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Energy consumption decomposition analysis using European official statistics: Methodology and input data

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Abstract. Deciphering energy efficiency is a critical component for the sustainability and energy policies of the European Union (EU) and its Member States. Decomposition analysis is a key method that helps distinguish real energy efficiency gains from other external factors. This article presents a decomposition analysis method using official EU statistics, its results, and associated limitations. Although separating structural changes and activity levels from energy efficiency poses a challenge, an adapted Logarithmic Mean Divisia Index (LMDI) method was utilised to isolate and highlight energy efficiency. This article outlines this method and how the European official statistics were exploited. Firstly, it examines the factors affecting energy consumption in various sectors within EU-27. Secondly, it examines the factors affecting energy consumption in various sectors. In doing so, it also addresses potential obstacles in data collection, and presents improvements to the LMDI analysis. The findings in this study make a substantial contribution to the fields of national statistics, methodological applications, and energy data analysis in the context of the EU's energy policies.

Keywords: Decomposition, energy consumption, LMDI, efficiency, european official statistics

1. Introduction

1.1. Objective of the decomposition analysis

For several decades now, the importance of energy efficiency has been well understood, both in the context of clean energy transition, and for its benefits to national economies in general. This has evolved to such an extent that after being labelled for some time as the 'hidden fuel', it is now more commonly referred to as the 'first fuel' [1], thus showing its prime role in the current energy efficiency debate. Another sign that energy efficiency is recognised in the political agenda is its presence in the United Nations' 7th Sustainable Development Goals (SDG7). This states that 'by 2030, double the global rate of improvement in energy efficiency' [2].

In the European Union (EU), energy efficiency improvement was one of three 20% targets that should be reached by 2020 (Energy Efficiency Directive 2012/27/EU). The target has since been updated to 32.5% by 2030, compared to projections of expected energy use (Energy Efficiency Directive 2018/2002).

If these ambitious goals are to be implemented effectively, actions need to be carefully planned and monitored. National administrations, academics, researchers, international organisations, and other stakeholders will need gain a solid understanding of what drives energy consumption.

Decomposition analyses have been widely used for many decades. The objective of the decomposition analysis is to separate the respective impact of different drivers from the total energy demand.

Different calculation methods can be applied, but the Logarithmic Mean Divisia Index (LMDI) method is becoming the reference as it provides various interesting mathematical properties and allows transparent analysis

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of the result, thanks to the absence of a residual term. This method was therefore chosen for this project.

The result consists in a series of coefficients which represent the estimated effect of each component of the initial equation on the overall energy consumption between different periods covered in the dataset. These coefficients can then be used to perform a variety of analyses, due to the possibility of separating out different aspects of scenarios, and they can also be presented in graphical form.

The research and analyses were carried out in the context of the project 'Lot 1: Decompositions of energy production and consumption trends' awarded by Eurostat to Artemis Information Management S.A. as part of the tenders on modernisation of the reporting and dissemination of energy statistics (ESTAT/LUX/2020/OP/0014) [3].

For the purposes of this project, energy consumption has been decomposed and presented for the following sectors of activities:

- The final energy consumption for the whole economy (industry plus agriculture[1] and services) based on employment;
- Final and primary energy consumption of the industry[2] sector (manufacturing industries and construction sector) based on value added;
- The residential sector;
- The transport sector based on traffic.

This project and research differed from other examples of energy consumption decomposition in several aspects.

Firstly, all the work is based on Eurostat datasets. This presents a number of advantages, namely:

- It is simple to reproduce the results obtained, since the calculation methodology is available as well.
- It highlights the work of statisticians in national administrations, by proposing a new way to use their data.
- It also enables potential data issues to be identified, such as lack of disaggregation or unstable time series, which can help administrations to focus their efforts on particularly important areas.
- Finally, by applying the exact same methodology to all European countries covered, a transparent comparison is possible, hopefully bringing interesting insights on the energy consumption analysis of each country.

1.2. Decomposition analysis of EU-27 and its Member States

One of the goals of the EU was to create a single market strengthening European economies and to allow a convergence of the least developed economies towards the richest. In 2022, the EU-27 not only represented around 6% of worldwide population and 16.6% of worldwide gross domestic product (GDP), but it also accounted for approximately 14% of the world's trade in goods, behind China. Consequently, due to the size of its economy, the EU also requires large amounts of energy. In 2022, the EU-27 met its energy demand through 23 545 PJ of primary energy production and 54 447 PJ of cumulated energy imports. The cumulated energy exports accounted for 17 909 PJ and the final energy demand (energy use in final sectors and in the energy sector) was 39 836 PJ in 2022 (Fig. 1). With global concerns over environmental impacts due to energy consumption, as well as its the interest in energy self-sufficiency, the EU-27 has multiple reasons for reducing its energy demand.

Following the Climate Target Plan and the European Green Deal, the EU-27 aims to meet several targets, including 55% less greenhouse gases (GHG) emissions in 2030 (compared to 1990 level), to 39% and 36% of energy efficiency for primary and final energy consumption by 2030 and net carbon neutrality by 2050. To monitor progress on these objectives, it needs to assess the impact of the different energy consumption drivers to enable it to implement efficient policies. However, the EU-27 is a union of vastly different countries, with differences in size, population, economy, energy policies, etc. A comparison between EU members concerning their energy consumption can therefore provide useful insights.

Final energy consumption in the EU-27 has fluctuated over the last decade, reflecting the complex interplay of distinct factors. Starting in 2010 at 43 378 PJ, it fell sharply to 41 606 PJ in 2011. Thereafter, the level remained stable until a noticeable drop was perceived in 2014, when it reached 40 450 PJ. The trajectory shifted upwards in 2018, peaking at 41 790 PJ, followed by a contraction in 2020, reaching its lowest point of the decade during the COVID-19 crisis. The resilience observed in 2021 marked a rebound, which was followed by a further decline in 2022, with a fall to 39 836 PJ as a result of the energy crisis.

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[1] Agriculture, forestry and fisheries sector. According to NACE Rev. 2, section A.

[2] Manufacturing, mining and quarrying and other industry sectors plus Construction. According to NACE Rev. 2, section B, C, D, E and F.

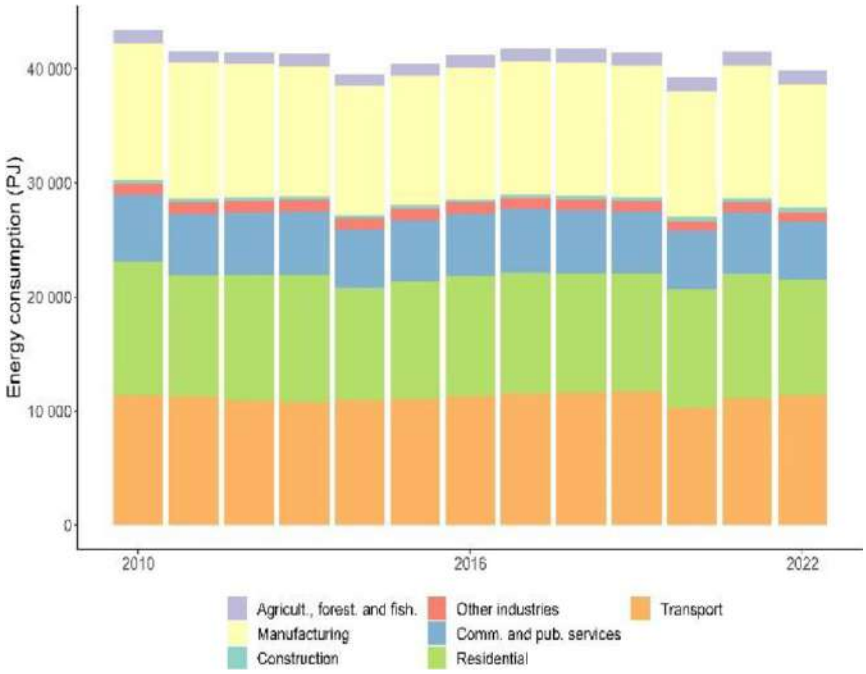

Fig. 1. Total energy consumption by industry, 2010–2022 *(Source: Eurostat (nrg_bal_c))*.

The objective of this project is to assess the impacts of the variation in activity level, sector structure and activity intensity on the total, in this case, the total energy consumption of a given sector. In other words, is this decrease in consumption due to gains in energy efficiency, to a decrease in activity or to other changes?

For this project and research article, data from the EU-27 Member States was used, as well as the EU-27 aggregate, for all years since 2010. A final data extraction was made in February 2024 to check the data availability for 2022 and to assess the impacts of the last crisis on our analyses.

The choice of reference years in decomposition analysis is crucial, with particular attention given to the initial and concluding years. Selecting a reference year influenced by a crisis, either as the starting or ending point, adds complexity, especially when analysing longer periods. Most of the results described in this article therefore refer to the period 2010–2019, with a small section describing decomposition analysis for the periods 2010–2019 and 2019–2022, to enable a comparative assessment.

Furthermore, although the article outlines the industry primary energy decomposition method, it does not present specific results, as they closely align with the final energy decomposition. However, comprehensive details regarding data limitations are provided in the section titled ‘Data Limitations and Limitations of the Analysis.’

After describing the methodology used for the decomposition analysis, certain results will be explained and assessed in more detail. These results have also revealed some data limitations, both in terms of coverage and other issues.

2. Decomposition methodology

2.1. General principle

The objective of the Indexed Decomposition Analysis (IDA) is to evaluate the respective share of different effects on the variation of a total quantity, in this case the energy consumption of a sector of the economy. These effects are commonly related to:

- the activity level of the sector (A);
- the energy intensity (I_i) of each subsector, i.e. the ratio of the energy use to the output of the subsector;
- the respective weights of these subsectors in the total activity (S_i).

Additional effects can also be included when they are assumed to have an impact on the overall quantity to decompose. To perform the decomposition, the starting point is to establish an identity, where the energy consumption of a sector (E) is expressed as a product of each element whose impact are to be quantified. In practice, the decomposition identity is usually expressed as follows:

$$E=\sum_i E_i=\sum_i A\times\frac{A_i}{A}\times\frac{E_i}{A_i}=A\times\sum_i S_i\times I_i$$

Where:

- E_i: Energy consumption of subsector i
- A_i: Activity level of subsector i
- $S_i = \frac{A_i}{A}$: Share of activity of sector i
- $I_i = \frac{E_i}{A_i}$: Energy intensity of subsector i

The IDA allows the respective contribution (measured in terms of energy consumption) of each of these driving factors to be determined. This can be expressed either additively (notation Δ) or multiplicatively (notation D), as is shown below:

$$\begin{aligned}\Delta E &= E_t - \Delta E_0\\ &= \Delta E_{ACT} + \Delta E_{STR} + \Delta E_{INT} + \Delta E_{RES}\end{aligned}$$

$$DE = \Delta\frac{E_t}{E_0} = DE_{ACT} \times DE_{STR} \times DE_{INT} \times DE_{RES}$$

- The additive form decomposes the difference between two points in time, while the multiplicative form decomposes the ratio of change with respect to the base year.
- The activity effect (E_{ACT}) accounts for changes in energy consumption due to the change in the economic activity of the sector: the activity effect is positive (i.e. the energy consumption increases) if the overall activity increases.
- The structural effect (E_{STR}) accounts for changes in energy consumption that are due to the change in the relative importance of more or less energy-intensive sectors. The structural effect is positive if the share of energy-intensive sectors grows.
- The intensity effect (E_{INT}) is represented by the [2] ratio $\frac{E_i}{A_i}$. It accounts for changes in total energy consumption due to technology advancements, efficiency improvements, policy, and other effects. The intensity effect is negative if there is a drop in energy intensity.
- The residual effect (E_{RES}) is an undesirable output from an imperfect decomposition, which occurs with some of the mathematical methods.

Decomposition is commonly calculated on a yearly base. In the case here, this would mean the first year of the period is marked as 0 and the last year as T. However, it could also be conducted on a shorter period if the corresponding data are available. For the present calculation, two approaches are possible:

- Chaining decomposition uses annual time-series data, and decomposition is made on changes between consecutive years. The results for each effect are then ‘chained’ to generate a time series.
- Meanwhile, non-chaining decomposition is conducted using data for only the first and last year of the period, without calculating it for the intermediate years.

2.2. Choice of the calculation method

After a review of possible methodologies, the LMDI presented the most advantages: firstly, because it enables changes in energy use to be decomposed into separate determinant effects, and secondly, because it presents interesting mathematical properties (including perfect decomposition). Additionally, the literature Liu, 2006 [4] highlights that the importance of the levels of disaggregation and data quality on results are more important than the decomposition methods themselves.

To support the selection, existing decomposition analysis works on European countries were also reviewed. Among the three examples reviewed, both the JRC [5] and IEA [6,7] rely on the LMDI methodology to perform the decomposition. The ODYSSEE database [8,9,10,11,12,13] uses a variety of custom-made decomposition methods for greater flexibility. However, this results in imperfect decomposition, causing difficulties with the interpretation. In terms of data sources, the IEA and ODYSSEE both mainly rely on their internal data collection for their work, while the JRC mainly uses Eurostat data.

The LMDI decomposition offers interesting mathematical properties:

- It results in perfect decomposition, i.e. the results do not contain any residual term.
- It can be used to investigate the effects of more than two factors (in the present case, three factors are needed). Moreover, the complexity does not increase as more factors are included.
- There is a simple relationship between multiplicative and additive forms.
- It is consistent-in-aggregation, meaning that the effect of subsectors can be aggregated to calculate the effect at the sector level.
- For the same reason, a decomposition between two time periods will be equivalent to any sum of decomposition on intermediate time periods. In other terms, the effect between year 1 and 3 is the same as the effect between year 1 and 2 plus the same effect between year 2 and 3. There is therefore no need to chain the calculations between the first and the last year of the study.

Table 1
LMDI coefficients

Method	Activity	Structure	Intensity	Weighting factor
Additive (ΔE)	$\sum_i w_{i,t} \ln\left(\frac{A_t}{A_0}\right)$	$\sum_i w_{i,t} \ln\left(\frac{S_{i,t}}{S_{i,0}}\right)$	$\sum_i w_{i,t} \ln\left(\frac{I_{i,t}}{I_{i,0}}\right)$	$w_{i,t} = L\left(E_{i,0}, E_{i,t}\right)$
Multiplicative (*DE*)	$e^{\sum_i \widetilde{w_{i,i}} \ln\left(\frac{A_t}{A_0}\right)}$	$e^{\sum_i \widetilde{w_{i,i}} \ln\left(\frac{S_{i,t}}{S_{i,0}}\right)}$	$e^{\sum_i \widetilde{w_{i,i}} \ln\left(\frac{I_{i,t}}{I_{i,0}}\right)}$	$\widetilde{w_{i,t}} = \frac{L(E_{i,0},E_{i,t})}{L(E_0,E_t)}$

- It can handle zero values.

This decomposition has been widely used and the main equations are shown in the Table 1.

Where:

$$L\left(X_1, X_2\right) = \frac{X_2 - X_1}{\ln\left(\frac{X_2}{X_1}\right)}) \; if \, X_1 \neq X_2$$

$$L\left(X_1, X_1\right) = X_1$$

2.3. Choice of the data sources

Conducting decomposition analysis requires information on activity and energy consumption at the subsectoral, mode, or end-use level. The availability of this information is the key element that will determine the breakdown that can be applied to each sector, and consequently, it will also impact the choice of the method for the calculation.

All the data used in the decompositions were sourced from Eurostat databases. This presents several advantages, namely:

- It is simple to reproduce the results obtained, since the calculation methodology is also available.
- It highlights the work of statisticians in national administrations, by proposing a new way to use their data.
- It also enables potential data issues to be identified, such as lack of disaggregation or unstable time series, which can help administrations to focus their efforts on particularly important areas.
- Finally, by applying the exact same methodology to all European countries covered, a transparent comparison is possible, hopefully bringing interesting insights on the energy consumption analysis of each country.

Nevertheless, the existence of missing data represents a significant limitation of LMDI applications.

2.4. LMDI application by sector

2.4.1. Total economy final energy decomposition based on employment

2.4.1.1. Calculation

In order to get as broad a picture as possible, applying the decomposition analysis on the overall economy, i.e. including industry, agriculture and service sectors can be of great interest. Through this, the effect of the shift between the sectors can be quantified, such as the transition from an industrial to a service-based economy. However, the challenge here can be defining a common activity indicator. The gross value added used for the decomposition of the industry subsector is not so relevant to assess the level of activity in other sectors. For example, agricultural production depends very much on the weather. To some degree, other variables impact the turnover in the service sector, (e.g. tech companies with very high value added). As a proposal, a decomposition based on the number of employees is suggested, based on the following identity:

$$E_{economy} = \sum_i E_i = N_{emp} * \sum_i \frac{N_{emp_i}}{N_{emp}} * \frac{E_i}{N_{emp_i}}$$

Where:

- i represents the different sectors of the economy.
- $E_{economy}$: Total energy consumption in the overall economy (see next section for coverage). It is measured in Terajoule (TJ).
- E_i: Energy consumption of the sector i.
- N_{emp}: Number of employees in total It is measured in thousands of employees.
- N_{emp_i}: Number of employees in the sector i.

2.4.1.2. Effects

In this decomposition, the activity effect stems from the variation in the total number of employees. The increase in the total number of employees over time should be linked to a larger economy size, and result in a positive effect (i.e. increasing) on energy consumption.

The intensity effect at sub-sectoral level is expressed by the energy consumption per employee in each subsector. An increase in the ratio results in a positive effect on the overall energy consumption.

The structural effect stems from the variation of the weight of each subsector in the total employment. If shares of the more energy-intensive industries increase, then the level of activity in these sectors may be increasing and the overall energy consumption would also increase.

2.4.1.3. Data sources

With the available data on energy and employment, the decomposition was performed for the following five sectors, namely:

- Agriculture, forestry, and fishing
- Manufacturing industries
- Construction industries
- Other industries
- Commercial and public service

These data were obtained from Eurostat's dataset '*Employment by A*10 industry breakdowns*' (*nama_10_a10_e*). The mapping between the Statistical classification of economic activities (NACE Rev. 2) and the sectors used in the dataset '*complete energy balance*' is provided in the **annex 01**.

2.4.2. Industry final energy decomposition based on added value

2.4.2.1. Calculation

This is the most commonly used decomposition analysis proposed for energy consumption in the industry sector, and it can be found in a number of publications on the topic (JRC, 2017) (IEA, 2020). It relies on the following identity:

$$E_{industry} = \sum_i E_i = GVA_{industry} \sum_i \times \frac{GVA_i}{GVA_{industry}} \times \frac{E_i}{GVA_i} \quad (1)$$

Where:

- $E_{industry}$: Total energy consumption in the overall sector. It is measured in terajoules (TJ).
- E_i: Energy consumption of the subsector i.
- $GVA_{industry}$: Gross value added in the overall industry sector in our decomposition it is measured in million euro (2015) at chain-linked volumes (2015). The total had to be recalculated for each country, based on the sectors that were available for the analysis (see discussion on limitations).
- GVA_i: Gross value added in the industry subsector i.

2.4.2.2. Effects

The activity effect stems from the variation of the total GVA of the industry sector. An increase in the total GVA over time would have a positive effect (i.e. increasing) on the energy consumption.

The Intensity effect at subsector level is expressed by the ratio of energy consumption over the GVA of the subsector. An increase in the ratio results in a positive effect on overall energy consumption (which can be understood as a higher energy consumption per unit of sectoral output).

The structural effect stems from the weight variation of each subsector's output, expressed as the GVA share. If the shares of the more energy-intensive industries increase, then the overall energy consumption also increases.

2.4.2.3. Data sources

The list of subsectors that could be treated separately corresponds to those mappable between the energy consumption and economic data. Mapping of industry sectors between the Eurostat datasets 'Complete energy balances' (*nrg_bal_c*) and 'National accounts aggregates by industry (up to NACE A*64)' (*nama_10_a64*) is provided in the **annex 02**. The decomposition was made for the following 13 industry subsectors:

- Construction
- Mining and quarrying
- Food, beverages, and tobacco
- Textile and leather
- Wood and wood products
- Paper, pulp, and printing
- Coke and refined petroleum products
- Chemical and petrochemical
- Non-metallic minerals
- Basic metals
- Machinery
- Transport equipment
- Other manufacturing

2.4.3. Industry primary energy decomposition based on value added

2.4.3.1. Calculation

In addition to the initially proposed decomposition of the final energy consumption, it is interesting to relate this consumption of electricity and heat to the primary energy that was used to generate it, this way the corresponding amount of primary energy can be allocated to each subsector of the industry based on its share of the total electricity demand. For instance, more industries are relying solely on grid electricity, and at the same time, the electricity grid is increasingly relying on renewables.

This decomposition emphasises how the variation in the electricity mix can influence the total primary energy consumption. This requires an identity such as the following:

$$E_{primary} = \sum_j E_{primary\ j} = \sum_j E_{final\ j} * \frac{E_{primary\ j}}{E_{final\ j}}$$

Where:

- $E_{final\,j}$: Final energy consumption of fuel j, which can include secondary products such as electricity or heat). It is expressed in *TJ*.
- $E_{primary\,j}$: Primary Energy consumption of fuel j, which includes only (considered) primary energy products.

And if we replace the final consumption of fuel j, as in the Eq. (2):

$$E_{primary} = \sum_j \sum_i GVA * \frac{GVA_i}{GVA} * \frac{E_{final\ i,j}}{GVA_i} * \frac{E_{primary\ i,\ j}}{E_{final\ i,\ j}} \quad (2)$$

The primary energy used for electricity and heat final consumption was calculated for each unit of electricity or heat produced in the country, each year.

Starting from Eurostat's energy balance dataset, the primary energy used per unit of electricity produced was calculated as follows:

$$\frac{E_{primary,\ ele}}{E_{final,\ ele}} = \frac{E_{input\ for\ electricity}}{ELE_{available}}$$

with

$$\begin{aligned} E_{input\ for\ electricity} = {} & E_{input\ main\ ele\ plants} + E_{input\ main\ CHP\ plant,\ ele} + \\ & E_{input\ auto\ ele\ plants} + E_{input\ auto\ CHP\ plant,\ ele} + \\ & HEAT_{derived\ for\ ele\ prod} + ELE_{input\ hydro\ pumping} \end{aligned}$$

Where for both main activity plant and auto producers

$$E_{input\ CHP\ plant,\ ele} = E_{input\ CHP\ plant} * \frac{ELE_{output\ CHP\ plants}}{E_{output\ CHP\ plant}}$$

and

$$\begin{aligned} ELE_{available} = {} & ELE_{output\ main\ ele\ plants} + ELE_{output\ main\ CHP\ plants} + \\ & ELE_{output\ auto\ ele\ plants} + ELE_{output\ auto\ CHP\ plants} + \\ & ELE_{output\ hydro\ pumping} + ELE_{output\ other\ sources} - \\ & ELE_{input\ heat\ pumps} - ELE_{input\ boilers} \end{aligned}$$

And for the calculation of the primary energy used per unit of heat produced:

$$\frac{E_{primary,\ heat}}{E_{final,\ heat}} = \frac{E_{input\ for\ heat}}{HEAT_{available}}$$

with

$$\begin{aligned} E_{input\ for\ heat} = {} & E_{input\ main\ heat\ plants} + E_{input\ main\ CHP\ plant,\ heat} + \\ & E_{input\ auto\ heat\ plants} + E_{input\ auto\ CHP\ plant,\ heat} + \\ & ELE_{input\ heat\ pumps} + ELE_{input\ boilers} \end{aligned}$$

Where for both main activity plant and auto producers

$$E_{input\ CHP\ plant,\ heat} = E_{input\ CHP\ plant} * \frac{HEAT_{output\ CHP\ plants}}{E_{output\ CHP\ plant}}$$

and

$$\begin{aligned} HEAT_{available} = {} & HEAT_{output\ main\ heat\ plants} + HEAT_{output\ main\ CHP\ plants}, + \\ & HEAT_{output\ auto\ heat\ plants} + HEAT_{output\ auto\ CHP\ plants,heat} + \\ & HEAT_{output\ biolers} + HEAT_{output\ other\ sources} + \\ & HEAT_{output\ heat\ pumps} - HEAT_{derived\ for\ ele\ prod} \end{aligned}$$

2.4.3.2. *Effects*

As for the final energy decomposition, the activity effect stems from the variation of the total GVA of the industry sector. An increase in the total GVA over time would have a positive effect (i.e. increasing) on primary energy consumption (which can be understood as a higher energy consumption per unit of sectoral output).

In the same way as the final energy decomposition, the structural effect stems from the variation of the weight of each subsector output, expressed as share of the GVA. If the shares of the more energy-intensive industries increase, then the overall energy consumption will also increase.

The intensity effect at sub-sectoral and fuel level is expressed by the ratio of fuel consumption of fuel over the GVA of the subsector. An increase in the ratio results in a positive effect on the overall energy consumption.

In addition to the final energy decomposition, a fourth coefficient was added to the identity, which represents the 'transformation effect'. An increase in the ratio of primary fuel consumption to the secondary fuel would result in a higher figure for the primary energy consumption, and a decrease would cause a lower primary energy consumption. This could be the conversion efficiency of the energy sector.

2.4.3.3. *Data sources*

In terms of data requirements, this decomposition requires the same level of disaggregation by subsector as the final energy decomposition for the GVA (obtained from Eurostat dataset *nama_10_a64*). Final energy consumption (from dataset *nrg_bal_c*), in addition, requires the energy consumption breakdown by type of fuel which is always available in the Eurostat energy statistics dataset.

The mapping between the national accounts industry subsectors and the energy data subsector can be found in **annex 02**).

2.4.4. Residential energy decomposition by end use

2.4.4.1. Calculation

Different decompositions have been proposed in the literature on the residential sector. Based on available data obtained from various Eurostat datasets, the proposed identity for the residential sector decomposition analysis is the following:

$$E_{residential} = Pop * \frac{Dwelling}{Pop} * \frac{E^{corrected}_{residential}}{Dwelling} * \frac{E_{residential}}{E^{corrected}_{residential}}$$

Where:

- *Pop*: Total population (regardless of the type of dwelling occupied).
- $\frac{Dwelling}{Pop}$: Reciprocate of the average household size (in capita per dwelling).
- $E_{residential}$: Total energy consumption in the overall residential sector

$$E^{corrected}_{residential} = E^{corrected}_{space\ heating} + E^{corrected}_{space\ cooling} + E_{water\ heating} + E_{cooking} + E_{light\ and\ appliances} + E_{other}$$

Theoretical energy consumption that would have occurred if the number of degree days (both heating and cooling) was the same as for the reference year.

- $E^{corrected}_{space\ heating} = \frac{E_{space\ heating}}{HDD_{norm}}$: Corrected energy consumption for space heating
- $E^{corrected}_{space\ cooling} = \frac{E_{space\ cooling}}{CDD_{norm}}$: Corrected energy consumption for space cooling
- $E_{water\ heating}$: Energy consumption for water heating
- $E_{cooking}$: Energy consumption for cooking
- $E_{light\ and\ appliances}$: Energy consumption for light and electrical appliances
- E_{other}: Other residential energy consumption
- $HDD_{norm} = \frac{HDD_{year}}{HDD_{average}}$: Normalised heating degree days of the year over the average (entire time series)
- $CDD_{norm} = \frac{CDD_{year}}{CDD_{average}}$: Normalised cooling degree days of the year over the average (entire time series)

2.4.4.2. Effects

The first effect evident here is demographic: an increase in overall population would result in an increase in residential sector energy consumption.

The second effect corresponds to the reversed household occupancy: as less people are living in a single household, energy consumption is assumed to increase, due to the economy of scale in more densely occupied households.

The third effect considered in the decomposition is the temperature-corrected energy consumption per dwelling.

It is important to note here that some significant simplifications or assumptions were made to allow calculation based on the available data:

- The number of dwellings is not the most appropriate indicator for heating consumption. The dwelling surface would be a better choice, the reason being that the average surface per household may change over the period.
- The number of appliances per dwelling would be a better activity indicator for appliance consumption.

Finally, the fourth effect corresponds to weather correction. This calculation is based on the actual energy consumption in the residential sector over the climate-corrected energy consumption.

2.4.4.3. Data sources

The end-use data were extracted from Eurostat's disaggregated final energy consumption in households dataset (*nrg_d_hhq*). When disaggregated data were not available, the total energy consumption in the residential sector was obtained from Eurostat's complete energy balance (*nrg_bal_c*).

The population data were extracted from the Eurostat demographic balance dataset (*demo_gind*).

The average household size was obtained from the Eurostat EU-SILC survey (*ilc_lvph01*). The figures are within two and three persons per household on average for all European countries.

Both the heating degree days (HDD) and cooling degree days (CDD) were obtained from the Eurostat heating and cooling degree days dataset (*nrg_chdd_a*).

In many cases the breakdown in end-use energy consumption data only starts in 2015. In the case of colder countries, energy consumption for space cooling use is often not reported at all (see **annex 03** for further details).

2.4.5. Transport energy decomposition based on traffic

2.4.5.1. Calculation

Transport usually comprises two distinct purposes: passenger transport and freight transport. They are each subdivided into different modes, e.g. road, air, waterways, and rail, which can then be again subdivided e.g. by type of vehicle.

At the current level of Eurostat's disaggregation of energy data, the only breakdown for energy consumption available in transport is a split-by-mode: road, water (national) and air (national). International air and maritime transport are also available separately, due to their different transport in GHG emissions accounting.

Decomposition of transport by purpose, mode and vehicle type is already available in Eurostat's dataset, but it cannot be fully used without further information on energy consumption. It is reported in three different units, depending on the purpose: passenger-kilometre (for passenger transport), ton-kilometre (for freight transport) and vehicle-kilometre (for both).

Consequently, the only decomposition identity that can be proposed currently is:

$$E_{transport} = VKM * \sum_i \frac{VKM_i}{VKM} * \frac{E_i}{VKM_i}$$

Where:

- VKM: total number of vehicle-kilometres
- VKM_i: Vehicle-kilometre per mode
- E_i: Energy consumption per transport mode

For energy statistics, the decomposition based on vehicle-kilometres was the only one that seemed feasible at the current level of detail. Hopefully, it will soon be replaced when data broken down by purpose become available. It is important to note here the main limitations of this decomposition:

Firstly, air is excluded because no domestic traffic-only dataset was identified. Likewise, water transport traffic (VKM) only covers inland waterways, and not maritime transport since this information could not be retrieved.

Secondly, and more importantly, the decomposition by vehicle-kilometres cannot carry out an in-depth analysis of the structural change, as the results can be complex to interpret:

- Consumption per VKM varies completely from one type of vehicle to the next.
- Also, the purpose of transport being to move goods or passenger, not the vehicle themselves, the $\frac{E_i}{VKM_i}$ is not the most relevant to represent the intensity effect.

2.4.5.2. Effects

In this decomposition, the activity effect is represented by the total traffic, or VKM. An increase in total traffic would result in a higher energy consumption.

The intensity effect is represented by the energy per vehicle-kilometre. An increase in the energy consumption per unit of VKM would result in a higher overall energy consumption of the sector.

The structural effect represents the variation of the respective weight of each of the transport mode within the total traffic. An increase in the share of higher consumption sectors would result in a higher energy consumption.

2.4.5.3. Data sources

The total energy consumption by mode was obtained from Eurostat's complete energy balance dataset (*nrg_bal_c*).

Transport traffic data were obtained from Eurostat's transport statistics (road, railway and inland waterways). These three modes of transport are available in these datasets: 'Motor vehicle movements on national territory' (*road_tf_vehmov*), 'Train movements' (*rail_tf_trainmv*), 'Vessel traffic' (*iww_tf_vetf*). Air traffic transport is currently not available in Eurostat's database.

As explained previously, road and rail traffic (VKM) and energy consumption include both transport of goods and passengers.

Water traffic only includes transport of goods on inland waterways, while energy consumption also covers maritime transport of passenger and goods. It is assumed that inland waterways represent most types of inland water transport. Additionally, the inland waterway dataset appears to be very incomplete, hence the decomposition could only be performed for a limited number of countries.

These differences in coverage may be of secondary importance given the decomposition chosen, since road traffic often covers almost all of the total transport, and most of the sector's energy consumption.

The mapping between Eurostat datasets '*Complete energy balances' (nrg_bal_c)* and the transport traffic datasets (*road_tf_vehmov, rail_tf_trainmv, iww_tf_vetf*) are presented in the **annex 04**.

3. Analysis of the results

3.1. Total economy final energy decomposition based on employment

3.1.1. Decomposition analysis for EU as a whole

The analysis for the whole economy decomposition was carried out at the highest level in terms of sector

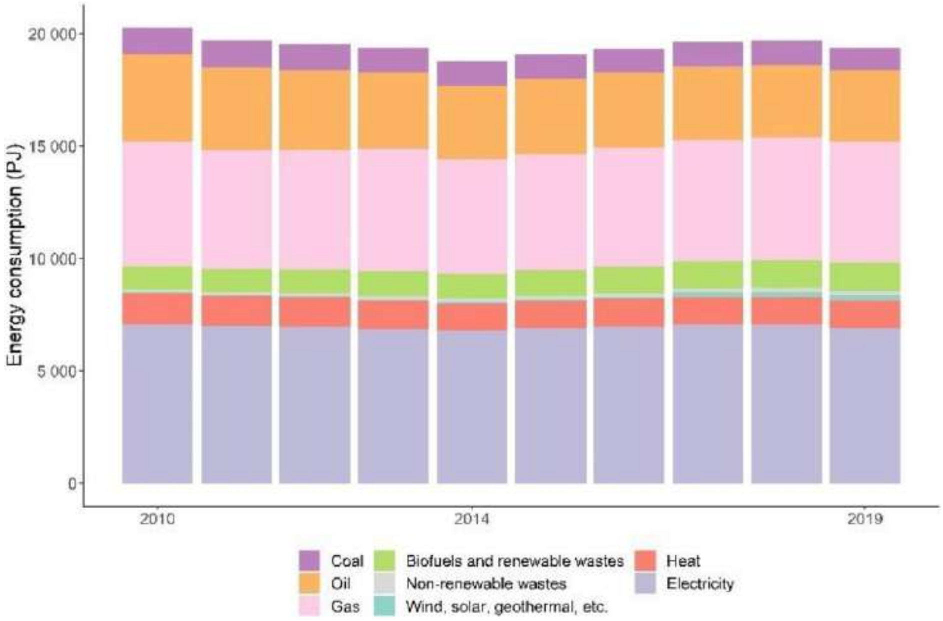

Fig. 2. Overall economy energy consumption by fuel, 2011–2019 *(Source: Eurostat (nrg_bal_c)).*

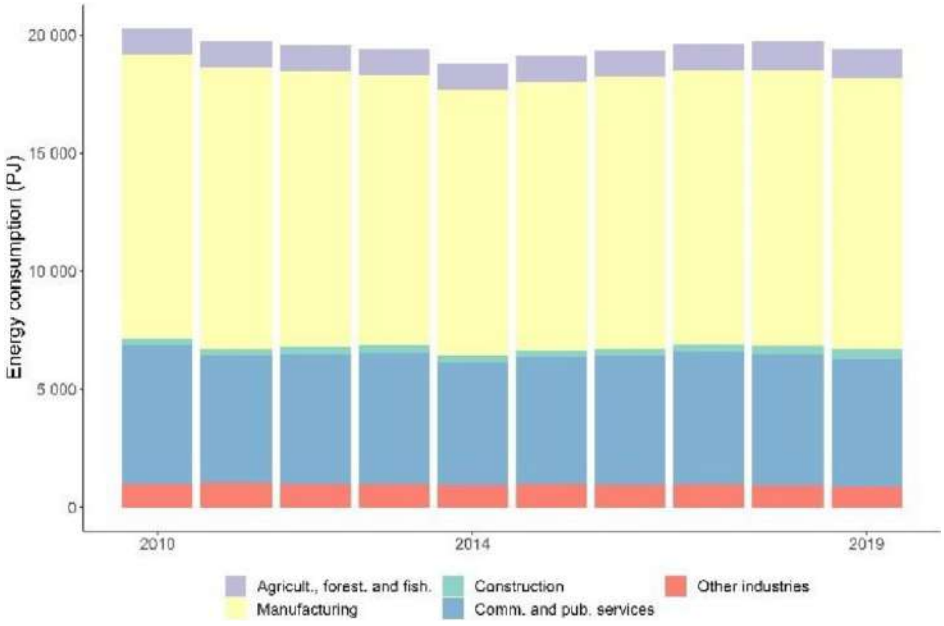

Fig. 3. Overall economy energy consumption by subsector, 2010–2019 *(Source: Eurostat (nama_10_a10_e)).*

(with only five sectors) and therefore data were complete for every EU-27 country (meaning that in all cases employment information was available when energy consumption was, and vice versa).

The EU-27 manufacturing industry sector accounted for almost 28% of the total final energy consumption in 2019, construction for 1%, commercial and public services for 13%, and agriculture, forestry and fishing for 3% (Fig. 1). The challenge when trying to cover all of these sectors simultaneously is to find a common indicator for the level of activity. In the decomposition below, the number of employees is used as a proxy for the level of activity, assuming that the trend in employment and shifts in each sector share represent the econ-

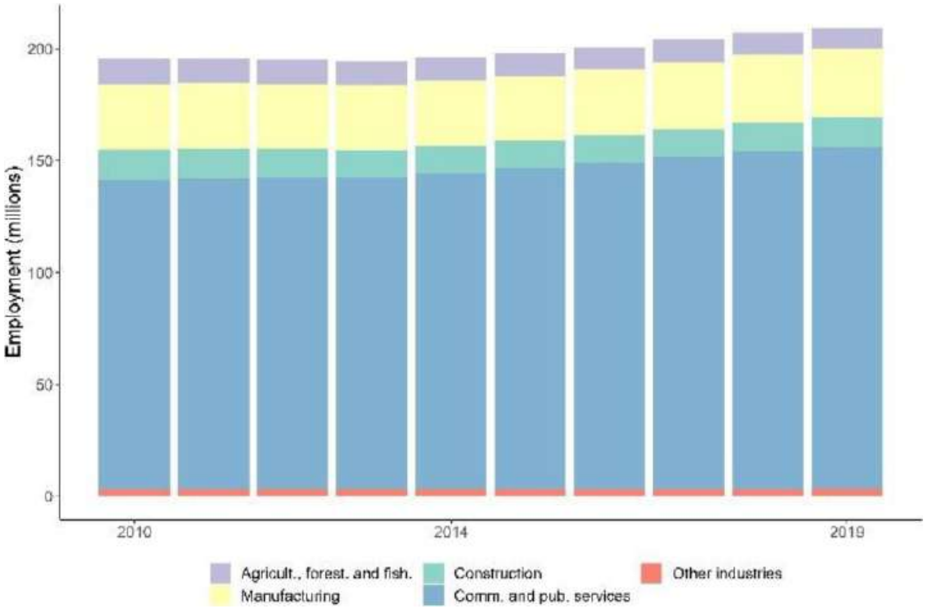

Fig. 4. Overall economy employment by subsector, 2010–2019 *(Source: Eurostat (nama_10_a10_e))*.

omy activity well enough. Additional information on data limitations and the use of the GVA or employment is provided in the data limitations section.

At the level of the economy as a whole, electricity is the first source of final energy consumption, maintaining a consistent share of 35% throughout the period analysed. This is followed by natural gas, oil and coal which decreased, while biofuels and wastes increased. Heat consumption stands out as the least consumed energy source, experiencing a decline over the same timeframe.

Final energy consumption of the different sectors of the EU-27's industry decreased from 20 271 PJ in 2010 to 18 778 PJ in 2014 before growing back to 19 707 PJ in 2018, and then dropping again to 19 397 PJ in 2019. Most of the energy consumption took place in the manufacturing industry, which remained stable over the period (59%).

The total active population in the EU-27 steadily increased from 196 million in 2010 to 209 million in 2019. Although the tertiary sector represents a relatively small share of total energy consumption, it includes the vast majority of the EU's workforce and is growing in shares (from 71% to 73%).

Over the decade, EU-27's energy consumption was driven upward (+1 330 PJ) by the increase in overall activity. However, this activity effect was counterbalanced, firstly by a reduction in energy intensity, expressed in energy consumption per employee (−1 760 PJ), and secondly, to a lesser extent, by structural changes in the economy towards less energy-intensive sectors, namely commercial and public services (−456 PJ).

Without the changes in energy intensity (Fig. 5), i.e. if the energy consumption per employee had remained the same as in 2010 while the total size of the workforce fluctuated as it did in reality, the energy consumption in the overall economy would have reached 21 157 PJ in 2019, which is 9% higher than the actual energy consumption and also higher than the 2010 level. It should be noted that the intensity effect has been a decreasing effect for the entire period studied, which means that the energy consumption per employee was at its highest in 2010.

By applying the decomposition analysis, it shows that while the increase in activity within the EU had a positive increase on energy consumption, this effect was more than offset by the increase in energy efficiency. This underscores that improving energy efficiency is crucial in mitigating the impact of increased economic activity on overall energy consumption.

3.1.2. *Comparison of the EU 27 Member States*

The comparison between the EU-27 countries again shows significantly large variations in energy intensities, ranging from about 34 TJ per thousand employees in Malta in 2019 to almost 255 TJ per thousand employees in Finland the same year. Every EU-27 country shows a decrease in energy consumption per employee between 2010 and 2019, except for Spain, Latvia and Bulgaria.

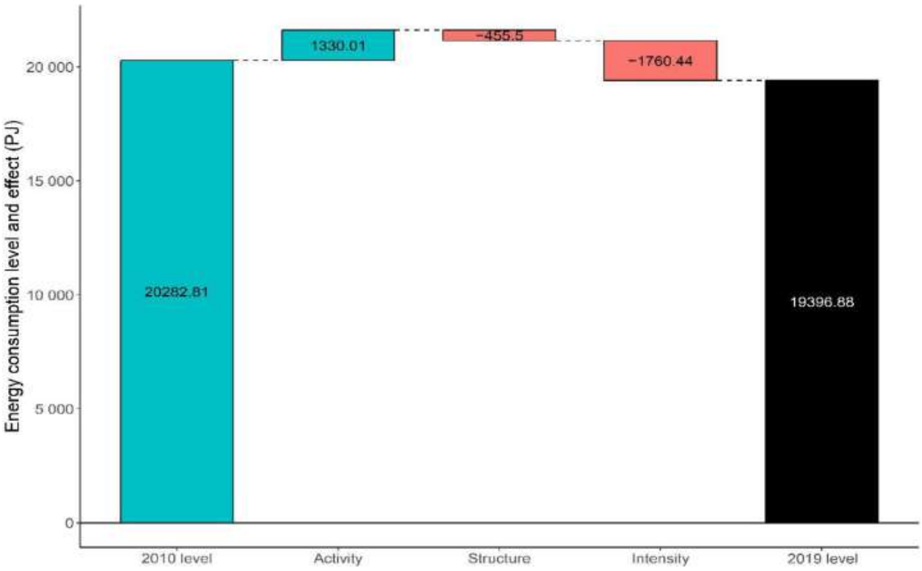

Fig. 5. Decomposition analysis of energy consumption for the overall economy, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_a10_e)).*

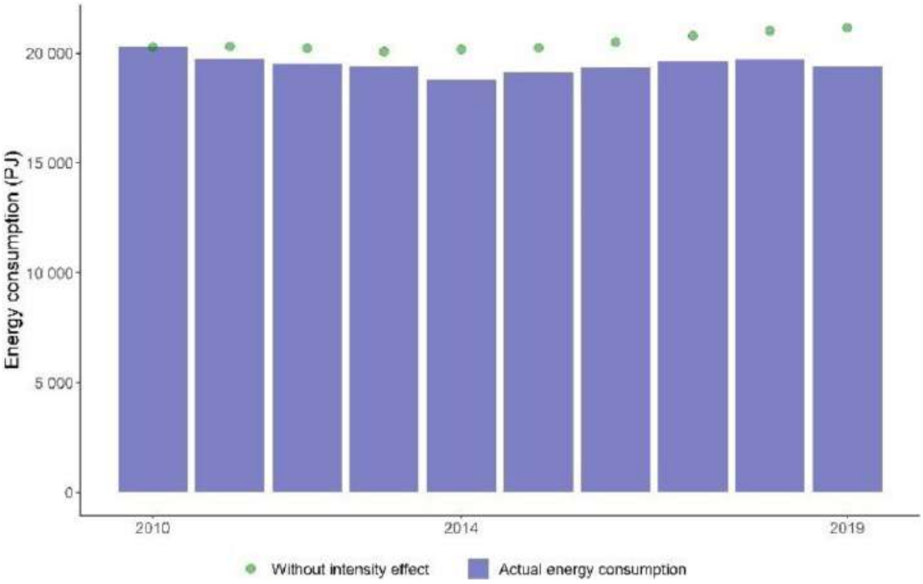

Fig. 6. Actual vs theoretical energy consumption in the economy, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_a10_e)).*

3.2. Industry final energy consumption decomposition based on added value

Czechia stands out as a compelling case study for analysing industrial final energy consumption, owing to its activity trends and significant structural shifts. The synergy between these two factors underscores the critical role of energy intensity within the national industrial landscape. The final energy consumption analysed in this section covers consumption of energy available ‘at the gate’, i.e. without considering types of energy or the transformation efficiency and distribution losses. This focuses on the sectors where the gross value added (GVA) can be used as an indicator for the activity level, i.e. as a proxy for the trend in the overall activity of the sector and to assess any shifts between the shares of

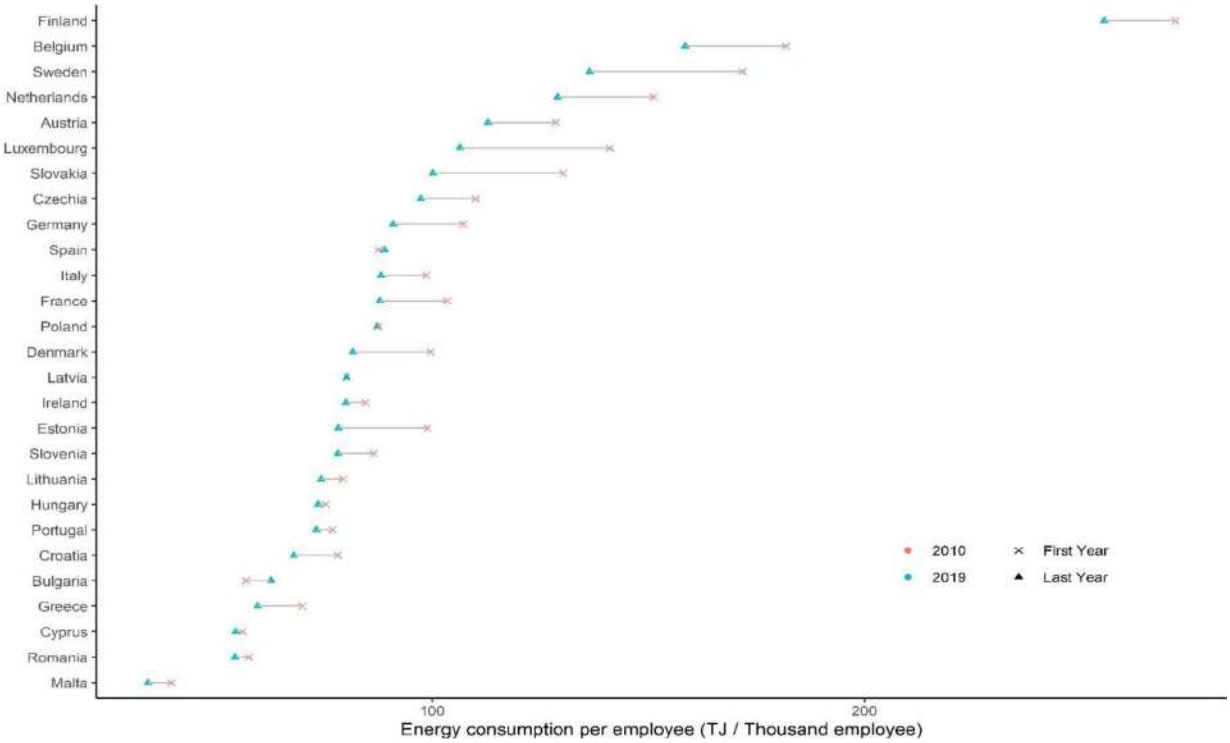

Fig. 7. Variations in energy consumption per employee in the total economy, EU-27, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_a10_e)).*

each subsector. The subsectors covered here include all manufacturing industries and the construction sectors.

3.2.1. *Decomposition analysis for Czechia for the period 2010–2019*

By applying the decomposition analysis, the slight decrease in energy consumption observed between 2010 and 2019 is due to the combined effect of several factors. The activity (quantified by the industry sector's GVA), which strongly increased between the two years, caused a significant rise in energy consumption (+83 PJ). Simultaneously, the structural transformation within the industry sector nearly entirely offset the increase through a substantial decrease of 86 PJ. This reduction can be attributed to the diminishing significance of energy-intensive sectors, specifically basic metals, coke and refined petroleum products, as well as chemical and petrochemical industries. Finally, the overall energy intensity in the sector decreased, leading to a light reduction (−14 PJ) in energy consumption.

From the results obtained, it can be estimated that without improvements in energy efficiency, i.e. if the energy required per unit of economic output had remained at 2010 levels while the total activity (quantified by the value added) of the sector fluctuated as it did in reality, total energy consumption in the industry sector would have reached 338 PJ in 2020, a figure 5% higher than the actual consumption figure.

Despite the stability or marginal decline in energy consumption, the industry's value added experienced a noteworthy increase over the period. While one might assume that energy intensity decreased due to enhanced energy efficiency, the analysis suggests this is not the main factor.

Indeed, as indicated earlier, the relative stability of energy consumption during the growth of economic activity results from a structural shift, replacing energy-intensive industries with those that are less consumptive yet more value-added. Energy efficiency, in this context, played a limited role during this period.

3.2.2. *Comparison of the results between Czechia and EU-27*

Overall energy intensity in Czechia was higher than the EU-27 average in 2010, at 7 MJ per euro of GVA, then it slowly decreased under the EU-27 average in 2019 at around 5 PJ. At the subsector level, Czechia is close in all but the mining and quarrying sector, where the intensity is above the EU-27 average, and for coke and refined petroleum products, where intensity peaked

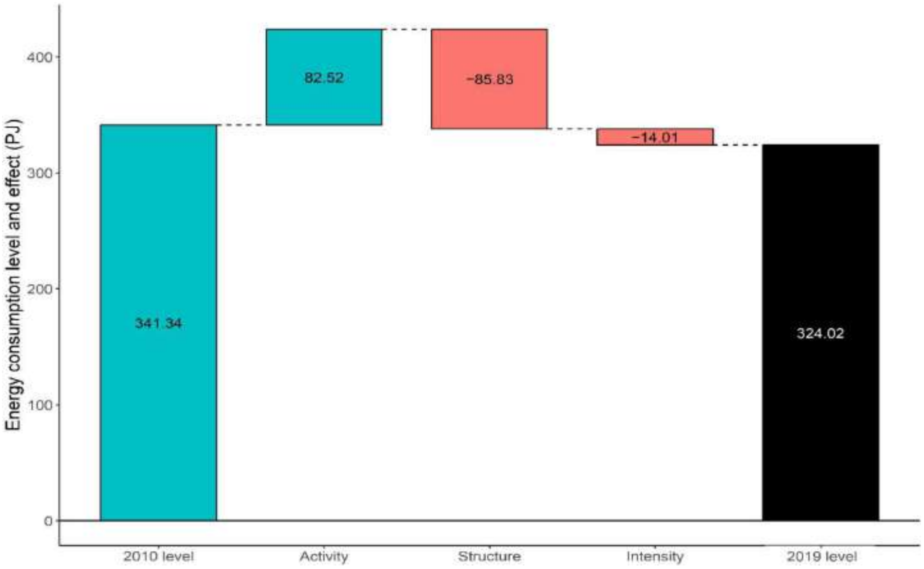

Fig. 8. Decomposition analysis of energy consumption of the industry, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_64)).*

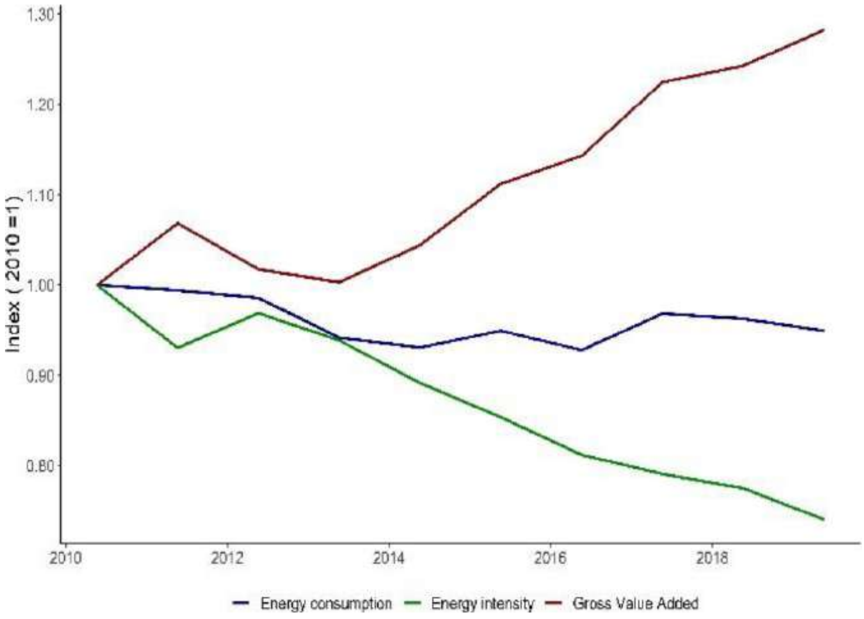

Fig. 9. Energy consumption, intensity, and gross value added of manufacturing industry (base year 2010 = 1); 2010–2019 *(Source: Eurostat datasets (nrg_bal_c and nama_10_a10_e)).*

during 2018–2019 and became the highest of any EU-27 country, due to very low added value figures.

3.2.3. Comparison of two periods to assess crisis impacts

In determining the reference years for a decomposition analysis, important consideration is given to the initial and concluding years. The following figures (i.e. the waterfall charts) describe the significance of this choice. These charts start with the first reference year and end with the last year of the period studied. Opting for a reference year affected by a crisis as the starting or ending point introduces complexities in the analysis, particularly when a long period is assessed.

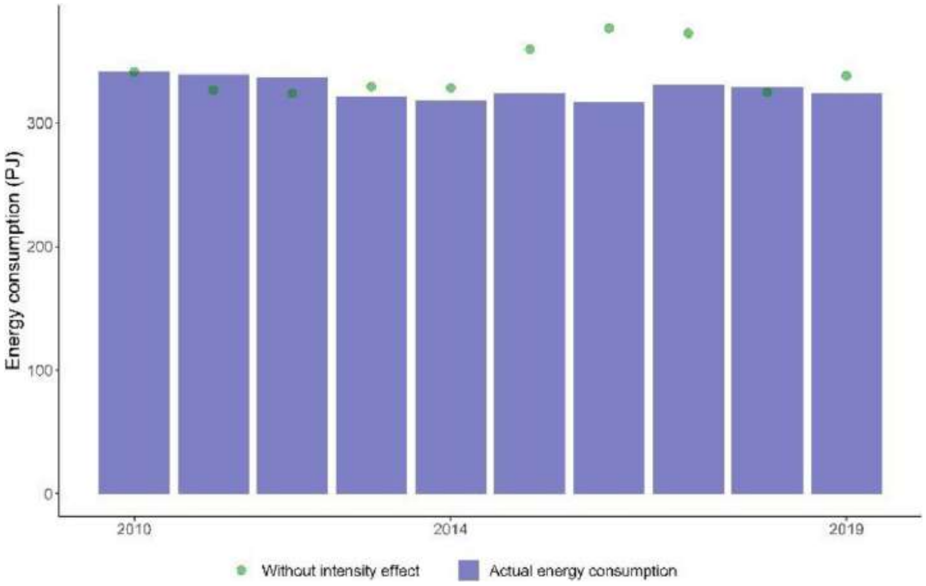

Fig. 10. Actual vs theoretical energy consumption in the industry, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_a64)).*

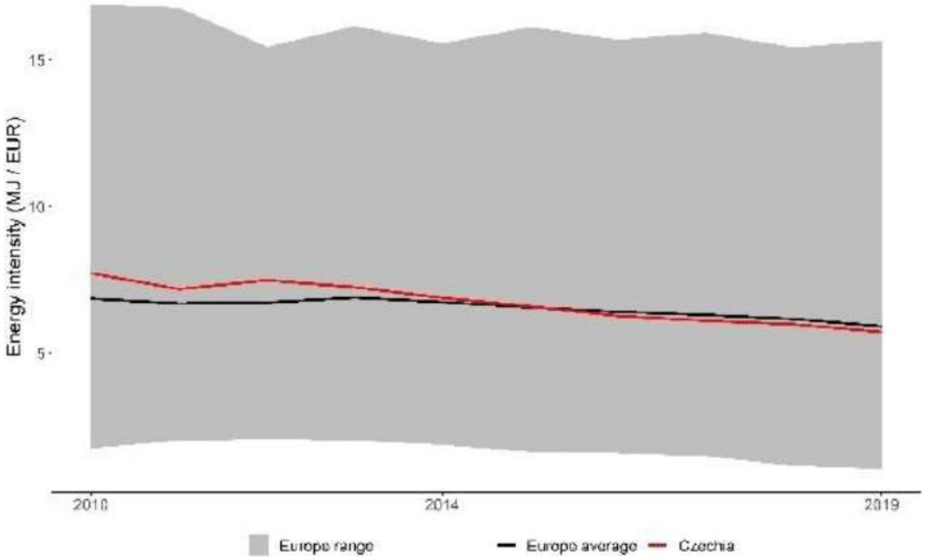

Fig. 11. Total industry energy intensity compared to the EU-27 average, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_a64)).*

However, it is just as interesting to focus on the repercussions of a crisis. Evaluating these two periods can reveal the effects attributable to the COVID-19 pandemic or the energy crisis, which manifest themselves in diverse ways depending on the country and sector of activity. For example, the industrial sector has undergone changes during this period in terms of GVA created, as well at the structural level. Some subsectors have experienced production slowdowns or continuity issues, depending on the policies of each country. These changes created artificial changes in activity and in structure.

A decomposition analysis was applied to Slovenia for the period 2010–2019 versus 2019–2022 to facilitate a comparative assessment of the results, albeit to a lesser extent, as it was not initially within the scope of our

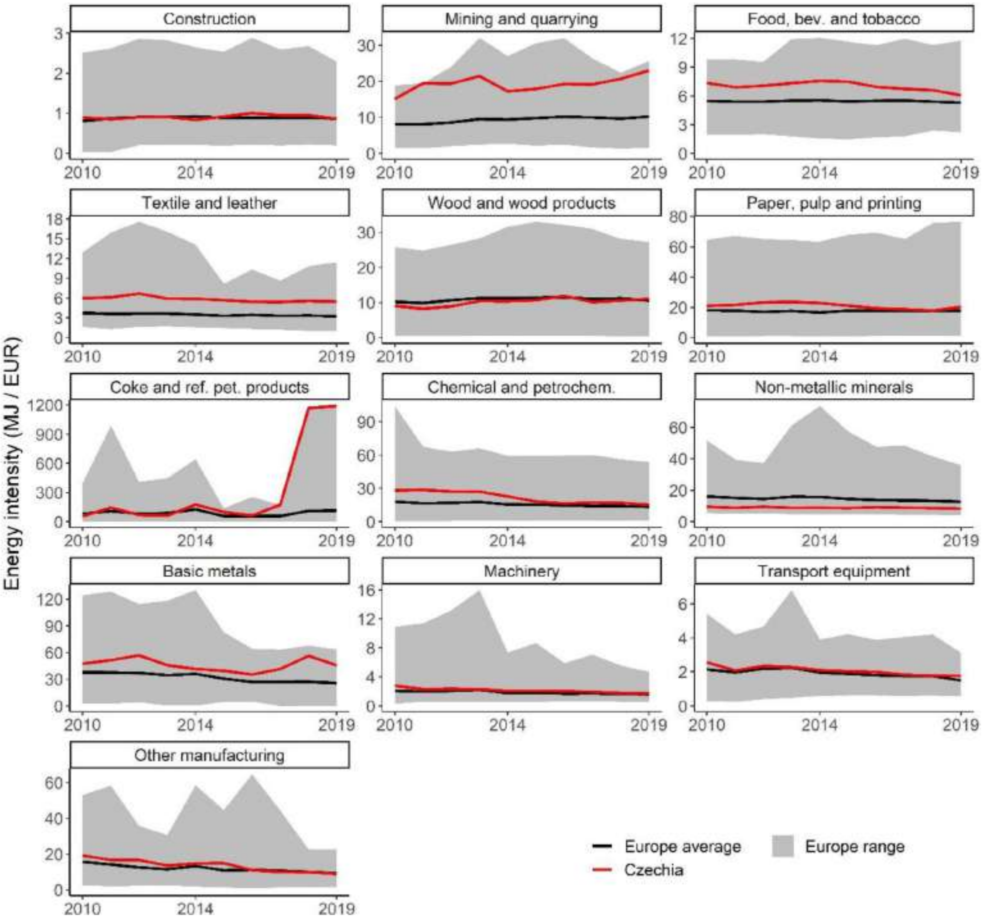

Fig. 12. Energy intensity in industry compared to the EU-27 average, 2010–2019 *(Source: Artemis based on Eurostat datasets (nrg_bal_c and nama_10_a64)).*

research. This also illustrates the rationale for choosing the period 2010–2019 for this article.

Slovenia experienced a notable expansion of its economic activity between 2010 and 2019, which resulted in an increase in energy consumption. However, energy intensity was reduced at the same time, effectively offsetting the increase in consumption. It can be concluded that there has been no significant structural change over this period.

However, between 2019 and 2022, which included the pandemic and lockdowns, structural change emerged as the main driver of changes in energy consumption, overtaking the influence of economic activity. This might appear counter-intuitive, given that the lockdowns restricted access to certain production facilities. Despite the fact that our model takes into account the value added created by activity, a structural shift towards industries that are less energy-intensive but equally productive in terms of value may be erroneously interpreted as an energy efficiency gain.

3.3. *Residential decomposition by end use*

The Netherlands was selected as a case study to clarify the decomposition analysis of residential energy consumption in light of its relevance. This selection was driven by two primary considerations. Firstly, several EU-27 Member States started to measure their energy consumption by end use only from reference year 2015. Secondly, the trends observed within this country facilitate a straightforward and informative decomposition analysis.

The application of the decomposition analysis reveals that the increase in the Netherlands' overall population between 2010 and 2019 had a slightly positive effect on energy consumption (+19 PJ), which was further emphasised by the impact of dwelling occupancy (+21 PJ).

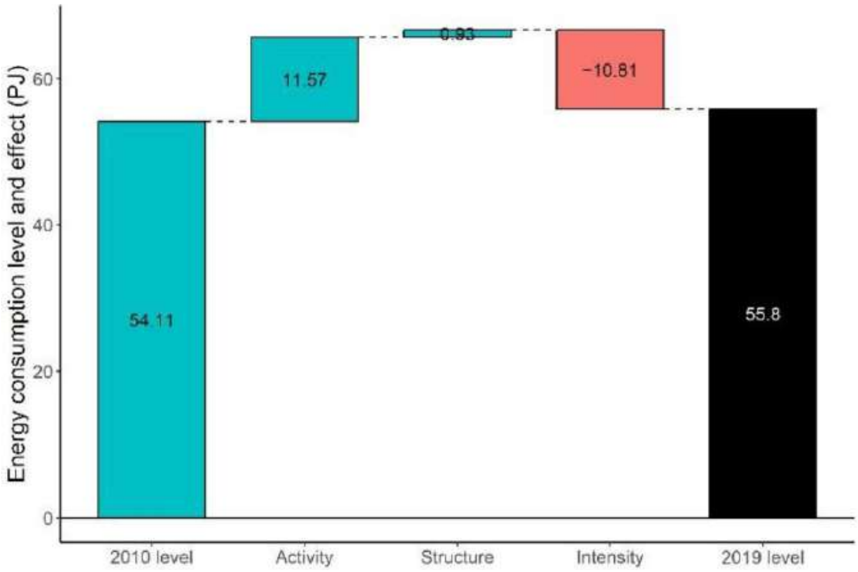

Fig. 13. Decomposition analysis of energy consumption of the industry, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_64)).*

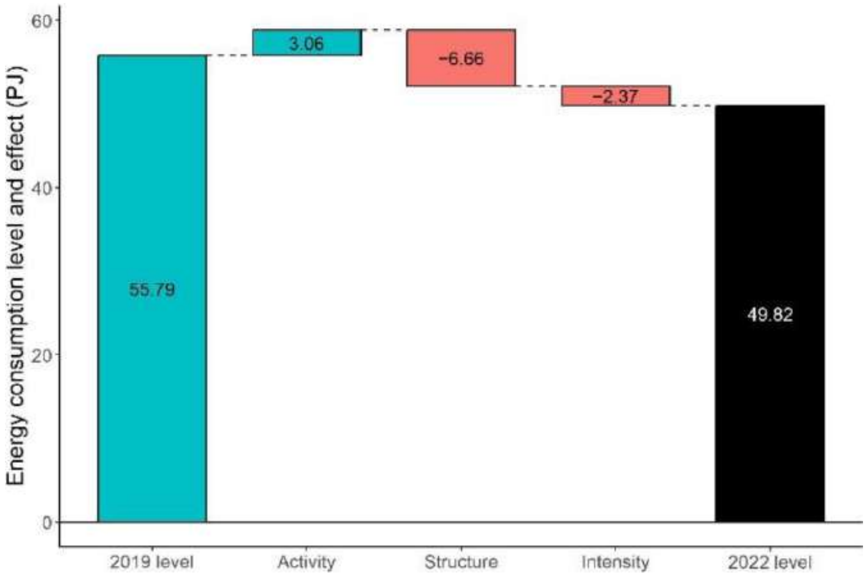

Fig. 14. Decomposition analysis of energy consumption of the industry, 2019–2022 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_64)).*

The decrease in energy consumption per dwelling had a strong decreasing effect (−90 PJ). Finally, the weather had a significant decreasing effect (−84 PJ).

The marked reduction in energy consumption in the residential sector can be primarily attributable to two factors: intensity and meteorological conditions. The temperatures, which are beyond control, do not allow for a sustainable reduction in consumption, especially with the climate crisis increasing temperature volatility. However, while temperatures played a role in the use of space heating, they are not the sole factor; energy intensity also contributed to a 50% reduction. This reduction can come from a variety of sources, including improved practices (turning off the heating when not needed, dressing warmly indoors), as well as thermal renovation efforts (changing heating systems, reinforc-

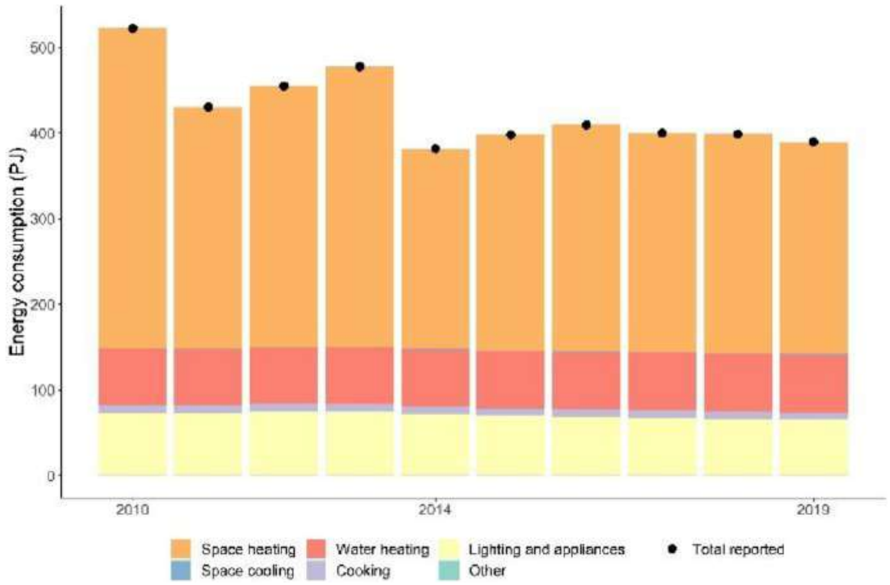

Fig. 15. Residential energy consumption by end-use, 2010–2019 *(Source: Eurostat datasets (nrg_bal_c and nrg_d_hhq))*.

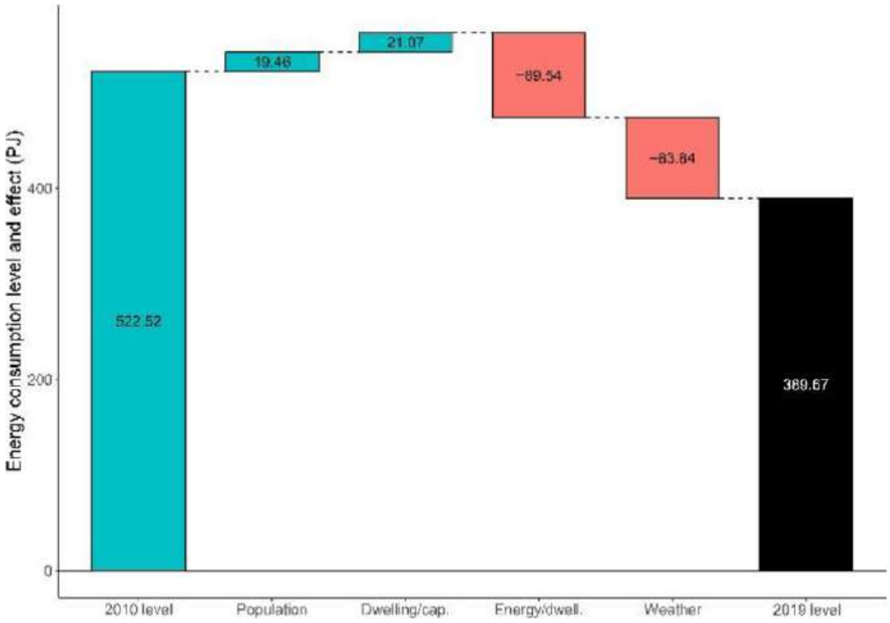

Fig. 16. Decomposition analysis of energy consumption of the residential sector, 2010–2019 *(Source: Artemis, based on Eurostat datasets (nrg_d_hhq, demo_gind, ilc_lvph01, nrg_chdd_a))*.

ing thermal insulation, etc.) which might have an even wider effect.

3.4. Transport energy decomposition based on traffic

For quite a number of countries, data for one mode of transport (mainly inland waterways) are missing and gaps in the time series can be observed. Additional information on the different limitations to apply the energy decomposition on the transport sector is described under the Section 4.3 'Missing energy consumption and traffic data in the transport sector'. This is the case of France, for which no data at all are available for the reference years 2010 and 2011 on transport traffic and,

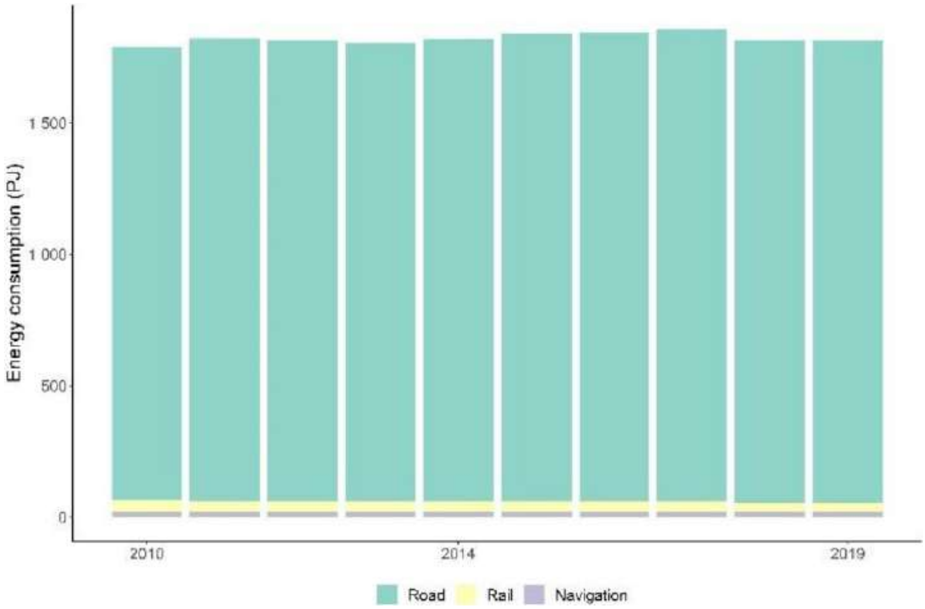

Fig. 17. Transport energy consumption by mode, 2010–2019 *(Source: Eurostat dataset (nrg_bal_c))*.

in addition, road traffic is only available from 2013 onwards. As road traffic represents at least 97% of the total traffic, the decomposition analysis has been performed for the period 2013–2019.

Energy consumption in the French transport sector oscillated between 1 804 PJ and 1 856 PJ between 2013 and 2019, staying relatively stable. During the same period, road traffic steadily increased from 587 billion VKM to 645 billion VKM.

Between 2013 and 2019, the slight increase in traffic caused an increase in energy consumption of about 164 PJ, which was almost offset by a decrease in energy intensity, causing a reduction of about 150 PJ in energy consumption. Due to the absence of variation in the share of the different transport modes, the structural effect was deemed insignificant.

In other words, while activity has increased, leading to a rise in consumption, this has been completely offset by a reduction in intensity. Given that road transport represents almost all traffic, this reduction has been brought about by improved practices (such as reducing average speed, better maintenance, etc.) and/or innovations in the road vehicle fleet (replacing old vehicles with newer, more energy-efficient ones).

4. Data limitations and limitations of the analysis

The existence of missing data represents a significant limitation of LMDI applications (as it would for any other decomposition methods). To be able to perform the calculation, data on both energy consumption and activity data are required. Consequently, sectors and subsectors that did not have both of these data points available were excluded from the analysis, resulting in an analysis performed on a subset of the total sector. This situation has particularly affected a few of the smaller countries where sectors included a small number of actors, resulting in confidentiality issues.

4.1. Missing final energy consumption and GVA data in manufacturing industries and construction

Performing energy consumption decomposition requires access to data on both energy consumption by subsector, and the activity, which in the case of industry, is represented by the GVA. For most countries up until 2021, the data for all subsectors were available. However, when the data were extracted, a certain number of countries had incomplete GVA data as illustrated in Fig. 20. Moreover, official data are generally available only two to three years after the reference year. For instance, in the figure below, we can observe that for data extracted in February 2024, almost no data for 2022 are available.

It should be noted that in Fig. 20 and similar ones that follow, a subsector is counted as missing if either the energy consumption is reported and not the activity, or vice versa. In this specific example, the two countries showing a high number of subsectors missing across

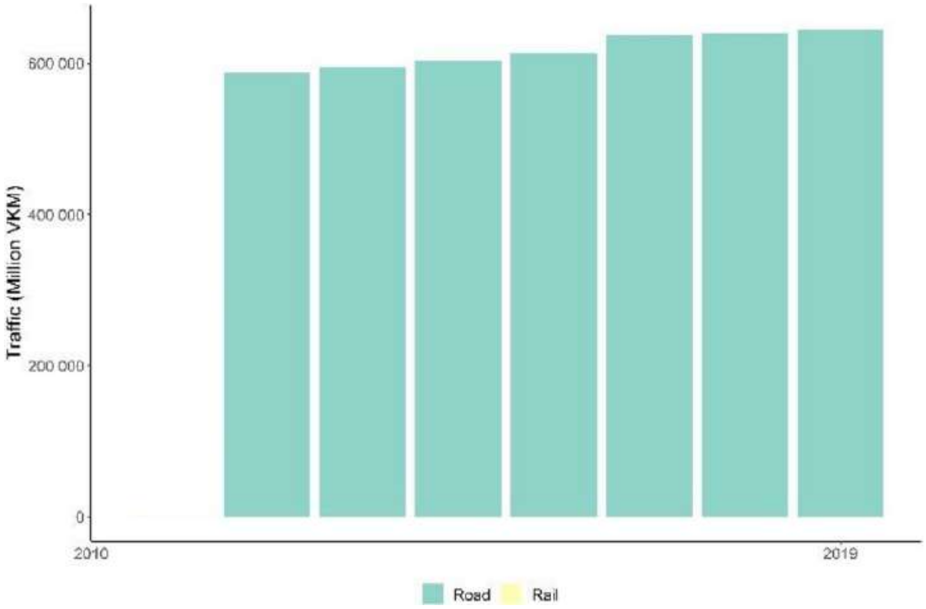

Fig. 18. Transport traffic by mode, 2010–2019 *(Source: Eurostat datasets (rail_tf_trainmv, road_tf_vehmov, iww_tf_vetf))*.

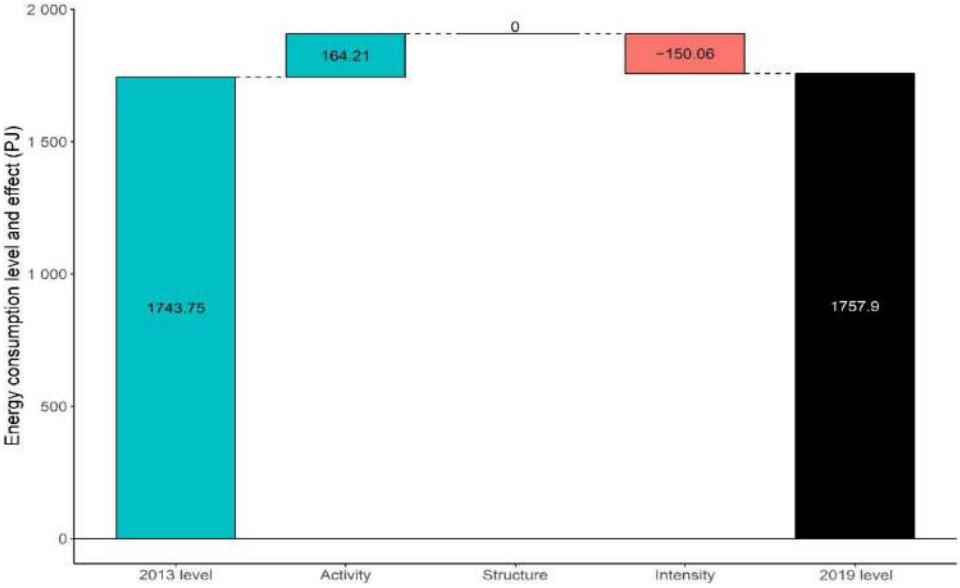

Fig. 19. Decomposition analysis of energy consumption of the transport sector, 2013–2019 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c, rail_tf_trainmv, road_tf_vehmov, iww_tf_vetf))*.

the entire time series appear to both be quite small. It is therefore likely that the energy consumption was too small to appear in the reporting unit, explaining the apparent lack of coverage. Any missing information usually occurs in small countries, where for certain sectors, a limited number of companies are present, causing issues of confidentiality, particularly for GVA data.

Additionally, it is important to point out that data quality was not part of the initial project.

4.2. Missing disaggregated energy consumption data in the residential sector

For residential sector decomposition, the energy consumption data disaggregated by end uses were often

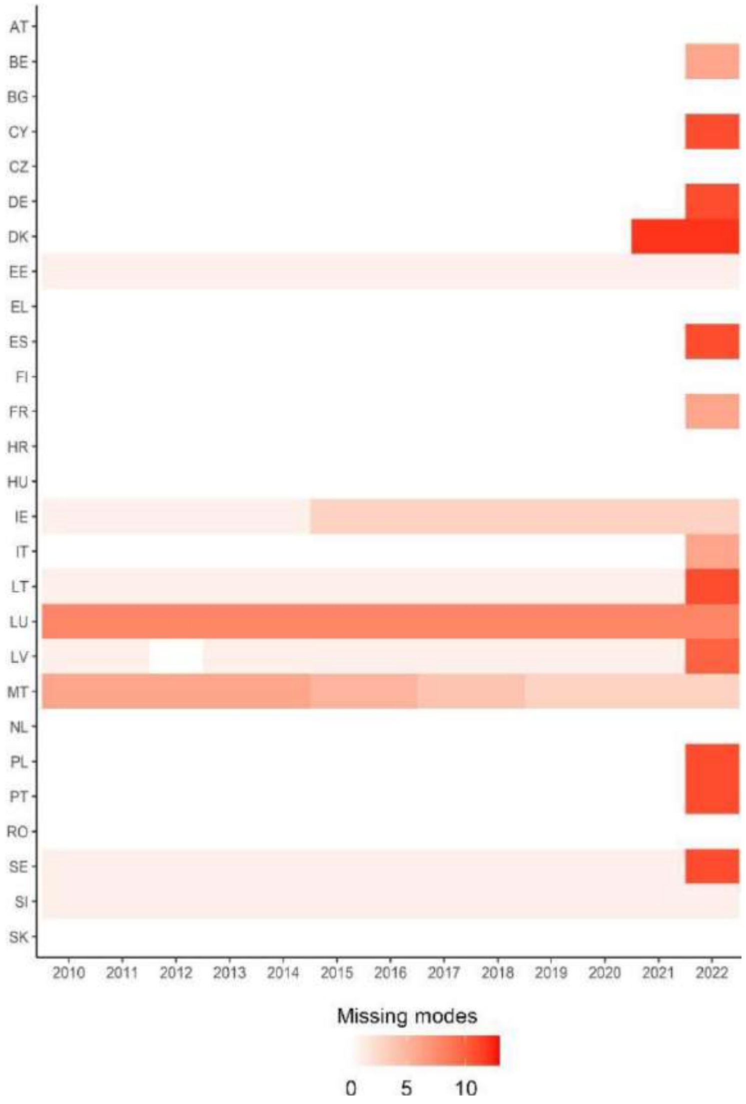

Fig. 20. Missing subsectors in the manufacturing industry of the EU-27 countries *(Source: Artemis, based on Eurostat datasets (nrg_bal_c and nama_10_a64))*.

available only from 2015 onwards, which mainly impacted the climate correction in the analysis. For these countries, the correction was only applied on the available years. Moreover, 2022 data are unavailable whatever the country.

4.3. *Missing energy consumption and traffic data in the transport sector*

Traffic information is missing for at least one mode of transport in most countries, meaning that in many cases, energy consumption is reported but not the corresponding traffic information (in VKM). Moreover, the time series presents several gaps, which often complicates the search to find a pair of years with relatively complete information.

4.4. *Other data issues*

Although an effort was made to stay as close as possible to the original data, in some instances corrections had to be applied in order to make the calculations possible, and to avoid making the comparison among countries unreadable due to some figures that were obviously out of the range.

This was the case notably with the GVA in the coke and refined petroleum products sector, where for Aus-

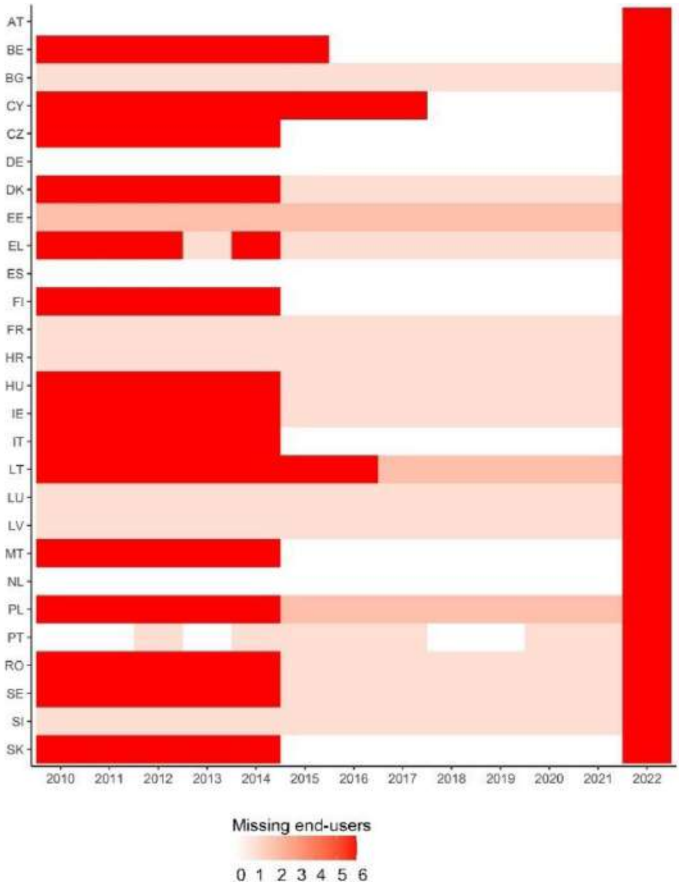

Fig. 21. Missing end-use in the residential sector of the EU-27 countries, 2010–2022 *(Source: Artemis, based on Eurostat datasets (nrg_d_hhq, demo_gind, ilc_lvph01, nrg_chdd_a)).*

tria, the figure had to be multiplied once by 10 (2013) and once by a 100 (2014) to be in line with the rest of the time series. Due to the limitations in the methodology applied, it was not possible to treat cases where the GVA turned negative for a year. When this occurred, it had to be corrected to be positive. This was the case for Spain (2020), Sweden (2020), Italy (2014 and 2020), Portugal (2020), Latvia (2020) and Bulgaria (2014 and 2020). It also happened for the basic metals sector in Latvia (2013 and 2014).

Another correction was applied to the road traffic data for Bulgaria, where the 2010 figure had to be manually entered because the reported one was out of range.

4.5. Limitations in the industry primary energy consumption decomposition based on value added

Primary energy decomposition really highlights the variation in the electricity mix (and similarly for commercial heat). The methodology used to calculate the primary energy equivalent is also of major importance. It is important to consider here that several assumptions were made to simplify the calculation:

- The Combined Heat and Power (CHP) inputs were divided between input for heat and for electricity based on the ratio of the total energy output. However, this is an oversimplification and somewhat misrepresentative, since transformation of fuel into heat can reach an efficiency of up to 90%, while conversion of heat to electricity will not reach more than 50%. For this reason, overall efficiency of a CHP plant highly depends on the ratio of output between heat and electricity, and the closer to a heat-only output it is, the higher the overall efficiency.
- The inputs of heat to electricity and of electricity to heat (e.g. in boilers and heat pumps) is included in a first-degree equation, i.e. the energy input of heat or electricity is considered. A more accurate approach would require additional iterations, where

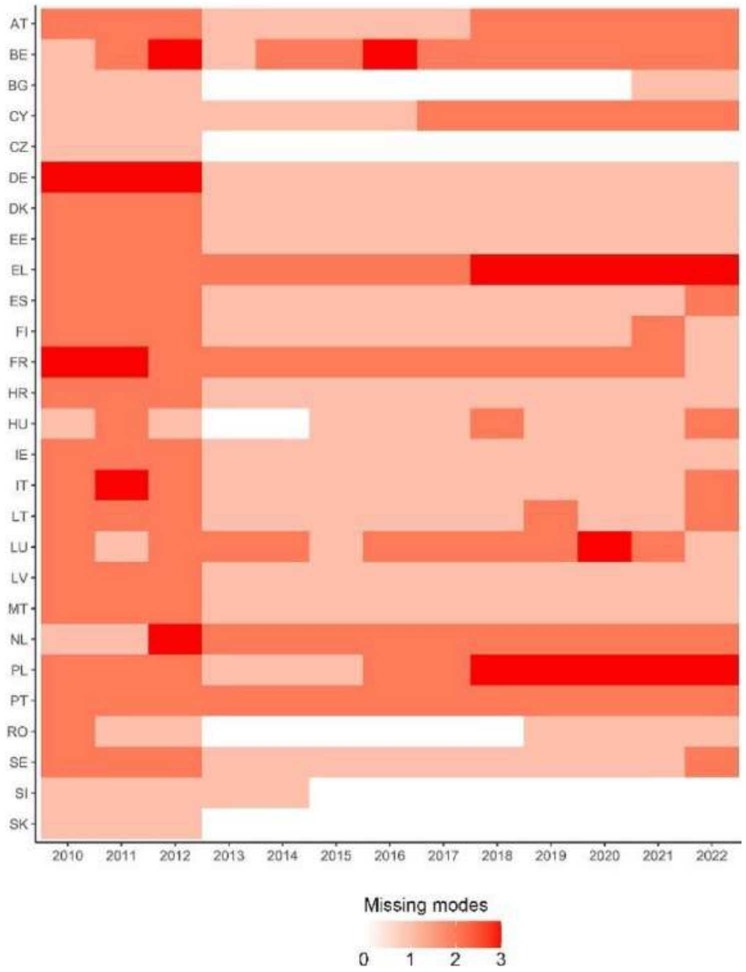

Fig. 22. Missing transport modes in the transport sector of the EU-27 countries, 2010–2022 *(Source: Artemis, based on Eurostat datasets (nrg_bal_c, rail_tf_trainmv, road_tf_vehmov, iww_tf_vetf)).*

the energy input for heat and electricity which was calculated following the first-degree approach replaces the respective figure in the equation to recalculate the energy input, and then again until the calculation converge to a constant figure.

- Similarly, the electricity imported, and corresponding energy input was not considered. All the electricity consumption is therefore assumed to have been generated within the country, or at least, at a similar conversion efficiency level.

Secondly, since the variation of the primary energy consumption is decomposed, it should be noted that the methodology applied for calculating the primary energy equivalent for electricity and heat production has a considerable impact on the effect measured. In the case of Eurostat's energy statistics, the following conventions are applied:

- For nuclear electricity, the primary energy considered is the heat input, which is back-estimated assuming an energy efficiency of 33% for the conversion, i.e. the primary energy equivalent is systematically three times higher than the electricity produced, in energy units.
- For hydro, PV and wind, the electricity produced is considered as the primary form of 'usable' energy, which is equivalent to saying that the conversion of the primary form of energy to the electricity is done with 100% efficiency.
- For geothermal and solar thermal heat and electricity, the primary heat is reported by countries, and the resulting efficiency is on average close to the following figures:
  - ∗ 10% for geothermal electricity;
  - ∗ 50% for geothermal heat;

  - ∗ 20% for solar thermal electricity;
  - ∗ 100% for solar thermal heat.

This methodology is referred to as the first practical point of measurement method and it is useful because different potential uses of the energy source can be compared, but it is not the only approach. Using the partial substitution method, electricity or heat output from renewables or nuclear sources is related to a theoretical amount of fuel that would be required to produce the same output, considering the average efficiency of thermal plants in the country or region.

A similar approach could also be applied for oil and coal products, where products (e.g. gasoline) would be related to the primary product used for their production (e.g. crude oil). This decomposition might blur the result and not yield much useful information, due in part to the following issues:

- An assumption would have to be made for allocating input to each output (i.e. considering one energy unit of any oil product, does it represent the same amount of crude oil input, irrespectively of the product and of its energy density).
- It would also put more weight on oil products in countries with refining activities, compared to countries that are importing already refined products, which may cause some issues when comparing between countries.
- Finally, it is unlikely that over the few years being studied, significant variation will appear in the primary product used for the preparation of secondary ones. Slight variation in the energy content (calorific value) can be expected, but probably not very significant, if at all.

Therefore, in the current approach, primary oil and coal products were not considered in the primary energy consumption. That is to say, the primary energy is set to be equal to the final energy consumption for these products.

4.6. Limitations of the analysis

The first and main limitation of the index decomposition analysis methodology is that the results obtained have to be understood under the prism of the initial equation that was decomposed. In particular, the metric chosen for the activity is of primary importance. For instance, the GVA used in the decomposition of the manufacturing industry is a good indicator of how dynamic the different sectors are, but it does not separate the effects of potential external factors, such as variability in the prices of goods produced. Likewise, the employment data used in the decomposition of the whole economy can reflect the shift between the sectors, but for the agriculture sector, for example, a lower workforce is usually related to a higher level of mechanisation. Finally, and although there was no simple alternative data available within the sources covered, the traffic data used in the transport decomposition are not a particularly good indicator, as they aggregate together traffic with multiple purposes (goods and passengers) and therefore do not allow the impact of the shift in transport between these purposes to be assessed. Due to the importance of the transport sector in overall energy consumption, and with transport activity data already collected at a very granular level, the availability of energy consumption by type of transport (goods and passenger first, then ideally by type of vehicle as well) would be the single most significant improvement to this work.

A second difficulty lies in the availability of disaggregated data. For industry for instance, the subsectors included in the study correspond to the smallest division of the economic sector where both economic and energy data were available, and in many cases, the latter was the limiting factor. It could be interesting to perform the same analysis within the different industry of the machinery subsector for instance but that level of detail in the energy consumption was not available at the time of the study. The availability of data on energy consumption by end-use also had large effect on the decomposition of energy consumption in households, as it is required to calculate the temperature correction, and the analysis highlighted the major impact that the weather has in the consumption of this sector.

The third limitation is in the impact of data coverage. Indeed, in order to apply the decomposition, the energy consumption and activity data for every subsector have to be available, otherwise neither the sub-sectoral intensity can be calculated, and nor the structural effect (which reflects shifts between these subsectors). Therefore, for many countries, only a selection of subsectors could be included in the decomposition, to avoid sectors with missing value added. In other instances, the period covered by the decomposition had to be restricted to a range of years for which sufficient disaggregated data were available.

Another caveat of the decomposition lies in its sensitivity to data quality. For instance, a very high variability in the calculated intensity can be observed for transport. This could partly be explained by the effect of the aggregation of different types of transport together, and by issues related to the definition of transport accounting, with residency and territory principles (although the data selected should include energy consumption of non-residents on the territory), but in some cases, this could also reflect data quality issues e.g. with figures that may have been reported in the wrong unit.

5. Conclusions

The importance of energy consumption monitoring has been widely recognised, and decomposition analysis is a particularly interesting tool for this purpose, as it can separate the different factors that affect the variations in the consumption level, especially by separating actual energy efficiency gains from external factors. The overall objective of this report was to:

- Present the methodology applied to perform the decomposition.
- Use the datasets that were identified as suitable for the task.
- Apply the developed tool to calculate the different effects which impact the energy consumption across all sectors, for each EU-27 country, and in the EU-27 as a whole.
- Allow comparisons of the energy consumption between countries.
- Enable potential data issues to be identified, such as lack of disaggregation or unstable time series.

In doing so, the overall objective is to enable the EU and its Member States to analyse their energy consumption and then develop efficient energy policies, adapted to their own characteristics.

In the first two decompositions, the final and primary energy consumption in the manufacturing and construction industries were treated. This provided useful insights on the importance of some subsectors in the energy consumption that did not always translate in terms of added value. Moreover, the primary energy consumption decomposition, although limited by some methodological aspects, highlighted the impact of the variation of the electricity mix on primary energy demand.

The third decomposition covered the economy as a whole, including manufacturing and construction industries, commercial and public services, agriculture and forestry. The most common observation was the growing share of the services sector in employment, while the same sector's share in energy consumption remained far below the industrial sector.

The fourth decomposition covered the residential sector energy consumption. The disaggregated energy consumption data, when available, highlighted that among all end use for energy, space heating is almost systematically the first, accounting usually for more than a half of the residential energy consumption. Of course, climate of the different countries played a significant role in it. Malta, Cyprus, and Portugal had far less energy consumption in space heating than countries with colder climate like Sweden, Finland, or Estonia, but other factors such as consumption of appliances and dwelling occupancy variation also impacted consumption significantly.

The fifth decomposition was applied to the transport sector, which is one of the most important sectors in terms of energy consumption for all countries. Unfortunately, due to limitation in the data available (no energy consumption disaggregated by type of transport, transport data not available for air transport), the decomposition only covered road, rail and navigation transport. However, most importantly, the activity was measured in vehicle-kilometre, which gathers together passenger and goods transport. Therefore, the only aspect that could really be highlighted was the importance of road transport compared to rail and navigation.

Comparing intensities across all EU-27 countries offers an interesting perspective because the national figures do not depend on the size of their respective economies. This enables an assessment of potential energy efficiency gains (or losses) over the period, and also highlights potential data quality issues. It is important to keep in mind the limitations that accompany the application of decomposition analysis for energy consumption. However, it should be noted that provided good quality and complete data are available, it can provide clear and valuable insight that can guide analysis before or after the implementation of energy-saving measures, and as such its use should be recommended.

In light of the insights gained from our current analysis, it is evident that there are ample opportunities to further deepen our understanding of energy consumption trends. One possible avenue for exploration is the translation of this energy consumption into GHG emissions. For instance, future research endeavours could significantly benefit from exploring the application of the OECD's System of Environmental-Economic Accounting (SEEA) energy and emissions accounts. The integration of these two factors could not only strengthen our understanding but also reveal more insights into the intricate dynamics between economic activities and environmental impact.

List of acronyms

CDD	Cooling degree days
CHP	Combined Heat and Power
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gases
GVA	Gross value added
HDD	Heating degree days
IDA	Indexed Decomposition Analysis
IEA	International Energy Agency
JRC	Joint Research Centre
LMDI	Logarithmic Mean Divisia Index
SEEA	System of Environmental-Economic Accounting
TJ	Terajoules
VKM	Vehicle-kilometres

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Supplementary data

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