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ORIGINAL PAPER

A methodology to characterize energy consumption in small and medium-sized enterprises at national level in European countries

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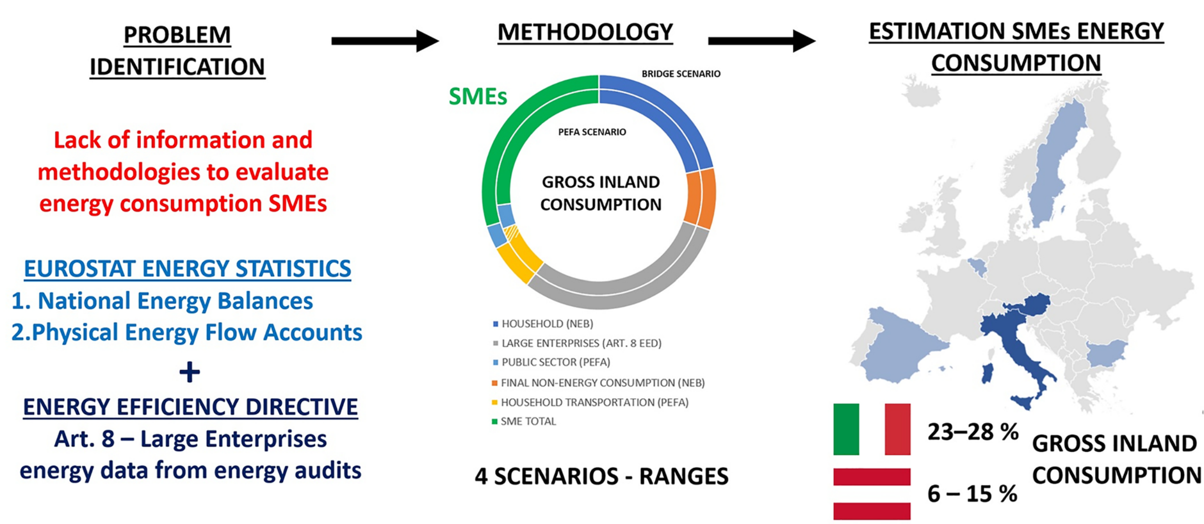
Abstract

The 25 million of European small and medium-sized enterprises (SMEs) represent 99% of businesses and account for the two thirds of total employment and a half of Gross Domestic Product. Thus, SMEs are considered as the backbone of European' economy. The crucial importance of energy efficiency and its potential in SMEs is worldwide recognized. However, the energy use and consumption information of SMEs are very limited, and the disaggregated data between SMEs and large enterprises are often not available at national or European level. The aim of this work is to present a methodology for the energy consumption characterization of European SMEs at national level. The proposed methodology, based on the combination of official national energy statistics and energy consumption data according to the European Energy Efficiency Directive Article 8, has been developed and applied to Italy and Austria. Preliminary results show significant differences in the relative weight of SMEs' energy consumption between the two countries mainly due to their specific productive structures. The application of this methodology to the available data on further five European countries provides useful insights on the impact of different national approaches to comply with Art.8. This methodology shows that harmonizing the different strategies to monitor energy audits obligation would significantly help to characterize the energy consumption of SMEs in Europe. Additionally, the knowledge of the distribution of energy consumption between large enterprises and SMEs would help in assessing the impact of mandatory and voluntary energy audits on potential savings in industrial and tertiary sectors.

Graphical abstract



Characterization of energy consumption in SMEs: Problem and data availability identification, development of analysis methodology, and application to seven European countries (focused on Italy and Austria)

Extended author information available on the last page of the article

Keywords Energy efficiency · Energy audits · Small and medium enterprises (SMEs) · Energy characterization · Energy efficiency directive · Energy policy

Abbreviations

AT	Austria
BE	Belgium
BG	Bulgaria
DE	Germany
DK	Denmark
EA	Energy audit
EED	Energy Efficiency Directive
EL	Greece
ES	Spain
EU	European Union
FI	Finland
FR	France
GIC	Gross Inland Consumption
HR	Croatia
HU	Hungary
IEA	International Energy Agency
IT	Italy
LE	Large enterprise
LT	Lithuania
MT	Malta
NACE	Statistical classification of economic activities in European community
NEB	National Energy Balance
NMVOCs	Non-methane volatile organic compounds
PEFA	Physical energy flow accounts
PPAs	Power purchase agreements
PT	Portugal
SBS	Structural Business Statistics
SE	Sweden
SME	Small and medium-sized enterprise

Introduction

The availability of comprehensive, reliable, consistent, and internationally comparable energy statistics is the first step in understanding energy market development and supporting policy planning. High-quality energy statistics are needed to understand, quantify and analyze the impact, cost, risk and benefits of policy options and also to monitor their performance indicators and expected impacts (Millard 2016). Additionally, robust energy statistics are necessary to evaluate the impact of energy subsidy and energy efficiency policies (Li & Solaymani 2021).

Since the mid-1970's enormous efforts have been made in this field (United Nations 2018). Current European energy statistics are comprehensive and provide insight to analyze the role of energy in the economy. However, in the past decades, several studies have analyzed the limitations on the availability and quality of data (Freeman et al. 1997), the difficulties in developing physical indicators (Farla & Blok 2000) and proposed models and indicators to analyze the impact of policies on energy efficiency (Patterson 1996). Very few industrial sectors characterized by a limited and homogenous range of products (glass, steel, cement, chlorine, lime, plywood, aluminum, ammonia, methanol, and ethylene) provide detailed critical analysis of the energy statistics. In the chemical industry, a sector characterized by the complexity of processes and heterogeneity of products, no solid conclusions on the development of energy efficiency could be drawn with data up to 2008 (Saygin et al. 2012) and several recommendations have been made to improve the quality of its statistics (Neelis & Pouwelse 2008). Other studies focused on improving the quality of non-energy use data which accounts for 7% of European energy consumption (Weiss et al. 2008).

This paper is focused on the definition of a novel methodology to estimate energy consumption at national level of small and medium-sized enterprises (SMEs), which are the backbone of the European economy. The importance of SMEs is shown by the economic database of Eurostat's Structural Business Statistics (SBS), which is categorized in NACE sections and divisions (the European standard classification of productive economic activities). They employ more than 100 million people, produce more than half of Gross Domestic Product and drive the increase in value added in every industrial and commercial sector (Di Bella et al. 2023). SMEs economic statistics are well consolidated; while, there is a lack of energy-related data for SMEs at European and National level. The contribution of academic work, at methodological level, should be usefully combined with national policy planning, in terms of its information needs. Indeed, the quality of existing energy-related data for SMEs is currently insufficient to provide a sound scientific-based support to the policy-making cycle.

The International Energy Agency (IEA) estimates that global consumption of SMEs accounts for about 13% (IEA 2015) of total global energy demand; while, their environmental impact is estimated to be about 60% to 70% of industrial pollution (including CO_2, SOx, NOx, PM10, NMVOCs emissions, waste, and hazardous waste) in the European Union (EU) in 2010 (Constantinos et al. 2010). Indeed, pollutant prevention techniques can be applied to SMEs with both environmental and economic benefits (Midžić Kurtagić et al. 2016).

Reducing the energy consumption of SMEs and increasing their energy efficiency is crucial for economies, environment, and SMEs themselves (De Schepper et al. 2014). The development of specific environmental sustainable policies for SMEs induces an increase in the financial efficiency of the companies, despite the increasing of production constrains (Cariola et al. 2020). Despite of the importance of energy efficiency issues in SMEs, both the development of specific policies and research in the field are still scarce (Johansson et al. 2019).

The estimation of potential of energy efficiency in SMEs ranges between 10% (Fresner et al. 2017) and 30% (IEA 2015) with cost-effective measures, of which 37% could be achieved with zero capital investment (BEIS 2014). However, the implementation of energy efficiency improvements in SMEs is lagging due to a lack of information, technical expertise and financing (Fleiter et al. 2012; Thollander et al. 2013). In this context, the development of energy audits can be considered the first step in understanding the structure of energy consumption of companies and promoting energy efficiency (Chiaroni et al. 2017), and can be supported by energy management systems tailored to SMEs (Laurinkevičiūtė & Stasiškienė, 2011). The SMEs need different mechanisms and incentives compared to large companies. For example, capital investment is generally considered a barrier to the SMEs; hence, other schemes such as power purchase agreements (PPAs) can be considered to help SMEs to reduce their energy impact (Raybould et al. 2020).

Research gap and contribution

The importance of energy efficiency policies is a topic of increasing interest in research.[1] Due to the intrinsic heterogeneity of the SME sector, designing energy efficiency policies specifically for SMEs remains a difficult task. The most successful approaches include promoting the development of energy audits (Kalantzis & Revoltella 2019), balancing the economic and supportive policies (Thollander, Kimura, et al., 2015), implementing energy efficiency networks as cost-effective actions for industrial SMEs (Johansson et al. 2022), and targeting interventions through strategic segmentation (Thollander & Dotzauer 2010). The main reviews on the field are usually focused on industrial SMEs and claims for a limited development of research and policies (Johansson et al. 2019), and the data availability of energy end-use information at an aggregated level in SMEs is scarce and limited to a sample of voluntary SMEs (Thollander, Paramonova, et al., 2015). Hence the lack of available information makes policy formulation a great challenge.

Mapping SMEs energy consumption is an important preparatory step to support a coherent planning of energy and environmental policies at national level and to achieve long-term saving targets. Despite the high importance of SMEs in both economic and energy terms, the methods to quantify their energy consumption at national level are lacking and estimates have been developed in a very limited number of papers published in the literature (Mazhar et al. 2022). In general, there is a lack of information about the methodologies applied to evaluate the energy consumption of SMEs. The available quantifications are often based on surveys at sectoral level and, for these reasons, they are not easily replicable for additional countries. As a consequence, quantitative analyses on the energy efficiency potential of SMEs at national level are still scarce.

According to Trianni and Cagno (Trianni and Cagno 2012), industrial SMEs in Italy could achieve 60% of domestic consumption, accounting for 16 Mtoe (Fondazione per lo sviluppo sostenibile and CNA, 2021). In Sweden, 30% of industrial energy consumption is due to non-energy-intensive SMEs (Paramonova & Thollander 2016). In the UK (and some other countries), the SMEs could account for more than half of total industrial and tertiary energy consumption (Fawcett & Hampton 2020). In Turkey, the potential of the energy efficiency of SMEs represents 42% of all the manufacturing industries (Özbilen et al. 2019).

The research work presented in this paper, developed in the framework of the LEAP4SME project, aims to introduce a novel methodology to characterize the energy consumption of SMEs using data obtained from official energy statistics and from the national transposition of Article 8 of the Energy Efficiency Directive (EED). On the one hand, Article 8 of Energy Efficiency Directive requires large enterprises (non-SMEs, LEs) to comply with the energy audit obligation every four years. On the other hand, the Member States must develop programs to encourage SMEs to develop energy audits and implement energy efficiency measures. Thus, the Art.8 of EED covers two complimentary aspects, the obligations for large enterprises, and underlining the importance of energy efficiency in the SMEs (Nabitz and Hirzel 2019).

The energy consumption of large companies can be estimated by means of the Art.8 EED databases at national level. These databases are usually managed by ministries or national energy agencies. This information is partially available in some countries, for the first cycle of mandatory audits 2015–2018 (Ricardo Energy and Environment, 2018), and the update data are only available for some countries such as Sweden (Berg 2019), Austria and Italy (Reuter et al. 2021). In this work, the data from Italy and Austria of large enterprises have been updated, refined, and made public.

The energy statistics of the Member States, at country level, are yearly published by Eurostat. Specifically, the global characterization of all the energy consumption

[1] 110 papers have been published in Scopus since 2007 under the search query: “energy” AND “efficiency” AND (“smes” OR “sme”) AND (“policy” OR “policies”).

associated with the economic activities are reported on the National Energy Balance (NEB), the cornerstone of European energy statistics, and the environmental-economic accounts such as Physical Energy Flow Accounts (PEFA), that provide complementary energy information.

This work presents a novel refined and detailed methodology to calculate the aggregated energy consumption of the SMEs at national level in Europe, in order to provide scientific evidence for policymaker, one of the objectives of the "Science for Policy" (or "Knowledge for Policy" K4P) principle from EU (Sienkiewicz and Mair 2020) This methodology lays the foundations for a subsequent disaggregation to different economic sectors to promote tailor-made policies after strategic segmentation, one of the most effectives approaches for policy-making on energy efficiency on SMEs (Bradford and Fraser 2008). For its characteristics, this method could be adapted and replicated in different European countries. Specifically, in this paper a detailed study of scenarios for Italy and Austria and a preliminary extrapolation to other EU countries are presented. For the first time, a range of SMEs energy consumption is provided for a set of European countries: This outcome represents key information both to scientific knowledge, and to policy planning and monitoring.

In addition, the uncertainties of the method are analyzed in detail. The main uncertainties are related to energy statistics, such as the correction methods between NEB and PEFA to allocate the transportation consumption, or to the transposition, implementation and monitoring of Art.8, which is crucial to determine the available information to be used in this methodology, and thus to obtain a reliable estimation of SMEs energy consumption.

Methodology

In this section the energy statistics framework is described, including a description of NEB and PEFA and the bridge table correction between them. SMEs energy consumption has been evaluated by considering two different approaches defined as "Base" and "Refined" that differ in the main assumptions applied in the calculation of consumption at national level. For each of them, a statistical correction is applied (bridge table correction), resulting in four different scenarios:

1. Base method–without bridge correction (BASE-PEFA)
2. Refined method–without bridge correction (REFINED-PEFA)
3. Base method–with bridge correction (BASE-BRIDGE)
4. Refined method–with bridge correction (REFINED-BRIDGE)

Energy data sources

The estimation of energy consumption of European SMEs proposed in this paper is based on two main data sources: national consumption data from large enterprises (managed by Energy Ministries or Agencies) and the official energy statistics published by Eurostat (European Statistical Office).

The first data source is "the large enterprises energy consumptions database" (according to EED Art. 8) collected and elaborated by the national energy agencies of Italy and Austria.

The second is the official national energy statistics published by Eurostat (European Statistical Office) in two main databases: National Energy Balances (NEB) (Eurostat 2022a) and Physical Energy Flow Accounts (PEFA) (Eurostat 2022b) (Reference year 2017). Hence, the presented methodology combines public information from national statistics, detailed by energy transformation and use, with data from national energy agencies, focused on the final consumption of large enterprises.

The National Energy Balance is the statistical source accounting for energy products and their flow in the economy of a country. The NEB is the key tool for the comprehensive analysis of the domestic energy supply and demand in domestic energy markets, monitoring the impacts of energy policies and analyzing the role of energy in the economy. Eurostat's methodology for the calculation of NEB is based on the physical energy content method, which considers the primary energy source as its primary energy equivalent (calorific value for combustible fuels, and heat or electricity for other sources). The energy balances follow the first law of thermodynamics and are divided into three blocks: top block (supply), medium block (transformation input and output, consumption of energy branch and distribution losses), and bottom block (non-energy final consumption and disaggregated final energy consumption). The Gross Inland Consumption (GIC) is an indicator that aggregates the overall consumption of medium and bottom block, including all the primary and final energy uses. Moreover, GIC ensures the continuity between old and new Eurostat statistics. Hence, the GIC is used as the main value of the total energy consumption of a country, and as the reference value in this work.

The evolution of GIC in the NEB has been previously used in literature to analyze the impact of energy policies at country level in the EU from different perspectives such as the replacement of fossil fuels and nuclear with renewables (Magda et al. 2019), the reduction of energy inequalities between European clusters of countries (Sáez et al. 2018); or the impact of energy prices and taxes on energy intensity (Filipović et al. 2015).

Figure 1 shows the distribution of energy consumption in the different economic sectors for all EU-28 countries. It is possible to observe that in a general overview the Gross Inland

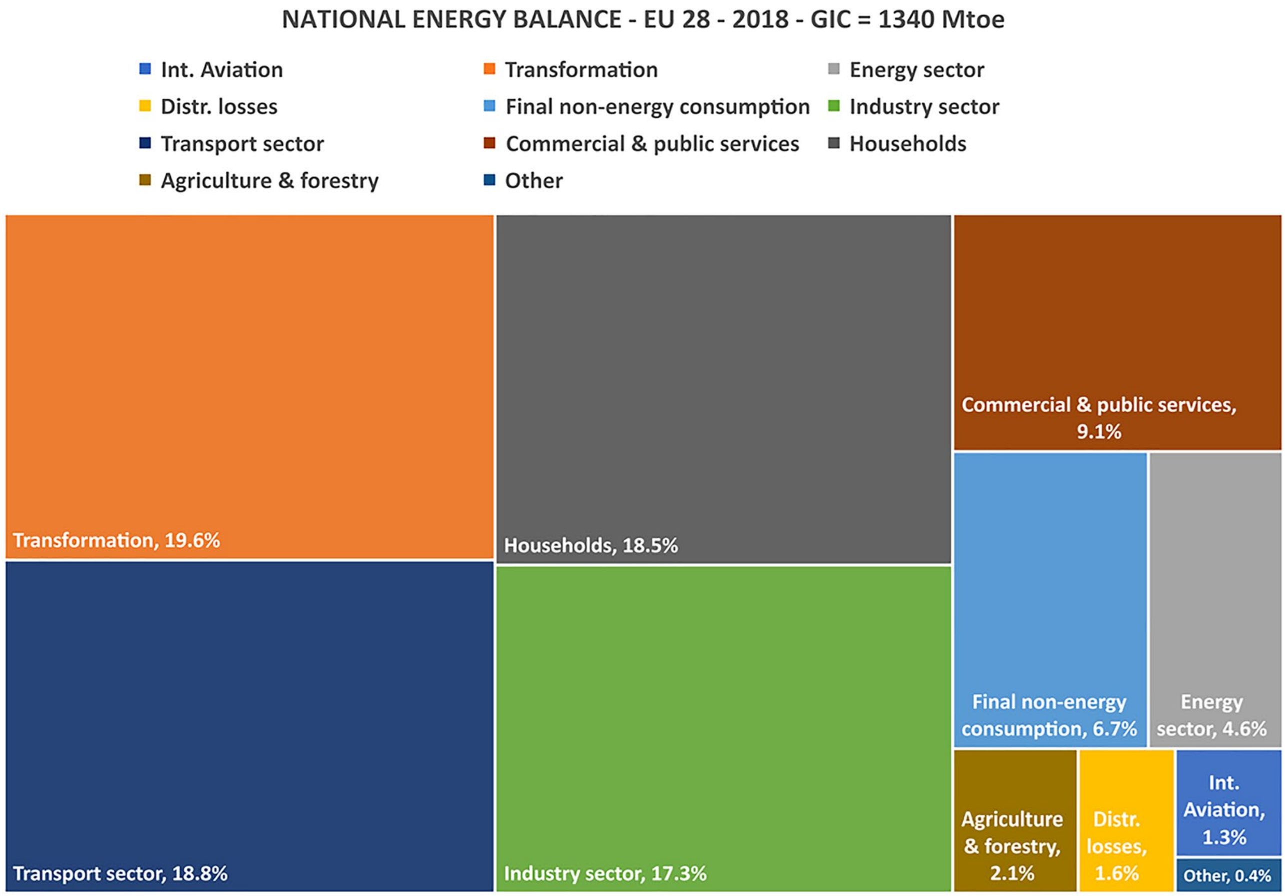


Fig. 1 Distribution of Gross Inland Consumption in the NEB (EU-28, 2018 year). Data from (Eurostat 2022a)

Consumption of the EU is divided into approximatively five parts: transformation conversion (mainly in power sector), household use (without considering private transportation), transportation (all means), industry use, and others (mainly primary and tertiary sectors, non-energy uses, energy sector, and distribution losses). Additional analysis can be done to examine the relative contribution of each energy carrier.

Physical energy flow accounts (PEFA) integrate environmental and economic data in order to analyze the interactions between anthropic (economy) and natural (environment) systems. PEFA record the energy flows.

- From the environment to economy, in terms of natural inputs,
- Within the economy, in terms of flows of energy and non-energy products,
- From economy to environment, in terms of residuals.

PEFA is based on the residence principle, accounting for the energy flows related to resident unit's activities, regardless of the geographic location where the activities take place. PEFA data complement the traditional NEBs and are comparable with the economic data of National Accounts. Figure 2 depicts the total energy use by resident units in the EU-28 countries. The distribution of energy use on households and economic activities by NACE sectors can be observed. By definition NACE sectors include only economic activities, excluding households. NACE classification is hierarchically structured into 4 levels:

- 21 sections identified by alphabetical letters A to U (i.e., C–Manufacturing)
- 88 divisions identified by two-digit numerical codes (01–99) (i.e., 17 Manufacture of paper and paper products)
- 272 groups identified by three-digit numerical codes (01.1–99.0) (i.e., 17.2 Manufacture of articles of paper and paperboard)
- 615 classes identified by four-digit numerical codes (01.11–99.00) (i.e., 17.24 Manufacture of wallpaper)

It can be observed in Fig. 2 that excluding consumption due to housing (around 26% of the total) the economic activities responsible for the highest consumption, accounting for almost 60% of the total, are the manufacturing sector

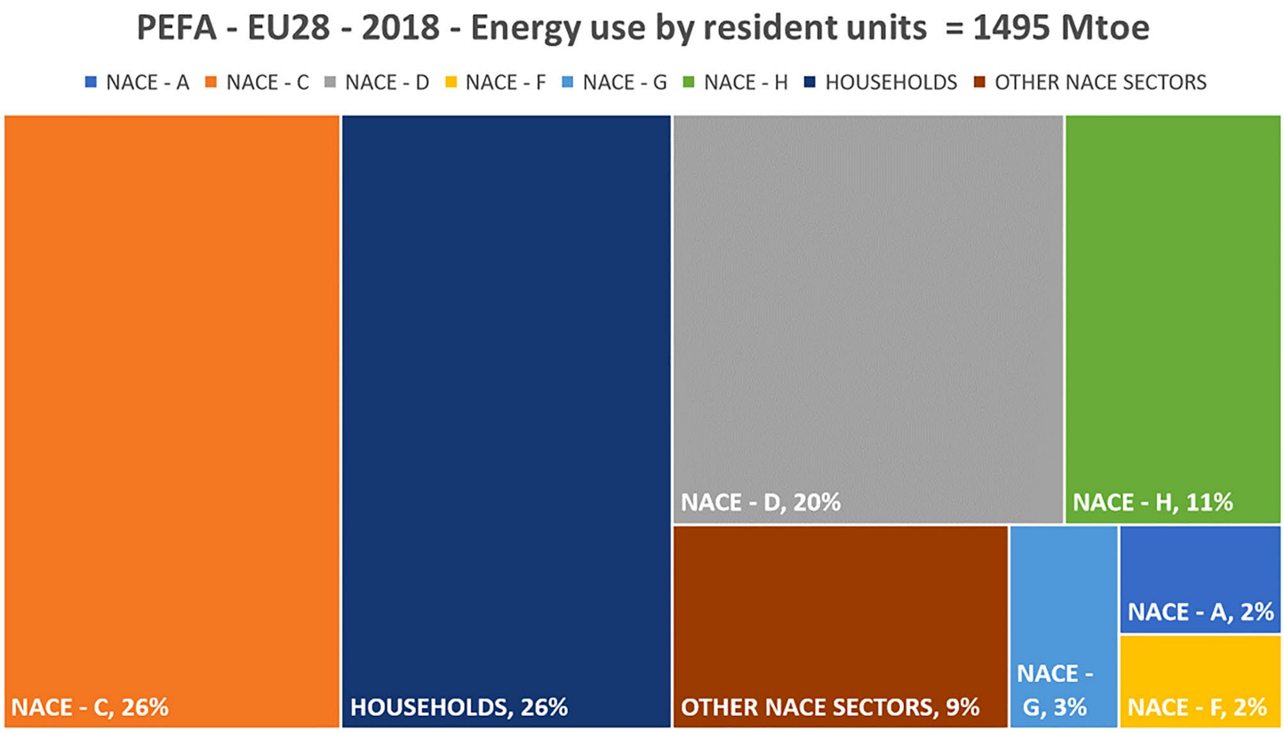


Fig. 2 Distribution of Total Energy Use in the PEFA (EU-28, 2018 year) Data from (Eurostat 2022b)

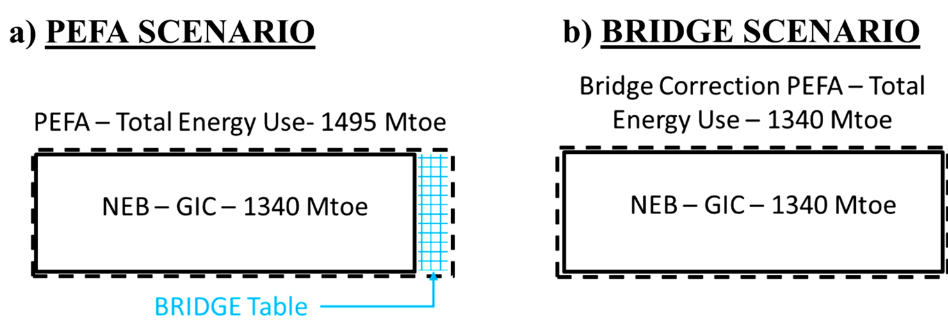


Fig. 3 Scheme of analyzed scenarios **a** PEFA scenario, **b** Bridge scenario (with proposed bridge correction)

(NACE C, 26%), the electricity, gas, steam and air conditioning supply sector (NACE D, 20%), the transport and storage sector (NACE H, 11%), the sector wholesale and retail trade (NACE G, 3%), the construction sector (NACE F 2%) and agriculture, forestry and fishing sector (NACE A, 2%).

The two main discrepancies between the NEB and PEFA databases are related to the structure of data and the aggregation of the consumption. On the one hand, it is possible to observe the different allocations of consumption. For example, households account for 19% of the GIC in NEB but for 26% of the total energy use in PEFA. This difference is due to the fact that PEFA include the energy consumption of residential transportation. Another example is the allocation of NACE C and D economic sectors that account for 46% of the consumption in PEFA. These consumptions are aggregated as transformation, industry sector, energy sectors, and partially

Table 1 Proposed reallocation of the “Bridge table” difference

	PEFA—Net domestic energy use
Land transport	50% NACE H/50% Household Transport
Water transport	NACE H
Air transport	NACE H
Other adjustments and statistical discrepancies	ALL ACTIVITIES (proportional to consumption)

in final non-energy consumption and distribution losses (51% of NEB). On the other hand, a difference of 10% of global consumption is observed between the GIC (1340 Mtoe) and total energy use of PEFA (1495 Mtoe). Moreover, it is important to note that these differences observed at European level

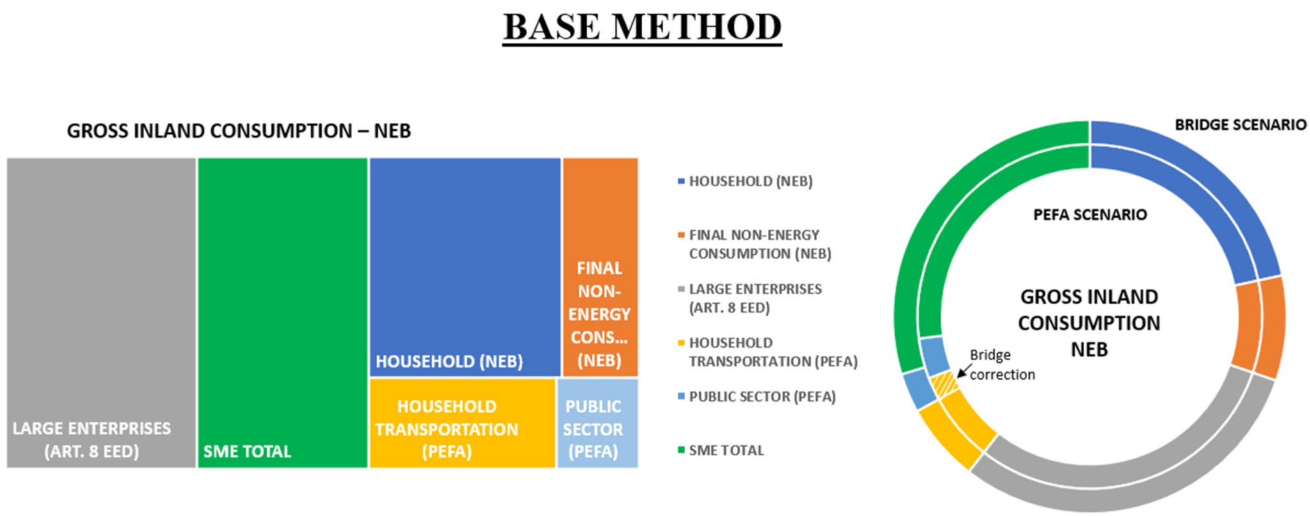


Fig. 4 Scheme of GIC distribution (left) and the allocation of "PEFA and "BRIDGE" scenarios (right) according to "Base method"

can also vary at national level. Hence, it is necessary to evaluate the reconciliation of data at country level.

PEFA bridge table correction

Due to the differences between the NEB and PEFA databases, Eurostat provides a "Bridge table" to reconcile the data from both databases (Eurostat 2018). The "Bridge Table" explicitly shows the difference between the "domestic energy use" derived from PEFA and the GIC from NEB (Fig. 3a). This divergence is mainly due to the different accounting of transportation fuel consumption. The PEFA follows the "residence principle" where the energy use is accounted for the resident units independently of where it takes place; while, NEB follows the "fuel-sales-on-the-territory" principle. PEFA database accounts for the energy consumption by NACE activity. A breakdown of fuel consumption among the different economic sectors and households, depending on the means of transportation, is proposed in Table 1. In particular, "Land transportation" discrepancy is accounted 1:1 between "Household" (that represent the 80% of energy consumption by cars and motorcycles) and NACE H sector (20% of cars consumption and 100% of trucks, aviation, and buses). Fuel consumption by sea and air transport is assigned to NACE sector H (Transport and storage). Finally, other statistical adjustments are assigned in proportion to the consumption of the sector.[2]

The impact of this adjustment is schematically presented in Fig. 3. The scenarios "Bridge" includes this modification, in contrast to "PEFA" where the consumption of household and public companies is not modified. It is important to note that the allocation of bridge values between different NACE codes depends on the statistics of each country. Hence, in some cases this adjustment can be positive or negative.

Base method

In this section, details about the base method functioning will be provided, based on the statistical sources previously described. The starting point of the methodology is Gross Inland Consumption (GIC), which, as described in Fig. 1 based on NEB, includes the energy consumption of households, private companies (LEs and SMEs), public entities and the non-energy consumption. Thus, the energy consumption of SMEs can be calculated from GIC by difference, as follows (in square brackets is presented the data source[3]) in Eq. 1:

[2] The basis of this allocation hypothesis is that cars account for 50% of the EU energy consumption in the transport sector, trucks for 30%, aviation for 12%, rail/water for 4% and bus/motorcycles for 4% (European Environment Agency 2011). Additionally, in order to disaggregate residential and professional use of cars, national information can be used: for example, in Italy the 20% of cars are dedicated to professional use (UNRAE 2020).

[3] In parenthesis is presented the acronym used in the official databases for each energy consumption. In square brackets is presented the data source [NEB] – National Energy Balance (Eurostat 2022a); [PEFA]—Physical Energy Flow Accounts (Eurostat 2022b); [EED Art.8] – National database of Art.8 implementation, for Italy and Austria this work, other countries (Ricardo Energy & Environment, 2018). For example, FC_NE [NEB] corresponds to Final Non-Energy Consumption (i.e., natural gas for ammonia production) in National Energy Balance database.

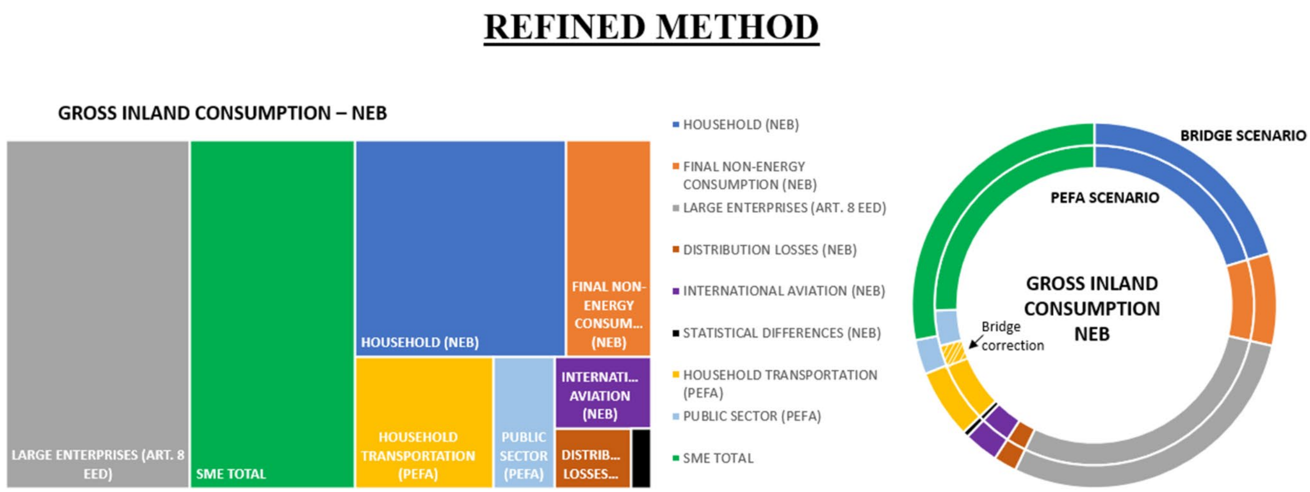


Fig. 5 Scheme of GIC distribution (left) and allocation of "PEFA and "Bridge" scenarios (right) according to "Refined method"

$$
\begin{aligned}
&\text{SMEs Energy Consumption(Base Scenario)}\\
&= \text{Gross Inland Consumption(GIC[NEB])}\\
&\quad - \text{Final Non} - \text{Energy Consumption(FC\_NE[NEB])}\\
&\quad - \text{Household(no transport)(FC\_OTH\_HH\_E[NEB])}\\
&\quad - \text{Household Transport(HH[PEFA]} - \text{HH\_TRA[NEB])}\\
&\quad - \text{Public Sector(NACE O} + \text{P} + \text{Q[PEFA])}\\
&\quad - \text{Large Enterprises Energy Consumption[EED Art.8]}
\end{aligned}
\tag{1}
$$

This formula is schematically presented in Fig. 4 (left). The sum of all energy consumption sections is the national GIC. The disaggregation of the other terms is presented in the different areas of the figure, with the data source in brackets.

In this formula, both NEB and PEFA terms are included. Non-energy consumption, included in NEB, must be excluded from this calculation. The consumption of households is obtained from the PEFA database (that includes all the energy uses) and the NEB (that excludes residential transportation). The consumption of public sector is obtained from PEFA, considering that their activities are mainly related to the NACE sectors "O" (Public administration and defense; compulsory social security), "P" (Education) and "Q" (Human health and social work activities). Finally, the aggregated consumption of large companies is obtained by the national EED Art. 8 databases.

This approach (BASE-PEFA) is enriched with an alternative scenario including the bridge correction (BASE-BRIDGE), as shown in Fig. 4 (right), which represents the sectoral distribution of the GIC and the allocation of the differences between "PEFA" and "BRIDGE" scenarios.

Refined method

The refined method involves three hypotheses for improving the base method; the data to support these hypotheses are all available from NEB. SMEs energy consumption is obtained according to Eq. 2:

$$
\begin{aligned}
&\text{SMEs Energy Comsumption(Refined Scenario)}\\
&= \text{Gross Inland Consumption(GIC[NEB])}\\
&\quad - \text{Distribution Losses(DL[NEB])}\\
&\quad - \text{International Aviation(INTAVI[NEB])}\\
&\quad - \text{Final Non} - \text{Energy Consumption(FC\_NE[NEB])}\\
&\quad - \text{Statistical Differences(STATDIFF[NEB])}\\
&\quad - \text{Household(notransport)(FC\_OTH\_HHE[NEB])\_)}\\
&\quad - \text{Household Transport(HH[PEFA]} - \text{HH\_TRA[NEB])}\\
&\quad - \text{Public Sector(NACE O} + \text{P} + \text{Q[PEFA])}\\
&\quad - \text{Large Enterprises Energy Consumption[EED Art.8]}
\end{aligned}
\tag{2}
$$

In particular, three new terms are included in the equation for GIC. First, "*distribution losses*" (mainly electrical transmission and pipeline losses) not considered in the base method are added to the analysis because they are generally excluded from the energy consumption of LE derived from energy audits. Second, the refined method excludes the consumption of "*international aviation*," covering the quantities of fuel delivered based on the departure and landing location, regardless of the nationality of the company; the consumption of domestic companies should be considered primarily in the context of EED Art. 8 energy audits. Finally, statistical differences are excluded from the consumption of private enterprises.

This approach (REFINED-PEFA), as in the case of the base method, is complemented by an alternative scenario

Table 2 Estimation of SMEs energy consumption in Italy [ktoe]

Italy		BASE [ktoe]		REFINED [ktoe]	
		PEFA	BRIDGE	PEFA	BRIDGE
Gross Inland Consumption	GIC [NEB]	159,513	159,513	159,513	159,513
Distribution losses	DL [NEB]			1992	1992
International aviation	INTAVI [NEB]			3419	3419
Final non-energy consumption	FC_NE [NEB]	7915	7915	7915	7915
Statistical differences	STATDIFF [NEB]			-352	-352
Household (no transport)	FC_OTH_HH_E [NEB]	32,899	32,899	32,899	32,899
Household transport	HH [PEFA]—HH_TRA [NEB]	20,705	18,033	20,705	18,033
Public sector	NACE O+P+Q [PEFA]	5919	5799	5919	5799
Large enterprises	Art. 8—ENEA	49,620	49,620	49,620	49,620
SME total	Calculated	42,456	45,246	37,396	40,187
SME total	% GIC	26.6	28.4	23.4	25.2
Large enterprises		54%	52%	57%	55%
SMEs		46%	48%	43%	45%

Table 3 Estimation of SMEs energy consumption in Austria [ktoe]

Austria		BASE [ktoe]		REFINED [ktoe]	
		PEFA	BRIDGE	PEFA	BRIDGE
Gross inland consumption	GIC [NEB]	34,423	34,423	34,423	34,423
Distribution losses	DL [NEB]			624	624
International aviation	INTAVI [NEB]			737	737
Final non-energy consumption	FC_NE [NEB]	1652	1652	1652	1652
Statistical differences	STATDIFF [NEB]			−0.8	−0.8
Household (no transport)	FC_OTH_HH_E [NEB]	6594	6594	6594	6594
Household transport	HH [PEFA]—HH_TRA [NEB]	3163	4840	3163	4840
Public sector	NACE O+P+Q [PEFA]	904	1040	904	1040
Large enterprises	Art. 8—AEA	17,026	17,026	17,026	17,026
SME Total	Calculated	5,082	3,270	3,721	1,908
SME Total	% GIC	14.8	9.5	10.8	5.5
Large enterprises		77%	84%	82%	90%
SMEs		23%	16%	18%	10%

including the bridge correction (REFINED-BRIDGE), as shown in Fig. 5. This figure shows the distribution of energy consumption in the GIC and the allocation of the differences between “PEFA” and “Bridge” scenarios for the “Refined method”.

Results and discussion

Detailed estimation of SMEs consumption in Italy and Austria

The estimations of SMEs energy consumption in Italy and Austria are presented in Tables 2 and 3, respectively.

The estimation of household consumption (including transportation) varies from 50.9 to 53.6 Mtoe in Italy and from 9.7 to 11.4 Mtoe in Austria. The consumption of public entities in Italy achieves 3.6% of GIC and 2.7% in Austria. The reported consumption of large enterprises under Art.8 accounts for 49.6 and 17.0 Mtoe in Italy and Austria, respectively.[4]

In the Italian case, the relative weight of SMEs energy consumption spreads from 23.4% of GIC in the case

[4] It is important to note that, in the case of Italy this is a minimum value (lower threshold) based on the analysis of more than 12,000 energy audits (reference years 2019–2021), but the energy audits of the fourth year of the cycle are still under evaluation to date.

Table 4 Estimation of energy consumption of LEs under EED Art.8

	GWh	ktoe	Adjustment
AT	200,554	17,245	AEA (This work) and (Ricardo Energy & Environment, 2018)
BE	30,824	2,650	Extrapolation from 265 companies [Wallonia] to 1050 obligated companies
BG	11,190	962	Extrapolation from 69 companies to 400 obligated companies
IT		49,620	ENEA (This work)
MT	999	86	
ES	259,036	22,273	Extrapolation from 80% obligated companies
SE	182,638	15,704	

"REFINED-PEFA" to 28.4% of GIC in the case of "BASE-BRIDGE", with 7.85 Mtoe of total difference. In these scenarios the rate of energy use from SMEs/LEs varies from 43/57% to 48/52%, almost a 1:1 ratio in the last scenario. In any case, it is possible to note that the energy consumption of SMEs reflects their importance for the national economy activities.

In Austria the consumption of SMEs varies from 5.5% to 14.8% of GIC (a 3.17 Mtoe discrepancy) from "REFINED-BRIDGE" and "BASE-PEFA," respectively. The ratio of the consumption of SMEs/LEs varies from 23/77% to 10/90%. Hence it is possible to note that the consumption of SMEs is significantly lower than that of large enterprises.

It is important to highlight that the application of different methods and scenarios allows the definition of a range of SMEs energy consumption for each country. Firstly, the "Base method" tends to overestimate the consumption of SMEs due to the allocation of losses and aviation fuel consumption. Secondly, the "Bridge correction" implies a different impact depending on the country. This correction reduces the household transport consumption by 2.7 Mtoe (− 13.0%) in Italy, and it increases in Austria by 1.7 Mtoe (+ 34.6%). Hence the "Bridge correction" presents a different trend in the two countries and its impact is not negligible. Finally, the different approaches are strongly dependent on the global GIC. The Italian GIC is practically quintuple of Austria; hence, the differences due to the approach have a higher effect in the Austrian case, increasing the relative weight of SMEs compared to LEs.

The different results for Italy and Austria can be correlated with the economic structure of the SMEs in the different countries. From a general point of view, both countries with a strong industrial capacity, could be considered similar in terms of share of SMEs and value added of the industry, respectively, 99.7% and 19.7% for Austria and 99.9% and 17.7% for Italy. Moreover, the SMEs of both countries present higher value added (66.9% Italy, 62.0% Austria, 56.4% EU) and employment (78.1% Italy, 68.4% Austria, 66.6% EU) than the EU average (Eurostat 2023). However, Italy and Austria present strong divergences in the SMEs performance.

The main reason is the weight of SMEs manufacturing, where the SMEs energy consumption is mainly concentrated. In Italy, manufacturing is the first SME sector, providing 30.4% of SME value added (European Commission 2019b). In Austria, the biggest SME sector is "wholesale and retail trade" with a 20% of SME turnover, followed by manufacturing (OECD 2022). Hence, the importance of SMEs in manufacturing, which generally includes energy-intensive industries, drives a structural difference between the range obtained in energy consumptions.

Another important fact is linked to the higher environmental (and directly energy) performance of Austrian SMEs with respect to Italian SMEs (European Commission 2019a). Austrian SMEs rank highest in the EU in environmental indicators. In 2017, practically half of Austrian SMEs have received governmental support for resource-efficiency, while only 17% of Italian SMEs were supported. Thus, another aspect to observe a lower energy consumption can be correlated with the higher energy efficiency of Austrian SMEs.

Finally, other aspects that can impact in the lower energy consumption of Austrian SMEs could be a) the higher averaged size of Austrian SMEs (5.9 people) compared to Italian SMEs (3.1 employees), that can drive a better awareness of energy issues at company level; b) the higher average SME labor productivity in Austria (62,700 €/employee) compared to Italy (62,700 €/employee), that marks a higher value added of the activities, uncoupled of energy consumption; and c) the density of SMEs is sensibly higher in Italy (> 70 SMEs/1000 inhabitants) than in Austria (30–40 SMEs/1000 inhabitants) (Gonzales et al. 2014).

These differences are also presented in the policies for SME energy efficiency in the different countries. On the one hand, the more popular Italian policies are directly correlated to manufacturing SMEs (and include also large enterprises), namely White Certificates and Energy-Intensive Industry program (*Energivori* in Italian). On the other hand, the *klimaaktiv* is the Austrian climate protection initiative that includes different sub-programs focused on industry, services, or buildings (Biele et al. 2022).

Table 5 Estimation of SMEs energy consumption in 7 European countries according to "REFINED-BRIDGE" approach

[ktoe]	IT	AT	BE	BG	MT	ES	SE
Gross inland consumption	159,513	34,424	57,451	18,128	726	122,176	49,231
Distribution losses	1992	625	366	469	19	2596	904
International aviation	3419	737	1368	220	124	3943	633
Final non-energy consumption	7915	1652	8458	496	9	4940	2178
Statistical differences	−352	−1	−29	−170	0	−1693	210
Household (no transport)	32,899	6595	8135	2254	81	15,063	7462
Household transport	20,705	3164	2952	630	106	15,917	3669
Public sector	5919	904	1623	320	30	3149	701
Large enterprises	49,620	17,027	10,261	5578	86	27,842	15,704
SME total	37,397	321	24,318	8333	271	50,419	17,769
SME total (%GIC)	23.4	10.8	42.3	46.0	37.4	41.3	36.1

Application to other EU countries

The proposed methodology has been subsequently applied to other EU countries using publicly available energy consumption data of large enterprises under EED Art.8. The public information is partial and refers to the first cycle of mandatory energy audits (Ricardo Energy and Environment, 2018). Hence, the values presented must be considered only qualitatively in order to assess the potential replicability of the method and to discuss policy recommendations, also relative to the implementation of EED Art.8. The data from Belgium, Bulgaria, Malta, Spain, and Sweden have been extrapolated to the complete number of obligated companies assessed by National Ministries (Hirzel et al. 2016), as presented in Table 4.

Table 5 presents the estimated energy consumption of the SMEs in the 7 EU countries according to the refined method that presents a downward estimation of energy consumption. The relative weight of SMEs in GIC spreads from 36.1% from Sweden to 46.0% in Bulgaria. The estimations of the five countries present a significantly higher consumption with respect to GIC than Italy and Austria. The main reason is likely to be the uncertainty of the values used, which probably underestimates the consumption of LEs. Indeed, the values considered are referred to the first cycle of the Art.8 implementation mechanism, and the number and quality of the national information collected in the second cycle is expected to be higher, as already witnessed by some national experiences. Once this information will be available on a wide basis, the evaluation could be easily updated.

The impact of the different scenarios on the estimation of SMEs energy consumption in the seven EU countries is presented in Table 6. It is possible to observe that in all cases the values obtained with the base method present a higher share of SMEs on GIC: The difference varies from 2% of GIC in Belgium to 20% in Malta, median 3.5%. The range observed for the values estimated decreases with GIC, as observed previously comparing Italy and Austria. Hence, the impact of the method is also dependent on the GIC. The impact of the Bridge correction in the additional five countries seems to be smaller than in Austria (the differences are close to 1% of GIC), since the Bridge correction is strongly dependent on the national energy structure, more than on the allocation hypotheses proposed in Table 1. Table 6 also shows the distribution of energy consumption between SMEs and LE. Hence, significant differences in country basis can be found in the PEFA data, as will be described in Table 7.

Table 6 Relative weight of SMEs energy consumption. a) SMEs / GIC and b) SMEs/Total private companies, in 7 European countries according to the different approaches

		Base		Refined	
		PEFA	Bridge	PEFA	Bridge
IT	% GIC	27%	28%	23%	25%
	% Total	46%	48%	43%	45%
AT	% GIC	15%	9%	11%	6%
	% Total	23%	16%	18%	10%
BE	% GIC	45%	44%	42%	42%
	% Total	72%	71%	70%	70%
BG	% GIC	49%	50%	46%	47%
	% Total	61%	62%	60%	60%
MT	% GIC	57%	57%	37%	37%
	% Total	83%	83%	76%	76%
ES	% GIC	45%	46%	41%	42%
	% Total	66%	67%	64%	65%
SE	% GIC	40%	40%	36%	36%
	% Total	55%	55%	53%	53%

Table 7 Relative impact of "Bridge correction" in 16 EU countries [ktoe]

	Energy consumption [ktoe]			Difference [%]		
	Households without transport (NEB)	Households transport (PEFA)	Households transport "Bridge Correction" (PEFA)	on overall households consumption with transport	on households transports	on GIC
BE	8135	2952	3417	−4.19%	−15.74%	-0.81%
BG	2254	630	442	6.53%	29.88%	1.04%
DK	4463	2115	1720	6.00%	18.67%	2.27%
DE	56,046	34,110	31,110	3.33%	8.79%	0.95%
EL	4287	2886	2916	−0.42%	−1.03%	-0.12%
ES	15,063	15,917	15,508	1.32%	2.57%	0.34%
FR	39,833	24,758	26,464	−2.64%	−6.89%	-0.69
HR	2393	1052	682	10.73%	35.14%	4.30%
IT	32,185	20,921	18,488	4.58%	11.63%	1.57%
LT	1440	1039	268	31.09%	74.18%	10.95%
HU	6157	2619	1995	7.12%	23.84%	2.43%
MT	81	106	110	−2.15%	−3.80%	-0.56%
AT	6324	3329	5006	−17.37%	−50.36%	-4.95%
PT	2621	2146	2217	−1.47%	−3.27%	-0.30%
FI	5292	1890	1661	3.19%	12.11%	0.66%
SE	7462	3670	3639	0.27%	0.83%	0.06%

Identification and analysis of methodological uncertainties

The proposed methodology could be considered a powerful tool to analyze the aggregated energy consumption of SMEs at national level. The methodology is based on different hypotheses, and each of them presents some uncertainties that could affect the results robustness to a different extent. It is important to note that these statistical discrepancies involve several high-level bodies at country and European level (Statistical Offices, Energy and Environmental Agencies, and Energy and Economy Ministries). Hence, the potential uncertainties are presented, but it is not possible in this work to deepen in detail de degree of methodological and statistical uncertainty, nor to develop an accurate sensitivity analysis.

In particular, the three main uncertainties should be addressed:

1. Uncertainties due to energy calculation methods for EED Art.8 Les
2. Impact of Bridge correction in PEFA
3. Harmonization of the definition of obligated companies

Uncertainties due to energy calculation methods for EED Art.8 LEs

The main source of uncertainty is the value of the energy consumption of large companies under EED Art.8. This uncertainty is twofold: First, the national public available data could be partial and uncomplete; second, the calculation method of the aggregated consumption is not generally published and often not homogeneous among countries.

The Italian case is used as example to assess the impact of uncertainties due to energy calculation methods for EED Art.8. After an in-depth analysis of the mandatory energy audits database, the uncertainties on LEs energy consumption data have been identified, analyzed, and addressed as follows:

- Large enterprises that have not complied with the obligation are not included in the analysis (7% of total obligated companies in 2019).
- The 3% of the analyzed energy audits reported a null energy consumption. These had been reviewed individually and they could account between 0.19 and 0.56 Mtoe.
- The Italian regulation allows the companies to present the energy audits of a representative sample of the most relevant production sites, instead of the EA of every site (Santino et al. 2019). Hence, the obligated companies present, on the one hand, the detailed EA of the most representative sites, and, on the other hand, a file with the aggregated primary energy consumption of the rest of the productive sites "clustered." The consumption of "clustered" sites has been estimated to be 2.5% of the total. This estimation is based on a large sample. However, all the clustered companies are still under review.
- The consumption of 2022 is estimated on the basis of the EAs submitted in 2021 (0.72 Mtoe). This value can

vary due to the difference on yearly obligation to submit the audit during the 4-year cycle from EED. The consumption of large companies audited was 43.52 Mtoe, 4.67 Mtoe and 0.72 Mtoe in 2019, 2020 and 2021, respectively.

A broad aggregation of all these assumptions could increase consumption of LEs by up to 10%, reducing SMEs consumption by 5 Mtoe, resulting in 20% of GIC in the most restrictive scenario (37% SMEs vs 63% LEs). The obtained estimation is aligned with a complementary analysis based on energy data of Regulation (EU) 2016/1952 on "European statistics on natural gas and electricity prices," where the energy consumption of SMEs is aggregated in the non-household energy category. According to this approach, the Italian SMEs account for between 12.9% and 24.8% of GIC (Reuter et al. 2021).

In the case of Austria, the structure of the Art.8 measure exhibits high robustness and data reconciliation. Almost 2000 companies reported 1500 EAs, mainly focused on processes (82%) (Ricardo Energy and Environment, 2018). The estimation based on energy threshold consumption provides a consumption of SMEs close to 16.3% of GIC (Reuter et al. 2021). This value is close to the consumption obtained using "BASE-PEFA." Hence, in a first analysis, the simpler method seems to be the most suitable for the Austrian case.

In addition, to better compare the results among different countries, it would be advisable to homogenize the national database and calculation procedures, and regularly update the public information on the Art.8 implementation.

Impact of bridge correction in PEFA

In Table 7, the impact of "Bridge correction" for 16 EU countries is presented. This adjustment of PEFA results in average changes of 6.3% of total household consumption, 18.6% of residential consumption for transportation, and 2.3% of GIC. Hence, the impact of Bridge table on the analysis cannot be considered negligible. Moreover, the impact is particularly important in Hungary, Denmark, Croatia, Lithuania, and Austria, resulting in adaptions of 2.4, 2.3, 4.3, 10.9 and −4.9% of GIC, respectively. This difference between the consumption with and without "Bridge correction" is directly allocated to SMEs in the present methodology.

Harmonization of definition of obligated companies

The EED Art.8 obliges LEs to carry out an EA every 4 years. However, the definition of LE varies among countries, and includes not only the number of employees (generally over 250) and economic turnover/balance, but also the definition of associated and linked enterprises. The definition of SME, and consequently of LE at country level, has a great impact on the evaluation of the overall energy consumption (European Commission et al. 2021), and the definition of SME would need to be harmonized.

Conclusions

This paper presents a novel methodology for estimating the aggregate consumption of SMEs at national level in Europe by combining public statistics from Eurostat with information from mandatory energy audits carried out by large enterprises under Article 8 of the EED.

The research conducted in this work points out that while SMEs economic statistics are well consolidated, there is a lack of energy-related data for SMEs at the European and national levels. This information is crucial to provide sound scientific support to the policy-making cycle, since a solid knowledge basis should always be considered as the first step to plan effective policy action.

The approach proposed is based on two main data sources: official energy statistics published by Eurostat, namely NEB and PEFA, and national consumption data from large enterprises, association to the implementation of EED art.8. Two methods are developed, differing in the main assumptions applied in the calculation of consumption at national level. For each of them, a statistical correction is applied, resulting in four different scenarios.

The application of this methodology in Italy and Austria provides a preliminary range of consumption on GIC between 23–28% and 6–15%, respectively. The methodology was applied to other EU countries to obtain the first estimation of SMEs energy consumption and analyze the main uncertainties of the method. In order to apply the methodology at the European level, further work is needed to harmonize the quality of information provided by mandatory energy audits and to homogenize different public statistics. Moreover, a precondition to apply this methodology is the availability of large enterprises energy consumption, deriving from the national database related to the implementation of EED art.8. This clearly shows that the efforts in managing a legislative obligation could have a value added in terms of data availability, providing a sound base for SMEs energy consumption estimation. The proposed method needs further investigation, and future work will focus on other aspects, such as the breakdown of consumption between the "Base" and "Refined" methods, or the impact of the reference year.

The analysis provides a first set of policy insights:

1. Member States should increase the availability of energy consumption data of large enterprises, deriving from the implementation of EED art.8, and they should also provide regular updates.
2. For a more effective use of these data, it is necessary for Member States to improve their quality and define a common methodology for the accounting the national consumption of large enterprises, detailing which items are included or not (transportation, distribution losses, etc.).
3. The NEB and PEFA databases are the cornerstones of Eurostat's public energy statistics: An official merging of both databases will be very useful to obtain a common, multilevel, and aggregated energy database for subsequent independent analysis at sectoral level.
4. A harmonized application of the definition of SME at European and national levels will be necessary to compare the energy structure across countries.

These recommendations could also help to improve the implementation of Article 8 of the EED and be useful in light of the forthcoming recast of the Directive.

The systematic assessment of energy consumption of SMEs at the national level, based on the proposed method, would allow to identify the potential for energy saving in SMEs and, on this basis, to plan reliable and effective policy options and to be able to quantify their performance and impacts.

Author contributions All the authors designed the concept, objectives and methods of the study and participated in the material preparation, data collection and analysis. GB, PL and SR developed a first version of the methodology that was subsequently refined by EB, CH, CM, CT and MS. The first draft of the manuscript was written by CH and all authors commented and contributed to improve the manuscript. All authors read and approved the final manuscript.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article itself and in cited Eurostat databases.

Declarations

Competing interests The authors declare no competing interests.

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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