ENERGY EVALUATION EUROPE CONFERENCE 2025
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www.energy-evaluation.org
25 SEP - 26 SEP 2025
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Invisible savings: how data deficiencies in energy efficiency of micro-enterprises influence policy design

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Note: This file is an intermediate version of the paper submitted to the special issue "Show Me the Evidence: Evaluation as the Decision Maker's Best Resource" of the Energy Efficiency journal. Final versions of the papers will be available at this link: https://link.springer.com/collections/gghbiedaaj

ABSTRACT

Micro-enterprises (M-E) in the European Union represent an important economic factor as they contribute almost 17% to the total net turnover of the EU economy. Even more, they also contribute directly to supply chains, local job creation, community development, decentralisation and diversity. Given the disproportion between their high number and low energy consumption, SMEs (especially M-E) are not always prioritised in energy transition initiatives, while their significance in the energy system comes from the aggregated energy consumption, spillover of energy expenses to households and significant influence on the sustainability of the supply chain.

To determine how M-Es are assigned in statistics needed for policy design, we combine a top-down cross-country analysis of publicly available datasets with a bottom-up case study from Croatia. The dataset assessment across ten EU Member States reveals serious deficiencies in core indicators such as energy consumption, sectoral classification by company size, and financial information. While some coverage can be achieved through complementary sources such as ORBIS, major inconsistencies remain, including significant discrepancies between Eurostat and research databases.

The Croatian case study, based on survey data from 470 M-Es, highlights extensive overlaps between household and business resource use: 43% share energy bills and 64% share vehicles with household purposes. These overlaps complicate both household and business energy statistics, suggesting that current data collection approaches underestimate M-Es' true energy significance.

Our findings underscore the need for systematic improvements in M-E data collection and integration into existing statistical frameworks. Addressing these gaps is essential for evidence-based policymaking, particularly in the context of the EU Social Climate Fund, policies targeting energy vulnerability and companies.

Keywords:

data, energy efficiency, micro-enterprises, policy design, statistics

Introduction

Micro-enterprises (M-E) play a vital role in European industries' ecosystems and value chains, with 93.7% of EU companies falling under this category of Small and Medium Enterprises (SMEs). According to Eurostat's Structural Business Statistics, M-E also contribute significantly to Europe's total net turnover, accounting for nearly 17% at the EU level and, when looking at the whole SME sector, M-Es contribute with 29.8% to total employment (Katsinis et al., 2024). They are a vital component of many economies around the world and even more in Europe, playing a key role in driving economic growth and providing employment. (Eggers, 2020) A large portion of households depend on micro- enterprises for their income, making their viability an important concern for the EU.

Despite their importance, M-Es have received limited attention in energy transition policies. On the EU level, there are no specific quantitative targets or mandatory energy efficiency requirements for M-Es; their involvement remains largely voluntary (Agrawal et al., 2023). At the national level, policy coherence is weak, and most support remains informational. One reason is that, compared to their numbers, individual energy consumption of M-Es is relatively low and highly differentiated. Yet, aggregated across sectors, their consumption and costs are far from negligible.

A key challenge is in the absence of dedicated datasets. European energy statistics do not distinguish by company size, and even on the SME level, national coverage is inconsistent. This makes it difficult to determine even "average" energy consumption for a micro-enterprise. Estimates of SME energy use vary widely: methodologies applied in different EU countries have produced results ranging from 9% to 18% of gross inland consumption, with some estimates reaching nearly 30%. (Herce, Martini, et al., 2024, Herce, Biele, et al., 2024)

The consequences of these data gaps extend beyond statistical precision. If M-Es are not represented in energy efficiency monitoring frameworks, policies may be poorly designed, inadequately targeted, or carry unintended effects. For instance, market-based policies designed with medium-sized firms in mind could impose disproportionate costs on micro-enterprises, requiring compensatory measures such as additional subsidies. Similarly, overlaps between household and business energy use, common among M-Es operating from home, blur the boundaries between business and household energy statistics. This may distort indicators of both household energy demand and energy poverty.

This paper investigates how data deficiencies influence the design and evaluation of energy efficiency policies for M-Es. We address the following research questions:

- What datasets are required to design and evaluate energy efficiency policies in M-Es?
- How complete and reliable are existing datasets across EU Member States?
- Can complementary sources fill the gaps, and with what limitations?
- How do these data gaps affect the accuracy of household and business energy statistics (illustrated by a Croatian case study)?

To answer these questions, we combine a top-down analysis of data availability across ten EU Member States with a bottom-up survey of 470 Croatian M-Es. Section 2 describes the methodology, Section 3 presents the cross-country data assessment, Section 4 reports on the Croatian case study, Section 5 discusses implications for policy and research, and Section 6 concludes with recommendations.

Background and methodology

Concept and literature

Micro-enterprises (M-Es) are underrepresented in energy efficiency research compared to SMEs and larger firms, despite making up 93.7% of EU companies and contributing significantly to turnover and employment (Katsinis et al., 2024). International organisations (OECD, IEA) have stressed that the lack of insight into M-Es' energy use risks leading to policies that are poorly targeted or that impose unintended burdens on this group. (Fawcett & Hampton, 2020) argue that this omission is systemic: M-Es are entirely overlooked in

policy development or evaluation, often being categorised under household or industrial categories or omitted entirely from policy evaluation frameworks.

Looking into energy consumption, it is practically impossible to determine what average consumption means for a M-E, as it highly depends on the sector and business activity of the company. Even on the level of all SMEs (not specifically micro-companies), most countries have no dedicated datasets and European energy statistics do not include company sizes. Some (non-European) case studies (Greve et al., 2023) show there is major difference among sectors. M-Es, for instance, in the transport sector, allocate nearly 60 percent of their total costs to fuel. On average, the combined expenditure on fuel and electricity represents between 15 and 20 percent of total costs across most sectors, except in retail and wholesale trade, where it is around 5 percent. As (Fresner et al., 2017) prove, investing in auditing energy consumption is cost-effective for smaller companies even when energy intensity (in this case, the cost of energy divided by annual turnover) exceeds only 2%. This highlights the significant impact energy consumption and expenditure have on micro-businesses.

These inconsistencies illustrate the uncertainty created by missing data. (Bhardwaj, 2022) stresses that data gaps in micro and small firms extend beyond energy to financial and operational indicators. Without reliable and disaggregated data, it is difficult to evaluate distributional impacts of policies. Most assessments focus on average treatment effects, overlooking heterogeneous effects across subgroups. (Hitsch & Misra, 2018) underline the risks of ignoring heterogeneity, while (Labandeira et al., 2020) show that distributional analysis is essential to identify winners and losers of efficiency policies. For M-Es, this matters directly. Market-based policies designed for larger SMEs may place disproportionate burdens on the smallest firms. The EU Emissions Trading Scheme for buildings and transport (ETS2), for example, is expected to raise energy costs for businesses. The Social Climate Fund was introduced partly to mitigate such effects (European Commission, 2023). Yet, without reliable M-E data, such compensation may be poorly calibrated.

Another overlooked dimension is the overlap between household and business energy consumption. Many M-Es operate from homes, share bills with households, or use private vehicles for business purposes. As (Hampton, 2017) and (Shi et al., 2023) note, household energy demand is strongly shaped by work-related practices. (Battisti et al., 2022) found that home working increases household electricity and gas bills by €20–25 per month. However, this research mainly addresses remote employees, not entrepreneurs.

(Y.-H. Chen et al., 2023) in their review research on household energy demand patterns, data acquisition and influencing factors introduce the drivers for household energy consumption and efficiency. They consist of climate, building type, and socio-demographic factors, which include household composition (adults, children, older people), income (per capita and disposable) and other cultural, policy, behavioural and similar aspects. Other authors (Taneja & Mandys, 2022) include also the composition, age of household members, or in case of (Wu et al., 2024) family size. However, although (Shi et al., 2023) find full-time teleworking leads to 16%–117% higher domestic energy demand, there is a knowledge gap on how exactly energy consumption of M-Es and households are overlapping, or how home-work influences energy consumption. There is, however, a significant number of employees or entrepreneurs working from home. Alternative sources for disaggregation of categories exist, based on regularity of home – work and availability of other options, as presented by (European Foundation for the Improvement of Living and Working Conditions., 2020) but this information cannot be easily adapted to the present evaluation.

Table 1 Types of working from home by type of employees, various sources

Individual homeworkers	Family businesses
Remote employment – having an employer somewhere else than at home, where you do work (example: analysist, programmers, accountants)	Home – based family business – operated from family members in home (catering, crafts, online stores)
Freelancers and gig workers, B2B – self – employment offering services (ex. designers, consultants, task-based)	Small family enterprise, small service – regular business operated by family but including employees, can share dwelling with the household (restaurant, store, small manufacture)
Entrepreneurs – running own business from home (ex. craft makers)	

(Hampton, 2017) discussed the ethnography of home working and the under-researched aspect of working from home within social scientific energy research, emphasising the importance of incorporating

practice, theory and the notion of affect to analyse energy demand and consumption patterns. Research also describes how characteristics of the practice, such as comfort, control, and flexibility, influence energy consumption behaviours and challenge traditional assumptions about energy conservation and demand shifting in the context of home-based work environments. This research highlights the potential for net energy and emissions savings through understanding of home workers' behaviours and practices, important for policymakers, regulators, and employers in shaping future energy management strategies. There are many interesting aspects of this setting in relation to policies targeting energy efficiency and energy poverty. The (ILO, 2020)(data from Delphi questionnaires) claims that 12-13% of workers from home are probably low income. This does not even include directly M-Es and family companies, which are by default disadvantaged.

Taken together, the literature shows a significant knowledge gap: while household energy demand and teleworking impacts are studied, there is almost no systematic evidence on how M-Es' energy use overlaps with household consumption. This overlap has major implications for both household energy statistics (which may overestimate demand) and M-E data (which may underestimate business energy needs). Addressing this gap is another core objective of this study. To examine how data deficiencies affect M-E policy design and evaluation, we combine a top-down dataset assessment with a bottom-up case study survey.

The research design follows five steps:

1. Defining data requirements for evaluating M-Es' energy efficiency.
2. Assessing dataset completeness across ten EU Member States using a pedigree matrix.
3. Identifying additional datasets that can fill gaps.
4. Conducting a case study survey of M-Es to capture household–business overlaps.
5. Linking top-down and bottom-up results to evaluate implications for statistics and policy design.

Step 1: Data requirements for policy evaluation

To determine the appropriate dataset for evaluating energy efficiency policies, we utilized the evaluation toolset from the ODYSEE-MURE project, which has been assessing energy efficiency policies for the longest period. From the analysis of (ODYSEE-MURE, 2020) , we establish the possible indicators and from them the dataset needed to design or evaluate energy efficiency policies in M-Es, based on current dataset needed for other sectors. It is important to consider that for M-Es this means all energy consumption in building uses, processes and transport. The suggested indicators for evaluating energy efficiency policies can include the following, as shown in Table 2:

Table 2 List of indicators for micro-enterprises energy efficiency, adjusted from indicators in (ODYSEE-MURE, 2020)

Type	Indicator	Unit
Total company	Energy expenditure per employee (and/or users)	EUR/employee
	Energy expenditure per revenue (or in all expenditure or profit)	%
	Energy consumption per unit or value added	EUR/unit
Building and process energy	Energy consumption per office space	toe/office
	Energy consumption per m^2	toe/m^2
Building energy – *supportive indicators*	Unit consumption with climatic corrections Unit consumption of electricity for cooling Unit cons. per office for space and water heating Unit cons. per office for cooking Unit cons. per office for lighting and other	toe/office kWh/office kWh/office toe/office kWh/office
Transport	Unit consumption of a vehicle	toe/vehicle
	Consumption of all vehicles (cars/buses/freight/light duty vehicles) in micro-enterprise	toe/company

From the above indicators' list in Table 2, we evaluate the needed dataset.

- *Company location:* The location of a M-E impacts its energy consumption through factors like climate conditions and energy dependence. Heating and cooling needs are linked to heating degree-days, as (D'Amico et al., 2019) argue, so they are needed to evaluate baseline consumption.

- *Building characteristics and dwelling (including ownership):* The buildings sector includes various typologies with differing physical (age, size, construction) and operational (activities, internal loads, ventilation, schedules) characteristics, which affect energy demand, as (González-Torres et al., 2022) describe. Besides these inputs, important information would be the square meters of the dwelling or part of the dwelling use and the purpose (office or industrial facility).
- *Ownership and/or use of vehicles* including number and type of vehicles, vehicle fuel and efficiency and average kilometres per year.
- *Size of the M-E (number of employees):* (Raggio et al., 2020) argue that for cross-sector comparison, the most relevant indicator of energy efficiency should be energy productivity. However, the most used indicators of energy efficiency are rather straightforward and link energy consumption to an economic activity in physical terms. (Kotsopoulos et al., 2023; Ricardo Energy & Environment, 2019) In the case of M-E, the simplest indicator can be energy consumption per employee, due to differences among M-E
- *Sector classification of M-Es, along with sectoral activity indicators:* The consumption of M-Es does not only differentiate at NACE division level (for example H49: Land transport and transport via pipelines), but on level 4 NACE class (for example H49.32 Taxi operation or 49.41 Freight transport by road). The companies in different NACE classes have significantly different energy consumption and patterns, as seen in the research on these two exact sectors (du Plessis et al., 2023; Weng et al., 2017), although they belong to the same NACE division. Therefore, to evaluate energy efficiency policy, sectoral distribution is an important data.
- *Financial information (revenue, expenses) and value added:* Financial information of the M-Es can help evaluate other direct indicators of energy efficiency, like energy efficiency in the units of produced outputs, turnover, revenue or profit.
- *Energy consumption:* Most important information to obtain is the energy consumption of micro- enterprise in terms of building and process energy and transport fuel consumption, shortly energy consumption per energy carrier.
- *Energy price:* Energy price is highly dependent on where (what kind of premises) M-E does their primary activity. A study by (PWC (for CREG), 2018) shows significant differences in prices among households and commercial sector. In general, the assumption is that prices referring to M-Es are those referring to the consumption of less than 1 000 GJ non-household consumers, all expenses included. Similar also applies to electricity, while other prices highly differentiate among countries. However, in all the calculations, there are still some implications of price regulation and capping as described in (Kuzemko et al., 2022) .
- *Number of offices or work premises:* Although this indicator is difficult to obtain, it provides a necessary proxy for space-related consumption (e.g. heating, lighting, cooking). Without it, building energy demand cannot be linked to business activity.

The indicators above highlight a recurring problem: while information exists in Eurostat (SBS, HBS, energy balances) or national statistics, it is rarely disaggregated to the micro-enterprise level. Some indicators (e.g. employees, sector classification at NACE 2) are available but insufficiently granular. Others (e.g. vehicle use, premises data, energy consumption by size class) are almost entirely missing. This justifies our subsequent cross-country completeness analysis (Step 2), where we assess which datasets exist, at what level of detail, and with what reliability.

Step 2: Cross-country completeness assessment

As described by (X. Chen & Lee, 2021; Ciroth et al., 2016; May & Brennan, 2003) and other authors, the pedigree matrix method is a suitable option to assess and quantify data quality across five aspects: reliability, completeness, temporal, geographical, and technological representativeness. We prioritize the criterion of completeness, as other indicators are inconsequential without it. This is due to the challenges associated with achieving the necessary level of completeness, which cannot be adequately addressed even through approximation. For data collection, we rely on publicly available resources, including national databases, government reports, and open-access datasets. Datasets we are referring to include number of M-Es, total (and average) number of employees, energy price for M-Es, sectoral classification, financial information, ownership

and use of vehicles and ownership or use of dwellings. However, as our dataset analysis involves subjective evaluation, we further elaborate on the criteria used for assessment. We add relevant quantification criteria to the datasets: 0. Poor quality / Not available – Data does not exist in any format, 1. Moderate quality / Limited availability or partial coverage (Data for the specific target group is unavailable, but data for the entire sector or all companies is accessible, such as "Legal entity car ownership.", Data does exist but does not perfectly fit the expected use, for example sectoral classification of M-Es which is sometimes available, but not on NACE 4 level.), 2. High quality / Fully available and representative.

Once each dataset has been rated, we aggregate the ratings to evaluate overall data quality score. We repeat the same method for the ten analysed EU countries. The assessment covered ten EU Member States: Belgium, Czechia, Denmark, Greece, Finland, Croatia, Lithuania, Latvia, Romania, and Slovakia. Information sources included Eurostat Structural Business Statistics (SBS), energy price statistics, national registries, ORBIS, and other publicly available data. The scoring was conducted by the authors in consultation with country experts. The results of this scoring exercise are presented in Results section.

Step 3: Identification of additional datasets

The evaluation of data availability in M-Es has revealed a considerable gap in accessible and reliable data. This lack of data is particularly evident in energy consumption, financial information, and sector-specific metrics, making it difficult to assess key performance indicators or implement targeted policies. To overcome this issue, we utilise alternative approaches such as research databases (e.g. Moody's ORBIS database), approximation methods, and modelling techniques to fill the gaps. Research databases provide secondary data that can offer valuable insights and serve as a proxy for the missing information. Approximation methods allow us to estimate key variables based on available data or related benchmarks, while modelling enables us to simulate potential scenarios and predict outcomes under different assumptions. These approaches collectively help to overcome data limitations and enable a more robust analysis, despite the absence of direct or complete data from M-Es.

The estimation of energy consumption baseline in M-Es is divided in building and process energy consumption (for space heating, cooking, domestic hot water and manufacturing processes) and energy consumption in transport. The baseline energy consumption is determined by analysing the energy usage of an average building, across various end uses, such as space heating, domestic hot water (DHW), and cooking, using data from the Integrated Database of the European Energy System, JRC IDEES 2021 (Rozsai et al., 2024). The IDEES database provides energy consumption data for all sectors' buildings by Member State but does not account for specific sector or company size. To estimate the energy consumption of M-Es, we first calculate the average useful energy consumption per employee and per building (as detailed below) and then extrapolate the average consumption for M-Es in each NACE sector based on the typical number of employees. Additionally, the IDEES dataset is used to estimate the energy requirements for thermal services, enabling us to quantify the energy converted into useful thermal energy. Example of calculation is shown below:

$$UEC_E = \frac{UEC_B}{SIZE} \text{ (1)}$$

- *UEC_B= Useful energy consumption/building for different purposes – available data, UEC_E = Useful energy consumption/employee, SIZE= Representative building cell size (employees/representative building cell) – available data*

In the second step, the calculated unitary final energy consumption for each end use is refined by incorporating the efficiency performance of specific technologies.

$$FEC_{E(HNG)} = FEC_{E(HNG)} \times Eff \text{ (2)}$$

- *FEC_E = Final energy consumption/employee- calculated, FEC_E = Useful energy consumption/employee- calculated*
- *Eff = Efficiency of certain energy transformations (useful to final energy) – known data, NG= natural gas (used as example)*

This adjustment allows us to estimate the final energy consumption of an average M-E relying on specific fuel, where applicable (e.g., heating, DHW, and cooking). Additionally, the IDEES database provides information on the share of buildings using various energy carriers for different end uses, enabling a more detailed analysis.

$$FEC_{ME(HNG)} = FEC_{E(HNG)} \times \left[{}^{no\ of\ employees}/_{(M-E)} \right] \text{(3)}$$

- *FEC_{ME} = Final energy consumption/M-E- calculated, NG= natural gas (used as example), H= heating (used as example)*

We then estimate the use of fuel in buildings by considering different possible combinations of fuels. Another option would be PEFA (Physical Energy Flow Accounts). While PEFA does not provide breakdowns by enterprise size, it offers valuable sectoral energy data that can be linked to economic variables such as value added. Including PEFA strengthens the consistency between energy accounts and structural business statistics.

For company-related data, we use the Orbis database, which provides comprehensive and detailed financial, operational, and corporate information on companies. Orbis allows us to access data such as financial statements, ownership structures, industry classifications, and key performance indicators. We use the Orbis database to gather relevant company-specific information, such as turnover, expenditures, and sectoral classifications. This enables us to perform detailed analysis, although we acknowledge that it refers to samples of companies in every country, where the results must be extrapolated to the general sum for the subsectors with M-Es. By leveraging Orbis, we can also segment companies by industry, size, and financial performance, ensuring a more accurate and granular analysis of energy consumption and efficiency across various M-Es.

Step 4: Case study survey

To address overlap between households and micro-enterprises, we conduct a case study by incorporating the questions into our broader questionnaire for M-E and administer it to a sample of 503 (of which 470 with complete answers) M-Es in Croatia, with the assistance of the national Ministry of Environmental Protection and Green Transition for the purpose of Social Climate Fund and vulnerability determinants research. The data is collected through a structured survey using EU-survey, ensuring consistency and comparability with other EU-based studies. The included questions, beyond those on the structure of the M-Es, are:

- What kind of space does your business operate in? *(where one of the possible answers is "House, apartment, household space (you operate where you live) ")*
- Do your business and household overlap, i.e., do you have shared bills for the space you use for both business and private/household purposes? *(yes, no, partially)*
- Do your business and household overlap, i.e., do you have a shared vehicle that you use for both business and private/household purposes? *(yes, no, partially)*

The "Partially" category was designed to capture hybrid situations such as separate electricity contracts but shared heating, or businesses operating one private and one dedicated vehicle.

Subsequent to data collection, we employed statistical analysis to examine the extent of overlap between M-Es and households regarding shared resources, specifically focusing on energy consumption and vehicle usage. This analysis involves quantifying the proportion of M-Es that exhibit such overlap, while also exploring how these overlaps are influenced by key factors such as the size of the M-E and its sector. Furthermore, we analyse how this can influence previously assigned drivers of energy consumption in households and therefore research, modelling and policy in energy efficiency of households.

Results

Data requirements for M-Es and completeness assessment across 10 EU Member States

Building on the indicator framework Table 2Table 2 List of indicators for micro-enterprises energy efficiency, adjusted from indicators in (ODYSEE-MURE, 2020) we confirm the data elements needed for policy evaluation. While Eurostat SBS provides basic information such as enterprise counts and employment, other key indicators (e.g. building characteristics, vehicle use, premises) are not systematically available for M-Es. Even when indicators exist, they are usually aggregated at the SME or sector level, requiring assumptions for micro-enterprises. This finding reinforces the methodological challenges discussed in Step 1. Applying the pedigree matrix approach described in Step 2, we evaluated the availability of datasets in ten countries.

Table 3 Simplified pedigree matrix of data availability, authors with experts' inputs

Data completeness	BE	CZ	DK	EL	FI	HR	LT	LV	RO	SK
Number of M-E.	1	2	2	1	1	2	2	1	1	1

Number of employees	1	2	2	1	1	2	2	1	1	1
Energy price	2	2	2	2	2	2	2	2	2	2
Sectoral classification	1	1	1	1	1	1	1	1	1	1
Financial information	0	1	1	0	0	1	0	1	0	0
Vehicles	1	0	1	0	1	1	1	1	0	1
Dwelling	0	0	0	0	0	0	0	0	0	0
Energy consumption	0	0	0	0	0	0	0	0	0	0
Average completeness	0.75	1.00	1.13	0.63	0.75	1.13	1.00	0.88	0.63	0.75

As seen in the Table 3, countries do not even have own statistics on the total number of M-Es. In this case, those assigned (1) are using dataset from (EUROSTAT, 2025), that does not match information on company's size with financial information. Only some countries have national datasets. In the case of energy prices, we find the aligned source, a combination of (EUROSTAT, 2025) energy prices and (*GlobalPetrolPrices.Com*). Neither of the sources specifically assigns prices to the M-E sector; therefore, we assume regarding the price category to which they belong. Most countries provide sectoral distribution of companies, but not by size. There is no information, assumptions or statistics for energy consumption in M-Es or on the workspace they use. Croatia from research (Vizek, 2021), and Latvia (*Statistikas portāls Latvija)* and Denmark (*Statistics Denmark*) from national statistics, offer similar levels of financial information, such as total expenditure and/or expenditure share in turnover or revenue. Regarding the number of vehicles per company, the distribution of vehicles between private and legal users are available for Belgium (*Federal Public Service Mobility and Transport*), Denmark (*Statistics Denmark*), Finland (*VATT Dataroom based on Statistics Finland data*)*,* Croatia (*Centar za Vozila Hrvatske | Statistika*), Lithuania (*Vehicles | REGITRA*), Latvia (*Dorohins (CSDD)*). Slovakia has only partial information. This, of course, does not include car ownership by M-Es. Our results show advantage of Denmark, that has established data collection above the average EU statistics.

We tested whether alternative sources could improve coverage. The challenge with the ORBIS database is the country coverage. In the case of M-Es, by comparing the overall M-Es number (based on data availability in Table 3), we can evaluate the coverage of M-Es per country. Using such datasets has a crucial role in enabling bottom-up modelling of energy consumption for M-Es. This approach can significantly contribute to determining the baseline energy consumption and energy intensity, which are essential for developing more accurate and tailored energy policies. Although this method may not provide the same level of precision as models based on statistical data, it allows for a more granular, context-specific understanding of energy consumption within the sector. This flexibility is valuable in capturing the heterogeneity of M-Es, which often lack standardised data. Nevertheless, while it offers insights into energy performance, it is important to recognize the challenges associated with data gaps and the need for further refinement in data collection and modelling techniques. IDEES allows estimation of useful energy per employee and per building, which we converted to final energy using efficiency factors (Equation 1). This produced plausible approximations but relies on strong assumptions. National sources (e.g. registries of company cars, building energy certificates) can add depth in some Member States but lack comparability. These datasets provide partial improvements but do not close the fundamental gap: the absence of systematic M-E–specific energy consumption statistics at EU level.

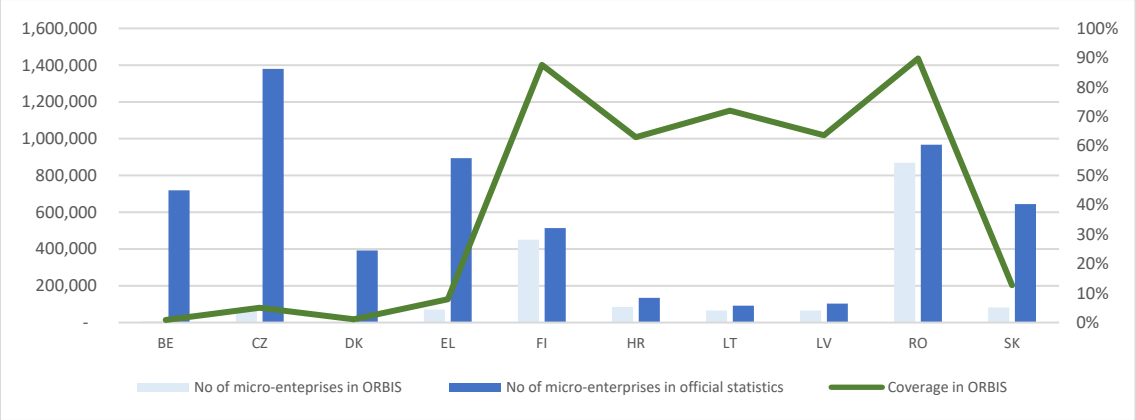

Figure 1 Coverage of M-Es in ORBIS, sources: national statistics, EUROSTAT SBS, ORBIS Moody's (BvD)

Croatia case study – household and business overlaps

As outlined earlier, we gather the data from 470 M-Es in Croatia through an EU survey (with dual purpose for other research also) with questions addressing the overlap between these M-Es and households.
In Figure 2, we show the number of M-Es using household space for operation of the M-E (53%)

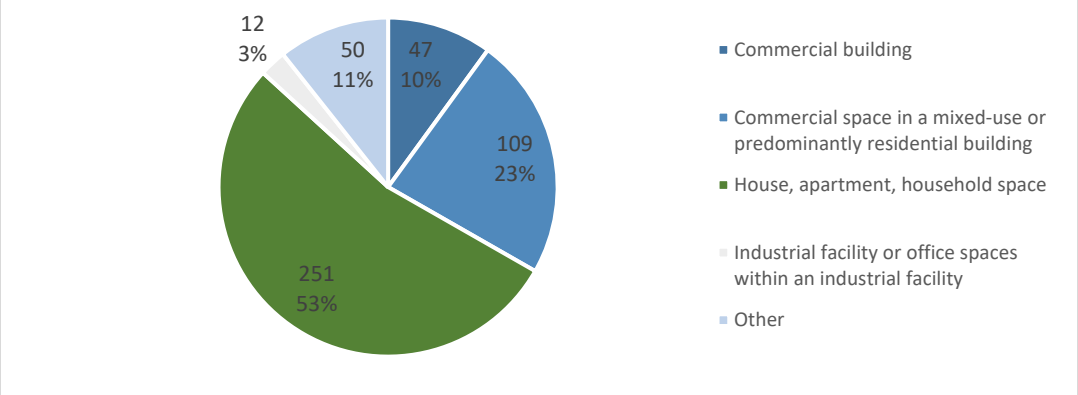

Figure 2 Distribution of workspace types, EU-survey with own analysis

Further analysis on the potential overlap of energy bills for business and households shows that 43% of businesses completely share bills between business and household expenses, 18% have partial overlap in their billing. Only 39% keep their business and household bills separate. Regarding the use of private vehicles for work purposes, 64% of respondents report having a vehicle in private ownership that is also used for business activities, as shown in Figure 3.

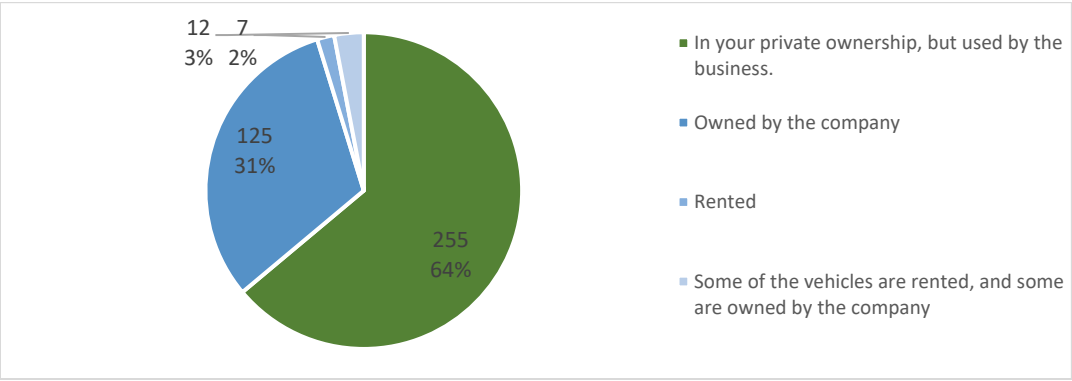

Figure 3 Distribution of vehicle ownership, source: EU-survey with own analysis

To further explain similar statistics, we posed a question on whether business and household overlap, i.e., *does a company have a shared vehicle that is used for both business and private/household purposes.* In that question, nearly two-thirds (65%) of businesses completely share vehicles between business and household use. 15% have a partial overlap, using both shared and dedicated vehicles. About one-fifth (20%) keep their business and household vehicles separate. This suggests that most businesses in the survey integrate their vehicle usage between business and personal purposes, which could have implications for expenses and energy consumption.

In summary, the results highlight a significant overlap between business and household activities among M-Es, particularly regarding workspace and vehicle usage. This overlap presents challenges in distinguishing between business and household energy consumption, which must be carefully considered when modelling energy use and formulating energy policies for both M-Es and households. When looking into independent variables, there is a statistically significant relationship between the number of employees and both types of overlap (vehicle usage and bills). Given that employee numbers may not follow a normal distribution, we applied the Kruskal-Wallis's test to assess whether the medians of employee numbers differ across the groups defined by overlap responses.

For example, for vehicle usage, businesses with partial vehicle overlap have the highest average number of employees (mean = 3.0), businesses with complete vehicle overlap have the lowest average (mean = 1.6) and those with no overlap fall in between (mean = 2.1). This makes sense as very small businesses use their own car and no other vehicles, and larger use their own care along with additional vehicles. For bills overlap, the situation is a bit different for a partial overlap, businesses with no overlap tend to have more employees, and businesses with complete overlap have fewest number of employees.

Table 4 Energy bills overlap by number of employees in M-E, authors' analysis of the survey

Employees (including owner)	Number of M-E	No Overlap	No (%)	Full Overlap	Full (%)	Partial Overlap	Partial (%)	Full+Partial (%)
0	22	4	18.2%	14	63.6%	4	18.2%	81.8%
1	256	78	30.5%	140	54.7%	38	14.8%	69.5%
2	86	42	48.8%	28	32.6%	16	18.6%	51.2%
3	42	24	57.1%	12	28.6%	6	14.3%	42.9%
4	22	11	50.0%	3	13.6%	7	31.8%	45.4%
5	14	6	41.9%	4	28.6%	3	21.4%	50.0%
6	12	6	50.0%	1	8.3%	5	41.7%	50.0%
7	4	3	75.0%	0	0.0%	1	25.0%	25.0%
8	7	5	71.4%	1	14.3%	1	14.3%	28.6%
9	4	2	50.0%	0	0.0%	2	50.0%	50.0%
n/a	1	1	100.0%	0	0.0%	0	0.0%	0.0%
Total	470	182	38.7%	203	43.2%	83	17.7%	60.9%

We did a statistical analysis to determine if this relation is significant. We calculate expected values for every number of employees, theoretical value if there is no statistical significance (example below is for 1 employee, answer "Yes"), and compare all expected values to the observed values, as shown in the table in Annex 1, using Chi-square calculation formula:

$$E_i = \frac{Rows\ number\ (1\ employee) \times Columns\ number\ (\text{"Yes"})}{Total\ relevant\ answers} \quad (4);$$

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \quad (5)$$

Our χ^2 is calculated as 55.657, while our p-value is around 0.00001, meaning that our observations are not in line with expected contribution of answers unrelated to number of employees (null-value), but are significantly dependent on the number of employees. This influences significantly our conclusions. In terms of sectors, the construction sector exhibits a very high overlap in both categories, with 76% for bills and 97% for vehicles. The digital services sector shows a notable overlap in bills (89%). The passenger transport sector also demonstrates consistently high overlap in both categories, with 75% for bills and 90% for vehicles, also the culture and creative sector.

Linking top-down and bottom-up

The case study results demonstrate how household–business overlaps complicate both household and business energy statistics. Household surveys may overstate domestic energy use when part of it is business-related, while business statistics understate the actual energy needs of M-Es. For example, energy poverty indicators based solely on household bills risk misclassifying households with energy-intensive home-based M-Es. By linking the survey evidence with the dataset completeness assessment, we show that top-down indicators could be adjusted if such overlaps were systematically captured. Incorporating this dimension into data collection would improve both the accuracy of M-E energy statistics and the robustness of household energy policy design.

Discussion

Contribution to literature

This paper contributes to the growing body of work on SMEs and energy efficiency by making micro-enterprises visible as a distinct category. While SMEs have been examined as a group, micro-enterprises are rarely separated in either analysis or policy frameworks. By applying the ODYSEE-MURE indicator set to M-Es and assessing dataset completeness across ten EU Member States, we show precisely where official statistics fail. The case study represents one of the first empirical attempts to measure household–business overlaps for M-Es. Prior literature on teleworking focused on employees, but not entrepreneurs. Our results extend this debate by showing that overlaps also distort official statistics, with implications for both household and business policy design.

Policy implications

The assessment of data availability across ten Member States reveals significant gaps in sector-specific information on micro-enterprises. Indicators such as energy consumption, financial details, and sectoral classification by size are either missing or only partially available. Many countries lack any disaggregated data on M-Es, while only a few offer limited financial information that is comparable across size classes. The absence of energy consumption data and workspace usage information necessitated estimation methods, but our work highlights even more strongly the need for consistent data collection and better alignment across statistical sources.

The survey confirms the importance of this issue. Among 470 respondents, 43% reported overlapping household and business energy bills, and 64% reported overlapping vehicle use. These overlaps complicate the distinction between household and business consumption and suggest that current statistics underestimate M-E energy use while overstating household demand. The implications are especially significant for very small M-Es with zero or one employee, which appear most exposed to these overlaps. These findings highlight several policy-relevant insights:

- *Improving statistical baselines:* Without systematic M-E data, EU and national policymakers cannot design evidence-based interventions. Current reliance on SME aggregates risks misrepresenting the distributional effects of policies such as ETS2.
- *Targeting support measures*: The Social Climate Fund is intended to mitigate energy cost burdens, yet our results suggest that households with home-based M-Es may be misclassified. These households could face both higher energy costs and business risks, making them doubly vulnerable.
- *Integrating household–business overlaps:* Policies addressing energy poverty, household energy efficiency, or SME competitiveness should explicitly consider overlaps. For example, building renovation schemes could target mixed-use dwellings, while transport policies could account for shared vehicle use.
- *Harmonising data collection:* A coordinated effort at EU level is needed to link SBS, PEFA, and household surveys with new M-E–specific indicators. Even simple additions such as recording whether households include home-based businesses, would improve policy evaluation.

Explaining anomalies and discrepancies, limitations

The completeness assessment revealed important discrepancies between datasets. ORBIS often diverges from Eurostat SBS, with coverage varying across countries. We hypothesise that this is due to differences in reporting requirements, treatment of inactive firms, and the exclusion of companies without employees. Similarly, energy price data often appear more complete than financial data, not because of higher quality but because proxies (for example non-household users <1000 GJ) are used. Recognising these anomalies is essential to avoid false confidence in apparently "complete" indicators.

Several limitations should be acknowledged. First, the pedigree matrix scoring, while systematic, remains partly subjective and dependent on our expert judgement. Second, the Croatian survey covers only 0.2% of national M-Es, although it is stratified. Third, survey questions captured overlaps, but analysis does not include energy quantities and measurement directly. Finally, our analysis focused on ten EU Member States and extending the approach to all Member States would provide a fuller picture.

Future research directions

Future work should expand surveys on household–M-E overlaps to other countries and sectors, develop methods for quantifying the share of household energy attributable to business activity, and test the integration of PEFA, SBS, and IDEES into harmonised indicators. There is also a need to evaluate distributional effects of policies such as carbon pricing specifically for M-Es, drawing on approaches that account for heterogeneous treatment effects

Conclusions

This study examined how data deficiencies affect the evaluation of energy efficiency policies for micro-enterprises, combining a cross-country completeness assessment with a bottom-up case study in Croatia. Across ten Member States, we found that key indicators such as energy consumption, building use, and transport activity are either missing or aggregated in ways that render them unsuitable for analysing M-Es. Financial data are available in some cases but remain poorly harmonised.

The survey of 470 M-Es revealed that nearly half of firms share household energy bills and almost two-thirds share vehicles with household use. These overlaps demonstrate how household statistics overstate domestic energy demand while business statistics understate the true energy needs of M-Es. The issue is particularly pronounced for very small firms with one or no employees.

These findings suggest that the invisibility of micro-enterprises in energy statistics is not only a technical issue but also a policy challenge. Better M-E–specific data collection, aligned with instruments such as the Household Budget Survey, would improve the design of efficiency and vulnerability policies. At the same time, household datasets such as HBS and EU-SILC should recognise business-related energy use to avoid biased indicators of energy demand and poverty. Recognising overlaps between households and M-Es is therefore essential for ensuring that the smallest firms, which form the backbone of EU economies, are not overlooked or disproportionately burdened in the European Green Deal transition.

Acknowledgements

We thank our colleagues here stated as country experts for the included EU countries, for their valuable contributions to the datasets.

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Annex 1

Table 5 Statistical significance of number of employees in overlap of bills, own analysis from survey results

Employees	Response	Rows number	Columns number	Expected value	Observed value
0	No	22	181	8.53	4
1	No	256	181	99.22	78
2	No	86	181	33.33	42
3	No	42	181	16.28	24
4	No	21	181	8.14	11
5	No	13	181	5.04	6
6	No	12	181	4.65	6
7	No	4	181	1.55	3
8	No	7	181	2.71	5
9	No	4	181	1.55	2
0	Yes	22	203	9.56	14
1	Yes	256	203	111.28	140
2	Yes	86	203	37.38	28
3	Yes	42	203	18.26	12

4	Yes	21	203	9.13	3
5	Yes	13	203	5.65	4
6	Yes	12	203	5.22	1
7	Yes	4	203	1.74	0
8	Yes	7	203	3.04	1
9	Yes	4	203	1.74	0
0	Yes, partially	22	83	3.91	4
1	Yes, partially	256	83	45.5	38
2	Yes, partially	86	83	15.28	16
3	Yes, partially	42	83	7.46	6
4	Yes, partially	21	83	3.73	7
5	Yes, partially	13	83	2.31	3
6	Yes, partially	12	83	2.13	5
7	Yes, partially	4	83	0.71	1
8	Yes, partially	7	83	1.24	1
9	Yes, partially	4	83	0.71	2