = (FE_{ijk_{2020}} - FE_{ijk_{2019}}) / \ln \frac{FE_{ijk_{2020}}}{FE_{ijk_{2019}}}$

Step 2: Bottom-up analysis Article 8

The Netherlands Enterprise Agency, RVO, has been tasked to report to the European Commission on the Dutch EED savings obligation (Article 8). The Netherlands aims to comply with the savings obligation using "alternative policy measures" (Article 10). Although RVO reports to the Commission the total energy savings in the built environment (residential and services sector combined, using the EU data template[10]), for households the applied method distinguishes between energy savings from insulation (existing homes), heating systems, and electricity consumption for household appliances (RVO, 2024). The deemed energy savings are calculated with a bottom-up simulation model (Niessink et al., 2024). For household appliances, the EED allows to include the

[7] By doing a year-to-year analysis, the new dwellings lower the average energy consumption of construction period 2015-2023 not only because new dwellings are more efficient, but also because part of the new dwellings are not occupied for the full year.

[8] Gas data has been normalized for heating degree days by Statistics Netherlands. Although this allows for a more accurate comparison of the different years, the normalization assumes a share of space heating in total gas consumption which may deviate from consumption patterns in individual households. Looking only at gas and electricity is a limitation of the study since we lacked data for district heating, biomass and solar heat assigned to house type and construction period. We cross-checked this limitation by carrying out a decomposition analysis for the residential sector for all fuels (but without construction periods and housing types). This analysis revealed a comparable efficiency effect for all four years. With an expected growth of district heating in the Dutch residential sector, however, its inclusion becomes critical for future studies.

[9] Statistics Netherlands, StatLine, themes "Energy" (subtheme "Energy consumers") and "Construction & Building' (subtheme " Dwellings & Buildings"). Gas consumption for space heating is normalized for heating degree days by Statistics Netherlands.

[10] This template is part of the National Energy & Climate Plans (NECP), see National energy and climate plans.

additional savings achieved on top of Eco-design regulation. However, RVO does not include these in the reported figures to the European Commission since the effect is small.[11]

For this study, we extracted the bottom-up savings figures for insulation and more efficient heating systems from Niessink et al., 2024. Savings figures for more efficient household appliances were taken from the Odyssee decomposition tool.[12] We did this for one of COVID-19 years (2020) and one of the price-hike years (2022).

Step 3: Combining the top-down and bottom-up analysis

For this step, we elaborated on the method used by Reuter et al. (2021), combining index decomposition analysis (top-down approach) and reported savings from policies (bottom-up approach). Energy savings calculated with decomposition analysis are assigned to the energy efficiency effect which include, apart from the effect of newly implemented policy instruments, the effects of autonomous savings, the effects of existing policy instruments, energy price effects, and effects from structural dynamics not captured by isolated structure effects in the decomposition identity. Bottom-up approaches are often based on deemed savings calculations, combining market data and estimated performance indicators. By combining the top-down and bottom-up analyses, the insights from bottom-up analyses can be used to (further) unravel the top-down efficiency effect, whereas the top-down effect can also be used as an indicative check for the bottom-up calculation (cf. the Commission Recommendation (EU)2024/1590).

Different from Reuter et al., we explicitly connected our analysis to the EED. In addition, there are some differences between our decomposition approach and the approach applied by Reuter et al.:

1) We used chained decomposition analysis. Unchained decomposition analysis is the common approach in many studies where decomposition is used for top-down evaluation (in Reuter et al., e.g., this is the period 2000-2016). Such approach works if individual years in the analysis period follow similar trends. However, if in between years show strong deviations, it is recommended to do chained decomposition analysis allowing to unhide the impact of the deviations that otherwise may (partly) cancel out (Ang & Lee, 1994). Since our analysis period covered the impact of the COVID-19-lockdowns (2020 and 2021), and the surge of energy prices (2022 and 2023), the choice of chained decomposition analysis was justified.
2) Rather than the one-level four-factor decomposition identify used Reuter et al. (Final energy use = Population x Households/Population x Floor area/Households x Final energy use/floor area), we used a three-level four-factor decomposition identity (step 1b) to analyze energy use in the residential sector. The main differences are:
    a. We distinguished between electricity and gas (the main fuels in the Dutch residential sector) to capture efficiency effects for both.
    b. We distinguished construction periods as a means to better link efficiency effects to policies. Changes in (normalized) gas consumption in newer houses are more likely explained by behavioral change (more residential gas consumption because of lockdowns, less gas consumption as a response to the energy price shock) than by building shell improvements.
    c. Within construction periods, we distinguished between single family and multi-family homes.
    d. We did not include data on floor area in the decomposition analysis. Floor area differences were to a large extent captured by the distinction between single family (larger) and multi-family (smaller) dwellings, whereas the average larger floor area of new single family homes

[11] Personal communication with RVO, 26 March 2025.
[12] Odyssee Decomposition Tool.

and the average smaller floor area of new multi-family homes (a structure effect) was captured by the construction period 2015-2023.

e. We did not include household density in the main decomposition identity but analyzed it separately because of data constraints (step 1a).

We combine the top-down analysis and bottom-up data for two years: 2020 (with COVID-19 impact) and 2022 (with impact of high energy prices).

Results

Step 1a: Chained decomposition of the change in number of private households 2019-2023

Figure 3 illustrates the contribution of the driving factors explaining the change in number of private households. Whereas the calculations were carried out for sequential years (2019-2020, 2020-2021, etc.), the results are presented for the entire period in Figure 3. Year-to-year results can be found in Table A1 in the Appendix.

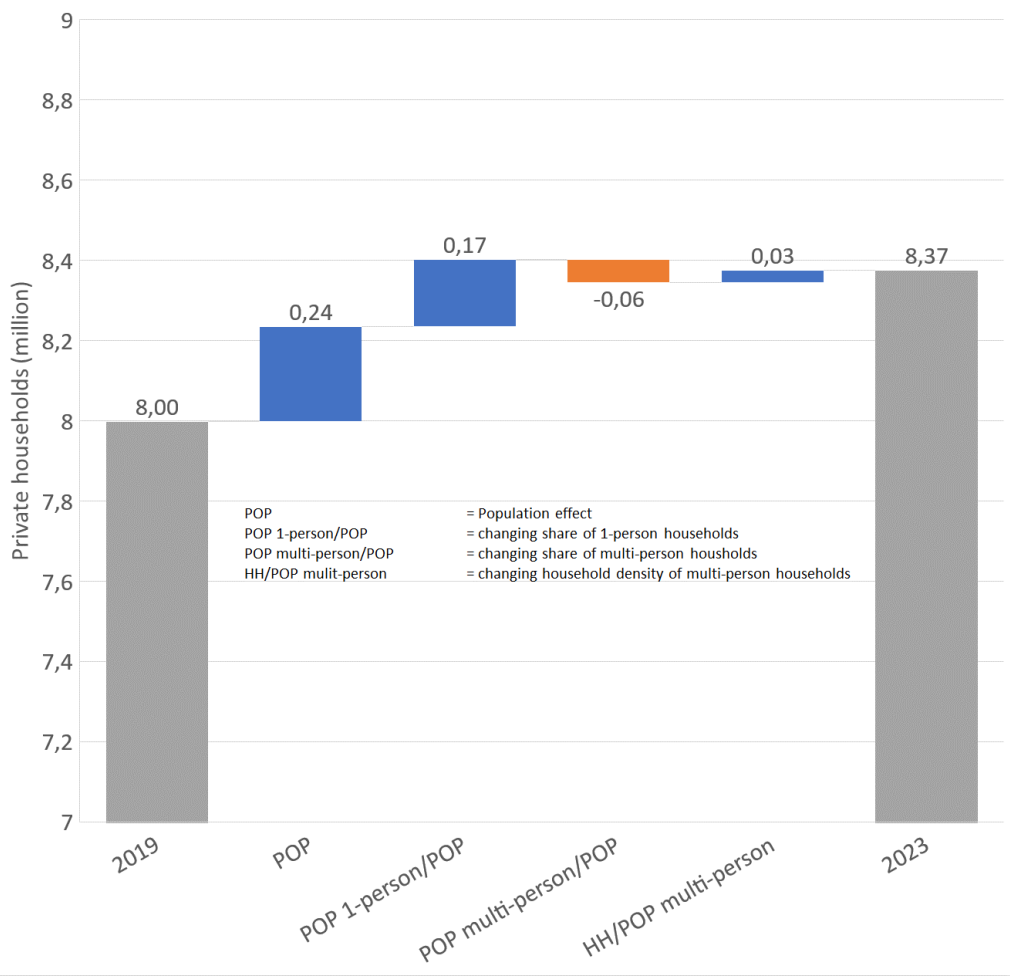

Figure 3. Decomposition of the number of private households 2019-2023.

From the end of 2019 to 2023, the number of private households increased by about 0.37 million. About 0.24 million additional households are explained by population growth (from 17.1 to 17.7 million), about 0.11

million (0.17 minus 0.06) by additional households because of the growing share of one-person households (from 38.5 to 39.9%), and another 30 thousand because of a slight decrease of the household density in multi-person households (from 2.9 to 2.8 persons per household). Most of the additional households (at least on a net-base) are sheltered by newly constructed homes (see Table 1).

Step 1b: Chained decomposition of the final energy use by private households 2019-2023

Figure 4 shows the results of the decomposition analysis for the analysis period 2019-2023. The effects show the effects for the years 2020, 2021, 2022, and 2023. For all years, the volume effect (increase in final energy use because of an increase in number of households) is small. The net HHi/HH effect is also small for the all the years. This effect mimics the change in final energy use because of changing shares of construction periods. Shares of construction periods change because of new construction (this is by definition only true for the construction period 2015-2023) and because of demolition, building transformation etc. (Table 1). The net effect is negative which means that the share of the construction period with the more efficient dwellings (2015-2023) is growing at the expense of the other periods.

Figure 4. Decomposition of final Dutch residential energy use 2019-2023 (HH = volume effect because of change in number of households; HHi/HH = structure effect because of changing shares of construction periods; EE = efficiency effect for gas or electricity).

For the purpose of this paper, our main interest concerns the efficiency effect. In the graphs, the effect is split in an efficiency effect for gas and electricity. Here, we see clear differences between the four years. In 2020, (partial) lockdowns were operational in March and April (not yet in the heating months January and February!) and in the period October-December, while for 2021 this was true for the period January-April, and November and December.[13] The small efficiency effect in 2020 (leading to a small reduction of final energy use) and the almost absent effect in 2021 (leading to a slight increase of final energy use) is likely explained as the net

[13] Coronavirus tijdlijn | Rijksoverheid.nl

effect of efficiency improvements and an increase of energy use because of lockdown immobility (people staying at home more often). The years 2022 and 2023 were characterized by high energy prices (Figure 2). These high prices led to less gas consumption because of more conscious heating behavior (Geerdes et al., 2024) and less electricity consumption. The total efficiency effect shown in the figures is a combination of behavioral change and efficiency improvements.

Figure 5 shows that most of the efficiency effect is found in the older construction periods and in single family homes. In 2020, the construction period 2006-2015 is the only period with a positive efficiency effect (more final energy use per household), whereas the construction period 2015-2023 has a negative efficiency effect for all four years (negative because of reducing average energy use for newly constructed homes). The size of the bars in Figure 5 is partly explained by the sensitivity of household energy consumption in the construction periods for the disruptions (lockdown, high energy prices), and partly by the number of households in the construction period. To control for the latter effect, Table 2 shows the efficiency effect per household in m^3 gas and kWh electricity.

Figure 5. Efficiency effect broken down in construction period and house type (note the different scaling for the top and bottom graphs!).

Table 2. Efficiency effect for gas (in m^3/household) and electricity (in kWh/household).

2020	single family		multi-family		single family		multi-family	
	m^3/HH	%	m^3/HH	%	kWh/HH	%	kWh/HH	%
1000-1946	-39.6	-2.1%	-10.0	-0.9%	12.2	0.4%	40.0	1.9%
1946-1965	-40.8	-2.5%	-10.0	-1.0%	9.2	0.3%	40.0	2.2%
1965-1975	-53.4	-3.3%	-10.0	-1.3%	1.9	0.1%	30.0	1.6%
1975-1992	-23.2	-1.7%	-10.0	-1.3%	-10.8	-0.3%	30.0	1.6%
1992-2006	-8.3	-0.7%	-10.0	-1.4%	8.9	0.3%	20.0	1.0%
2006-2015	9.2	0.8%	-10.0	-1.8%	46.8	1.3%	50.0	2.4%
2015-2023	-70.7	-12.6%	-19.9	-5.1%	175.5	5.8%	129.4	7.3%
2021	single family		multi-family		single family		multi-family	
	m^3/HH	%	m^3/HH	%	kWh/HH	%	kWh/HH	%
1000-1946	12.7	0.7%	10.1	0.9%	70.7	2.1%	50.4	2.4%
1946-1965	0.2	0.0%	0.0	0.0%	30.2	1.0%	29.9	1.6%
1965-1975	10.3	0.7%	10.0	1.3%	30.1	1.0%	0.0	0.0%
1975-1992	11.1	0.8%	10.1	1.3%	2.3	0.1%	0.0	0.0%
1992-2006	16.7	1.3%	0.0	0.0%	13.0	0.4%	10.1	0.5%
2006-2015	0.2	0.0%	0.0	0.0%	81.8	2.2%	20.0	0.9%
2015-2023	-127.6	-19.8%	-88.6	-18.9%	358.1	8.7%	50.9	2.1%
2022	single family		multi-family		single family		multi-family	
	m^3/HH	%	m^3/HH	%	kWh/HH	%	kWh/HH	%
1000-1946	-319.9	-17.0%	-162.9	-13.9%	-218.1	-6.4%	-112.0	-5.1%
1946-1965	-261.5	-16.7%	-139.1	-14.6%	-161.0	-5.4%	-99.3	-5.2%
1965-1975	-286.4	-18.0%	-110.4	-13.9%	-201.4	-6.5%	-100.4	-5.4%
1975-1992	-225.7	-16.4%	-111.3	-13.9%	-214.7	-7.0%	-101.2	-5.4%
1992-2006	-197.8	-15.6%	-91.1	-13.2%	-256.7	-7.2%	-121.4	-5.8%
2006-2015	-192.4	-17.3%	-69.9	-13.0%	-252.9	-6.7%	-109.8	-5.1%
2015-2023	-210.6	-16.7%	-93.7	-20.0%	-162.7	-3.0%	-125.3	-4.1%
2023	single family		multi-family		single family		multi-family	
	m^3/HH	%	m^3/HH	%	kWh/HH	%	kWh/HH	%
1000-1946	-212.1	-13.6%	-103.1	-10.1%	-159.8	-5.0%	-103.1	-4.9%
1946-1965	-170.3	-13.1%	-79.3	-9.8%	-134.1	-4.8%	-89.2	-4.9%
1965-1975	-162.8	-12.5%	-60.5	-8.8%	-137.6	-4.7%	-110.8	-6.3%
1975-1992	-146.9	-12.8%	-61.0	-8.8%	-166.7	-5.8%	-111.8	-6.3%
1992-2006	-133.1	-12.4%	-40.7	-6.8%	-200.4	-6.0%	-142.3	-7.1%
2006-2015	-81.1	-8.8%	-39.9	-8.5%	-181.5	-5.2%	-159.6	-7.8%
2015-2023	-164.6	-17.0%	-94.9	-20.8%	59.2	1.0%	-114.3	-3.2%

For the construction period 2015-2023, we observe a consistently lower gas use because of efficient new construction and more full electric houses. Because of the growing stock of this construction period (Table 1), it cannot easily be used for comparison with the other construction periods.

The construction period 2006-2015 fits such comparison purpose. If the normalization of gas consumption for heating degree days is accurate for all households and heating behavior is constant, one would *not* expect an efficiency effect for this construction period since there is no need (yet) to improve the building shell, nor to replace the heating system. For 2020 and 2021, despite a possible lockdown effect, we observe only a marginal change in gas consumption. For 2022 and 2023, however, we observe a significant decrease both for single family and multi-family homes. As said, since it is unlikely that many dwellings from the construction period 2006-2015 underwent major building shell improvements, the majority of this decrease in gas consumption can most likely be assigned to behavioral change (more conscious heating behavior) or low-investment measures (e.g., optimized heating settings). As the percentage reduction in 2022 (-17.3% for single family, -13.0% for multi-family) is comparable with the other construction periods, a plausible hypothesis might be that the majority of the reduction in 2022 is because of the (sudden) price surges.

For 2023, the percentage decline of the 2006-2015 construction period (-8.8%) is for single-family homes significantly smaller than the effects for the other construction years (around -13%). Here, a plausible hypothesis could be that the additional savings percentage in the other periods is due to efficiency improvements. For multi-family homes the percentages are comparable for 2022 and 2023. Since it is, organization-wise, more difficult to implement building shell improvements in multi-family homes, most of the percentage reduction might, again, be assigned to more conscious heating behavior.

While the impact of higher energy prices on the efficiency effect seems clear (although we cannot say how much of the effect is policy impact and how much comes from behavioral change), the impact of the COVID-19 lockdowns (a positive efficiency effect) is less clear. For 2020, this might be partly explained since heating months January and February (pre-COVID) did not add to the effect. For 2021, it is likely that lockdown effects (a positive efficiency effect) and policy effects (a negative efficiency effect) have cancelled each other out to a large extent.

For electricity, the effects shown in Table 2 are less pronounced. Again, construction period 2015-2023 cannot easily be used for comparison because of the growing housing stock (being increasingly full electric). The impact of high energy prices seems visible but is less significant compared to gas. A COVID-19 lockdown effect is more difficult to trace for electricity because of the ongoing electrification trend.

Figure 6 illustrates some of the electricity consumption trends. Space heating and water heating demand are increasingly served by electric and hybrid heat pumps, both for new and existing dwellings. The slight increase of electricity consumption for lighting is most likely explained by the increased number of dwellings. With LED-lighting as the new normal, additional efficiency gains are limited. The electric appliances stock is growing but still becoming more efficient leading to a small net decrease in electricity consumption. Air cooling is still a small share in total residential electricity consumption but its use is growing fast.

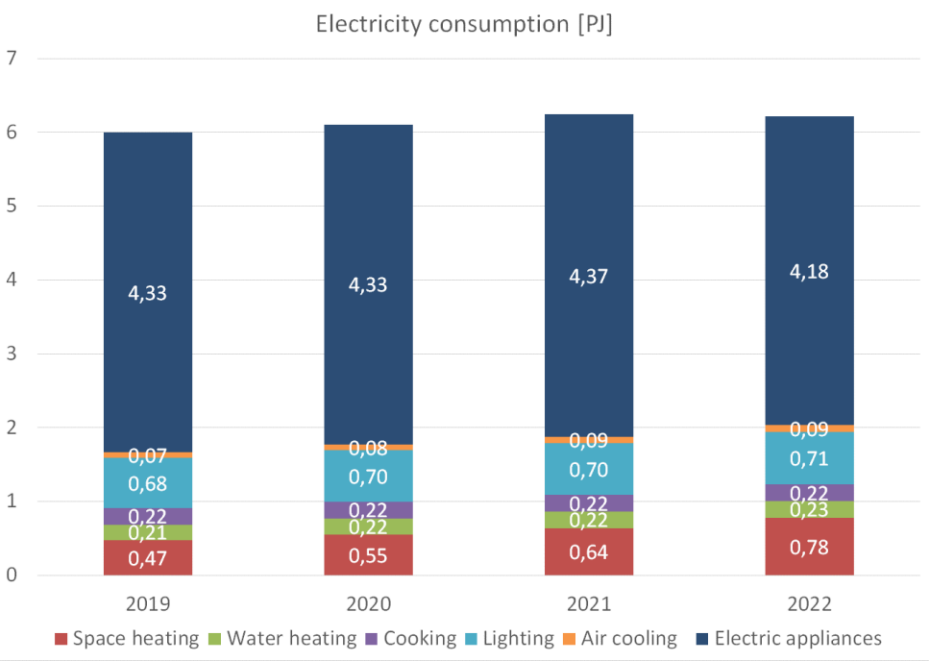

Figure 6. Development of Dutch residential electricity consumption. *Source: Odyssee*.

Step 2: Bottom-up analysis Article 8

Table 3 presents the bottom-up savings figures. The savings from insulation and heating systems exclude new construction. The savings from heating systems are decomposed into gas savings and additional electricity consumption by heat pumps to feed step 3 of the analysis. As indicated in the methods, energy savings from electric appliances are not included in the Dutch EED Article 8 reporting to the European Commission.

Table 3. Bottom-up energy savings residential sector.

	2020	2022	Source/ comment
Re-insulation existing stock [PJ]	6.0	5.3	Niessink et al. (2024). Data is taken from figure 4.13 (p.36) in the report.
Heating systems existing stock (e.g., more efficient gas boilers, (hybrid) heat pumps) [PJ]	1.9	1.8	
Of which gas savings [PJ]	2.1	2.1	Own calculations*
Of which additional electricity consumption for (hybrid) heat pumps [PJ]	-0.2	0.3	
Savings electric appliances [PJ]	1.4	1.2	Odyssee Decomposition Tool
Total incl. savings electric appliances [PJ]	9.3	7.3	
Total reported to the European Commission under Article 8 (excl. savings electric appliances) [PJ]	7.9	6.1	These figures are lumped with the policy impact in the services sector

*19,000 heat pumps in 2020 and 35,000 in 2022 (Niessink et al., 2024, fig.4.4, p.32); electricity consumption heat pump: 2651 kWh/year (Niessink et al., 2024, table 3.7, p.23).

Step 3: Combining the top-down and bottom-up analysis

As indicated in the Methods, we combine the top-down and bottom-up results for two years, 2020 and 2022. When comparing the net efficiency effect (-5.4 PJ) shown in Figure 4 and the bottom-up savings in Table 3 (9.3 PJ) for 2020, a considerable part of the difference is likely explained by the impact of COVID-19 lockdowns. Part of the bottom-up savings are not visible in the efficiency effect because of additional residential energy use due to lockdown immobility. For 2022, the difference between the efficiency effect (-55.7 PJ) and the bottom-up savings (7.3 PJ) is more significant, and likely largely be explained by behavioral change because of the energy price shock. Although we observe inconsistencies between the efficiency effects and the bottom-up savings (research question 1), and can explain the differences (research question 2), the results cannot be used to assess the accuracy of the Article 8 savings estimate (research question 3). This is because the analysis period 2020-2023 is characterized by disruptive events, implying that the efficiency effects for the Article 4 analysis cannot be used as an (indicative) benchmark for the bottom-up savings estimates. For the remaining of step 3, we therefore assume that the bottom-up energy savings from step 2 have materialized.

The decomposition outcomes of step 1b provide insight in the efficiency effect for gas and electricity at the level of construction periods and house type. In the analysis, some plausible hypotheses were formulated offering a first step for unraveling the efficiency effect and unhiding the energy efficiency policy impact and the impacts from disruptions (COVID-19, high energy prices). In step 3, we further unravel the top-down efficiency effect for 2020 and 2022 by combining the bottom-up energy savings from step 2.

The efficiency effects for gas found in Figure 4 (2019-2020) are further decomposed in the gas savings from new construction (derived from the disaggregated top-down figures) and the gas savings from more efficient installations and insulation (taken from the bottom-up analysis). The resultants are the additional gas consumption as a result of the lockdowns (Figure 7) and the decreased gas consumption as a result of the high energy prices (Figure 8). The gas savings from new construction in Figure 7 could not be further corrected for the lockdown effect. This implies that both gas savings and lockdown effect might be higher than shown (with the sum of them remaining unchanged).

For the efficiency effects for electricity, the resultants are the additional electricity consumption because of the lockdowns (Figure 7) and the decreased electricity consumption because of the high energy prices (Figure 8). The electrification effect corrects for the fact that part of the gas savings for installations come from (partial) fuel shifts, from a heat boiler to a (hybrid) heat pump (Table 3).

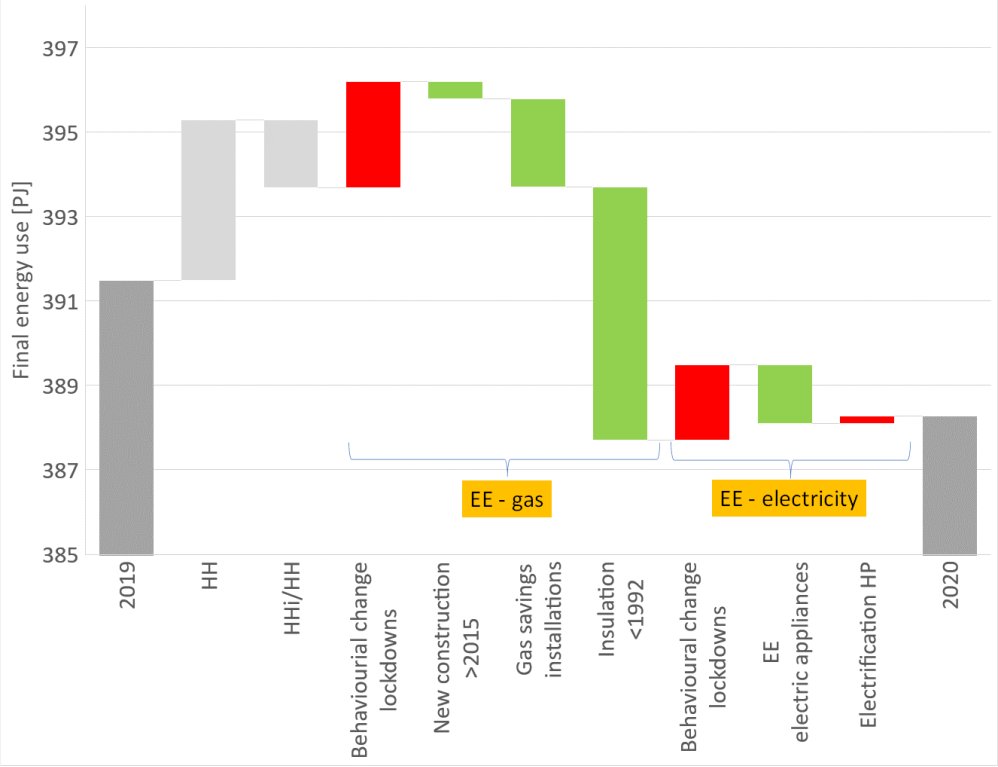

Figure 7. Connecting the top-down and bottom-up analyses for 2020 (EE – gas or electricity refers to the values in Figure 4).

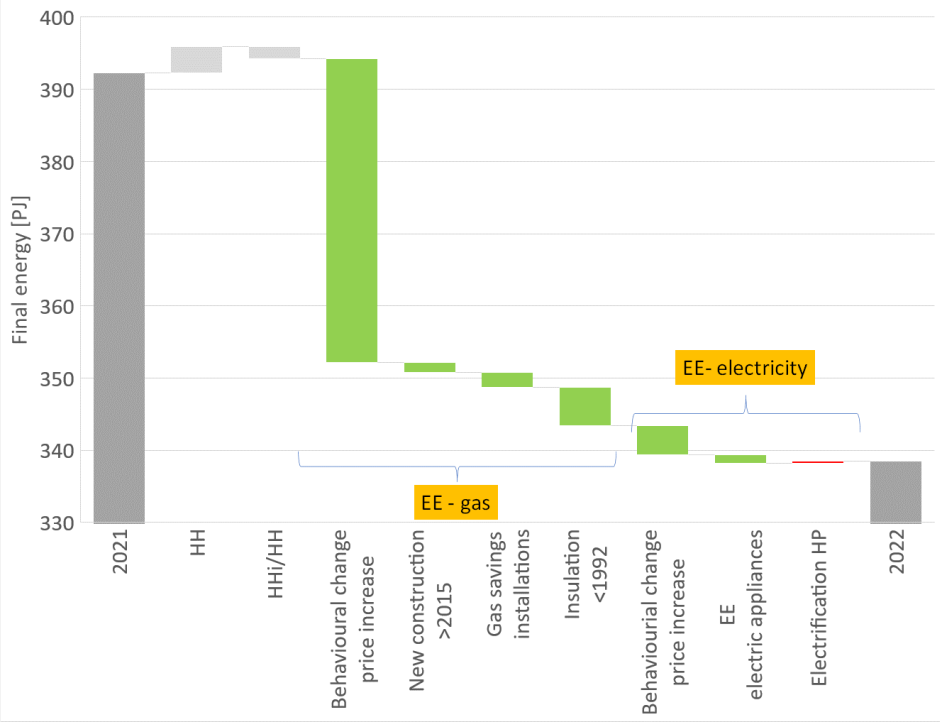

Figure 8. Connecting the top-down and bottom-up analyses for 2022 (EE – gas or electricity refers to the values in Figure 4).

Discussion

Contribution

We elaborated on the method for combining top-down and bottom-up evaluation data proposed by Reuter et al. (2021). Here, our contribution lies in the application of a chained year-to-year decomposition analysis that better allows to further decompose the top-down efficiency effect, and the direct connection to the European EED (Article 4 versus Article 8). Recalling earlier work by, e.g., Thomas et al. (2012), our analysis demonstrates the importance and added value of combining top-down and bottom-up evaluations in the context of policies such as the European EED. Top-down evaluations alone may overestimate or underestimate the impact of the combined energy efficiency policies as they lack the means to fully unhide the interference of structural dynamics with the efficiency effect. Bottom-up evaluations alone are not or only loosely connected to volume and structure effects. Whether an EU Member State is on track, or not on track, towards its Article 4 efficiency target does not tell us if a Member State has a sufficiently strong energy efficiency policy package or must further strengthen it. Whether a Member State is on track, or not on track, with its Article 8 savings obligation does not tell us if the reported savings have all materialized. Our synthesis of the top-down results of 2020 and 2022 with the bottom-up figures reported under the Article 8 energy savings obligation allowed us to isolate the loss of energy savings due to the COVID-19 lockdowns and the energy savings from behavioural changes triggered by the energy price shock.The combined top-down and bottom-up analyses offer, therefore, a more balanced view than the separate analyses, and, as such, supports the recommendation of the European Commission to look into the consistency between EED Article 4 and Article 8 trends, and to explain the gaps between them.

Limitations & further research

This apparent inconsistency between the Article 4 target and the Article 8 obligation could not be fully explored in this paper, meaning we were unable to assess the accuracy of the Article 8 savings estimate (research question 3). This is because the analysis period 2020-2023 is characterized by disruptive events, implying that the efficiency effects for the Article 4 analysis cannot be used as an (indicative) benchmark for the bottom-up savings estimates. Therefore, the assumption in our analysis was that the bottom-up energy savings have materialized. The bottom-up savings used in our analysis are deemed savings based on housing stock details, sales information about measures, allocation rules (including allocation of measures to residential and non-residential buildings), and performance indicators (Niessink et al., 2024). It is therefore a technical assessment using a bottom-up simulation model. By calibrating the model results to the final energy statistics, the deemed savings are linked to the reduction of final energy use (RVO, 2024). Since final energy consumption is also influenced by volume changes and structural dynamics, this calibrating does not guarantee that estimated savings can be one-to-one compared with efficiency effects. Researchers will be aware of large discrepancies between the top-down efficiency effect and the bottom-up savings when analyzing normal years. However, if disruptions obscure the top-down efficiency effect, it is almost impossible to trace discrepancies, and to assess (and possibly improve) the accuracy of savings estimates under Article 8 as encouraged by the European Commission (European Commission, 2024, Article 4.6).

The current research worked with publicly available data sources from Statistics Netherlands allowing for replication of this work, but also coming with some data limitations regarding fuels that could not be considered in the analysis, such as district heating (see Methods). These limitations can partly be overcome by using microdata.[14] Using microdata would also allow to distinguish between more house types (single family split in detached, semi-detached, terraced) and ownership (private owned, social rent, commercial rent). Adding such

[14] Microdata: Conducting your own research | CBS

detail becomes even more relevant if bottom-up figures reported to the Commission would also be presented in such detail, which is currently not the case.

Conclusion

The objective of this paper was to assess the more recent alignment of the efficiency target (Article 4) and the savings obligation (Article 8) by analysing final energy use of the Dutch residential sector. Our first research question ("To what extent are the policy induced energy savings reported under Article 8 of the EED consistent with the trend in final energy consumption (Article 4)?") led to the conclusion that the results of the two EED mechanisms are not consistent, at least not for 2020 and 2022. For both years, plausible explanations were identified for the observed differences (Research Question 2): in 2020, increased residential energy use due to reduced mobility during COVID-19 lockdowns; and in 2022, decreased use resulting from behavioural changes triggered by the energy price shock. However, because these inconsistencies stem from the Article 4 analysis, the results could not be used to assess the accuracy of the Article 8 savings estimates (research question 3). Such an assessment is only possible, at least in indicative terms, when combining top-down analyses from "normal" years with bottom-up savings calculations.

Although encouraged by the European Commission, monitoring of the consistency between the efficiency target and the savings obligation is not (yet) a given. The EED energy savings obligation, while designed to track national policy-induced savings, faces challenges in transparency, partly because the required data template aggregates savings from both the residential and services sectors. As a result, the reported figures sometimes seem to serve more as a compliance checkbox than a meaningful tool for refining or steering the national energy efficiency policy package, at least for Member States like the Netherlands that have chosen to comply with the savings obligation by alternative policy measures rather than an energy efficiency obligation scheme.

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Appendix A

Table A1. Year-to-year decomposition results step 1a (complementing Figure 3)

	POP effect	Effect changing share of one-person households	Effect changing share of multi-person households	Effect changing density multi-person households
2019-2020	31710	5129	-1795	10599
2020-2021	52220	55215	-19356	7070
2021-2022	97488	55227	-19371	-1691
2022-2023	56050	52271	-18357	14196

In all years, population grew, the share of one-person households grew at the expense of multi-person households, and apart from 2021-2022, the number of people living in multi-person households slightly decreased.