Navigating efficiency, productivity, and profits: A deep dive into firms' energy use in the EU and the US

Anastasia Bruni[a,b], Fotios Kalantzis[c,d], Matteo Manera[a,b], Debora Revoltella[c]

[a] *Fondazione Eni Enrico Mattei, Italy*
[b] *Department of Economics, Management and Statistics, University of Milan-Bicocca, Italy*
[c] *Economics Department, European Investment Bank, Luxembourg*
[d] *Corresponding author: f.kalantzis@eib.org*

Abstract

This study uses unique firm-level data covering approximately 12 000 firms across the EU27 and 800 in the United States from European Investment Bank Investment Survey (EIBIS) to investigate the links between energy efficiency, productivity and profitability. Many firms seeking to maximise profits may not recognise the potential financial benefits of enhancing energy efficiency and productivity. We employ meta stochastic frontier analysis to estimate energy efficiency for each firm, accounting for differences in technologies across 14 sectors. Energy productivity is then assessed using two methods: (1) Total-Factor Energy Productivity estimation via the Malmquist productivity index, and (2) traditional Total Factor Productivity (TFP) estimation using the Levinsohn-Petrin method, followed by decomposing TFP into energy and non-energy components. This initially allows us to identify the best and worst performers in energy efficiency and/or energy productivity, comparing them with their profitability. We then investigate the separate effects of energy productivity and energy efficiency on profitability using an instrumental variables (IV) approach, hypothesizing a U-shaped relationship—initially declining but increasing at higher levels of productivity or efficiency. After recovering the initial costs of actions adopted to increase energy productivity and/or energy efficiency, firms may reach higher profitability caused by these factors. Hence, it may be beneficial for profit-maximising firms to consider both energy efficiency and energy productivity in their decision-making process.

Keywords: energy efficiency, productivity, total-factor energy productivity, profitability, stochastic frontier analysis, input distance function

1. Introduction

Transitioning to a net-zero economy is not just an environmental imperative but a strategic one, pivotal for the sustainable future of our planet (Bonsu 2020). As we stand at the crossroads of climate change, the collective effort to reduce carbon emissions to net zero emerges as a crucial goal (Rootzén et al. 2020; Colding et al. 2022). It is essential that every individual, community, and especially firms, which are the backbone of our economy, actively engage in this transformation (Hamann et al. 2023). They must lead the charge in adopting energy-saving innovations and practices, setting a precedent for efficiency and responsibility (Dieperink, Brand, and Vermeulen 2004). However, this path is not without its challenges. Concerns loom over the economic ramifications of such a transition, with apprehensions that certain firms and sectors may struggle to keep pace, potentially facing obsolescence (Madureira 2012). This study aims to address these complexities, exploring how a balanced approach can ensure that the march towards a greener economy is both inclusive and economically viable, leaving no entity behind in the quest for a cleaner world (Noman et al. 2024).

Numerous studies in non-energy fields mention the importance of distinguishing between efficiency and productivity (Coelli et al. 2005; Fried, Lovell, and Schmidt 2008; Grosskopf 1993; Kumbhakar, Denny, and Fuss 2000). These two concepts are often used interchangeably but their difference is particularly important in the assessment of their impact on profitability (Dimitropoulos 2007; Kumbhakar, Horncastle, and Wang 2015). In the field of energy economics, the papers typically choose to concentrate either on energy efficiency or energy productivity in relation to profitability. However, when measuring energy efficiency as the inverse of energy intensity it may be that some of the existing studies truly capture the energy productivity. The methods we use in estimating both energy efficiency and energy productivity that are outlined in the methodology section aim to ensure that the differences between efficiency and productivity are taken into account when exploring their effect on firm's financial performance. The choice of energy efficiency could be more suitable when the objective of the analysis is related to climate goals, while the difference between energy efficiency and energy productivity may be more pronounced when considering the firm's perspective, in which case the accurate estimation of energy productivity is likely to provide ways of reaching higher levels of competitiveness.

Existing research consistently shows that both energy efficiency and productivity can significantly enhance firms' profitability. In particular, Cantore, Calì, and Velde (2016) and Fan et al. (2017) found a positive relationship between energy efficiency and profitability, with the latter also highlighting the role of firm growth in this relationship. Both papers by Romm (1995) and Kalantzis and Niczyporuk (2022) further underscore the potential for energy efficiency to improve labour productivity, with the latter specifically focusing on investments in energy efficiency of the European firms. Schleich (2007) and Lee (2015) identify barriers to profitable energy efficiency investments, such as financial and non-financial factors, and the potential for energy management to reduce production costs. Moreover, McGinley, Geary, and Dodenhoff (2015) emphasised the role of technology in driving improved energy productivity, particularly in manufacturing process applications.

The following conceptual map illustrates the key features and potential connections explored in this study.

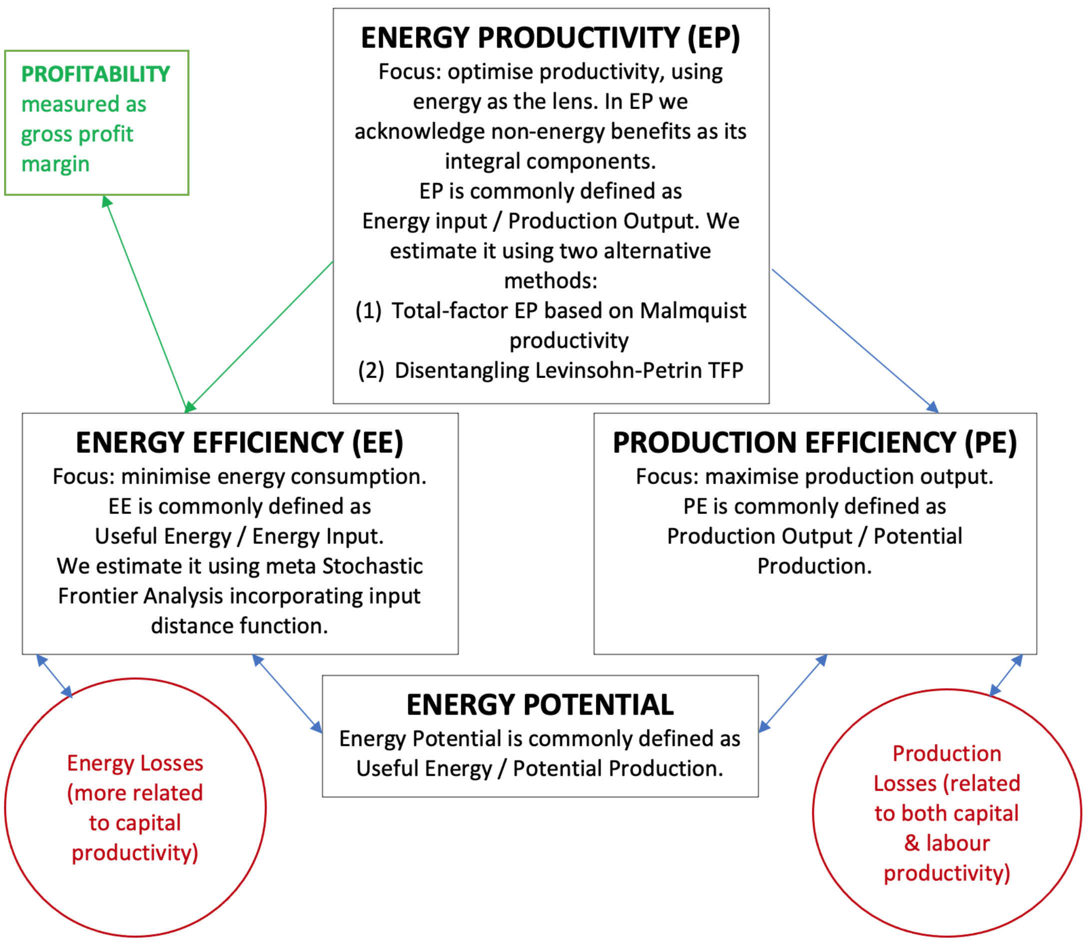

Figure 1: Conceptual map.
Source: International Energy Agency (2021), Rely Ability Energy Productivity (2021) and authors' own ideas.

2. Data

The European Investment Bank Investment Survey (EIBIS) stands as a unique source of information on investment activities and needs of firms within the European Union. Conducted annually since 2016, it encompasses a representative sample of over 12,000 firms from various sectors and sizes, ensuring its representativeness at the EU, country, sectoral, and firm size levels (Brutscher et al. 2020). EIBIS primarily focuses on gathering data on firms' investment activities, financing requirements, and their responses to climate-related challenges. The latter includes inquiries into firms' perceptions of climate risks and opportunities, their strategies for climate change adaptation and mitigation, and their investments in green technologies and practices. The survey uses a stratified sampling methodology, drawing its sample from the Bureau van Dijk ORBIS database (European Investment Bank 2023; Bureau van Dijk 2023).

In order to evaluate the impact of firm-level characteristics and sector-related and country-specific conditions on climate change investments, our analysis utilises cross-sectional data for the year 2023 for 27 EU countries, with variables other than energy spending available for the panel from 2016 until 2023 and a possibility of estimating energy spending for the year 2022. Firm-specific data were collected from the EIBIS, which include firm-level variables, such as age, size, turnover, fixed assets, wages, number of employees, total investment, profit, investments in energy efficiency in all available years and the energy spending variable that was introduced in 2023. Additionally, there are variables that indicate the country and the sector the firm belongs to at 4-sector (manufacturing, construction, services, infrastructure), NACE 2-digit and 4-digit classifications. We further use the 14-sector classification (energy, food & agriculture, textile, chemicals & pharmaceuticals, electronics, machinery, raw materials, construction, trade, transportation, tourism & arts, IT & telecommunications, other services, water supply) based on the categorisation of a more disaggregated NACE 2-digit classification conducted in line with the sector classification and aggregation methodology in Eurostat (2008). Table 1 in Appendix A describes the variables used in this study in further detail.

3. Methodology

The first methodological step in this study is to estimate energy efficiency (EE) and energy productivity (EP). The energy efficiency is estimated using the parametric approach, namely Stochastic Frontier Analysis. In this respect, our study generally follows economy-wide EE SFA-based estimations as in Zhou, Ang, and Zhou (2012) featuring the Cobb-Douglas functional form, with the difference of choosing translog functional form as in Honma and Hu (2013) and for sectors and Honma and Hu (2018) for regions in Japan due to its potentially greater flexibility regarding the restriction of parameters in a priori assumptions related to substitution and output elasticities (Lau 1986). In this choice, we follow Pascoe et al. (2003) in testing key distributional assumptions and Zelenyuk and Wang (2023) in their model selection approach that incorporates Akaike's Information Criteria (AIC) and Bayesian Information Criteria (BIC).

Furthermore, we consider various features of the firm-level energy efficiency SFA estimations based on studies of firms located in Germany in Lutz (2016), plants in the US in Boyd (2008), and specific energy-related considerations when using SFA, as proposed in Filippini and Orea (2014).

The SFA literature points out three main ways of dealing with heterogeneity in technology. The first method is Bayesian SFA used in some of the firm-level studies, in particular Haider and Mishra (2021) in case of energy efficiency as well as Arbelo, Arbelo-Pérez, and Pérez-Gómez (2022), Haschka, Schley, and Herwartz (2020) and Tsionas and Mallick (2019) estimating other (i.e. non-energy) types of efficiencies. The second aproach is the latent class SFA, for example the papers by Becchetti and Trovato (2011), Dakpo, Latruffe, and Desjeux (2021), Baráth et al. (2024) and Cullmann (2012) estimating various types of efficiencies, while a few studies focus specifically on energy efficiency, in particular Lin and Du (2014) and Orea and Jamasb (2017). The third approach is an estimation of the meta-frontier, which consists of the division of decision-making units into subgroups and estimating frontiers for each subgroup and subsequently using those separate estimations in the construction of the final meta-frontier. Our paper adopts the meta-frontier approach for 14 sectors as it does not require numeric priors to be specified an an informed manner as in the case of the Bayesian SFA and is fairly easy to conduct in comparison with the latent class SFA, which in turn may be used in further analysis as an additional method to ensure the reliability of the results.

Particular attention is given to the incorporation of the input distance function within the SFA analysis as it ensures that the efficiency is estimated with respect to energy input and not other inputs such as capital or labour. In order to follow this approach, we estimate the distance function that is homogeneous in energy, which is achieved by dividing all other inputs (capital and labour) by the energy input (Zhou, Ang, and Zhou 2012; Honma and Hu 2018; Cao, Qi, and Ren 2017). Hence, in the SFA estimation we use energy as a dependent variable, while the independent variables are the turnover (considered as output) as well as distances between each input other than energy and the energy input. The SFA approach also allows us to specify the variables that have the direct effect on inefficiency, which in our analysis include energy costs, availability of finance, total assets, investments in energy efficiency and country. The preliminary results of estimating efficiencies using the Meta-SFA across 14-sector classification over three geographic regions in the EU are shown in a spider diagram in Figure 2 and its distribution in Figure 3 in the Appendix B.

Following the estimations of energy efficiency, we estimate energy productivity. In this estimation, we follow a two-step stochastic meta-frontier Malmquist Index approach, as in Cao, Qi, and Ren (2017) and in line with Du and Lin (2017). The estimation of Malmquist productivity, which is typically defined as the product of the technical efficiency change and the technological change, allows productivity estimation with flexibility related to multi-input, multi-output and intertemporal dimensions. After estimating and taking into consideration the Malmquist Productivity Index, we take it into account when estimating the energy productivity Khoshroo, Izadikhah, and Emrouznejad (2022).

An alternative method we use to estimate the energy productivity and to cross-check our previous estimations is to estimate the TFP using the Levinsohn-Petrin approach detailed in Levinsohn and Petrin (2003), followed by the disentangling procedure of the TFP into its energy and non-energy components using a method analogous to Doraszelski and Jaumandreu (2018) while being applied in the context of TFP and the energy input related to it.

The second methodological step is to investigate how the EE and the EP affect profitability. We initiate this analysis by using the estimated energy efficiency and energy productivity to identify which firms are the leaders and which are the laggards in relation to either energy efficiency or energy productivity, as well as both EE and EP (McCauley et al. 2023). We then compare the EE and EP leaders and laggards with the most profitable firms.

Furthermore, we estimate two separate regressions both containing profitability as a dependent variable, while changing the main explanatory variable being either the estimated EE or the estimated EP. We also include the main explanatory variable being squared as there is an expectation of the U-shaped pattern caused by the initial costs of eliminating inefficiency or increasing productivity. Endogeneity is addressed using the Instrumental Variable (IV) approach with the energy audit or climate targets of the firm as the IV (Sande and Ghosh 2018; Kalantzis and Niczyporuk 2022).

4. Contribution of this study

The first major contribution of this study is its thorough improvement of the understanding of energy performance measures, especially energy productivity and energy efficiency. Unlike previous research that examined the nexus between energy efficiency and productivity by focusing on total factor productivity or labor productivity, as demonstrated in studies by Montalbano, Nenci, and Vurchio (2022) and Santos, Borges, and Domingos (2021) or by analyzing the overall productivity stochastic frontier as done by Shui, Jin, and Ni (2015) our study innovatively separates productivity into its distinct energy and non-energy components. This nuanced approach provides a clearer, more precise evaluation of energy performance. Moreover, our commitment to transparency and replicability is underscored by meticulously detailing the methodologies employed in measuring energy efficiency and energy productivity, setting a new standard for future research in this field.

The second significant contribution is the utilization of unique EIBIS data, which enables an in-depth examination of heterogeneity across different countries and sectors on a pan-European scale and in the US (Brutscher et al. 2020). This extensive dataset allows us to capture and analyse variations in technology adoption, resource availability, and institutional factors across diverse regions and industries. By incorporating these dimensions, our research offers a more granular and comprehensive understanding of energy performance across different contexts, highlighting the critical factors that influence energy efficiency and productivity.

Furthermore, our study delves into the complex relationship between energy use (efficiency and productivity) and financial performance. By exploring these connections, we aim to provide actionable insights and strategic guidelines for firms striving to enhance their competitiveness. Our analysis considers significant barriers and challenges, including the availability of finance for firms and the perception of energy costs as a substantial impediment to investment activities. By addressing these practical difficulties, our research offers a holistic view of the decision-making processes within firms, emphasizing the importance of integrating energy considerations into their overall strategic planning.

To sum up, this study not only advances the academic understanding of energy performance measures but also provides practical insights for policymakers and business leaders. By differentiating productivity components, leveraging comprehensive data, and exploring the financial implications of energy performance, our research contributes valuable knowledge to the ongoing discourse on energy efficiency and productivity enhancement.

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Appendix A. Description of main relevant variables from EIBIS

Variable	Question in EIBIS or formula	Obs.
Capital	What is the firm's total investment spend across all these areas?*	12,600
Labour	How many people does your firm employ either full or part time?	12,832
Wages	How much was the spend on wages (gross, i.e. including benefits)?	12,052
Energy spend	How much was the total spend on energy?	11,973
Turnover	What is the turnover your company received?	12,555
Value added	Calculated as EBIT + wage bill	10,814
Profit or loss	Was there a profit or a loss before tax, or a break-even?	12,334
Profit %	Profit or loss (EBIT) as a % of turnover in 5 categories of % ranges	10,990
Profit (cont.)	Profit or loss (EBIT) as the average % of turnover X turnover / 100	10,822
EE inv. (binary)	Did your company invest in improving EE?	12,087
EE inv. %	What proportion of the total investment is for improving EE?	10,349
EE inv. (cont.)	EE inv. % of total investment * total investment in euros / 100	10,349
Energy costs	Are energy costs a major obstacle to investment activities?	12,087
Avail. of finance	Is availability of finance a major obstacle to investment activities?	12,087
Energy audit	Was the energy audit conducted in the past 3 years?	11,633
Climate targets	Does your firm set and monitor targets for its own GHG emissions?	11,911
Total assets	Value of total fixed assets (incl. tangible assets & intangible assets)	11,241
Size (categ.)	Company size (Micro, Small, Medium, Large)	12,087

Table 1: Summary of main variables and observations. *Data: EIBIS.*

*The areas that are listed in the survey: A. Land, business buildings and infrastructure B. Machinery and equipment C. Research and Development (including the acquisition of intellectual property) D. Software, data, IT networks and website activities E. Training of employees F. Organisation and business process improvements, such as restructuring and streamlining. *This question is followed by asking how much each business invested in each of the areas listed above with the intention of maintaining or increasing their company's profits.* Note: There are a few other questions regarding investments reported below.
Q: What proportion of the total investment was for each of the following areas: A. Develop or introduce new products, processes or services B. Replace capacity (incl. existing buildings, machinery, equipment and IT) C. Expand capacity for existing products/services.
Q: Is your company investing or implementing any of the following, to reduce Greenhouse (GHG) emissions? (there is a binary variable for each of the following areas) A. My company is investing in new, less polluting, business areas and technologies B. Investing in energy efficiency (including heating and cooling improvements, energy management (e.g. energy smart technologies, EMAS) C. Onsite/offsite renewable energy generation D. Waste minimization and recycling E. Sustainable transport options (e.g. Fuel efficient and hybrid/electric vehicles, electric rolling stock) F. None of these.

Appendix B. Preliminary energy efficiency estimations from SFA

The following diagram shows the efficiency indicator estimated using the Meta Stochastic Frontier Analysis across 14-sector classification over three geographical regions.

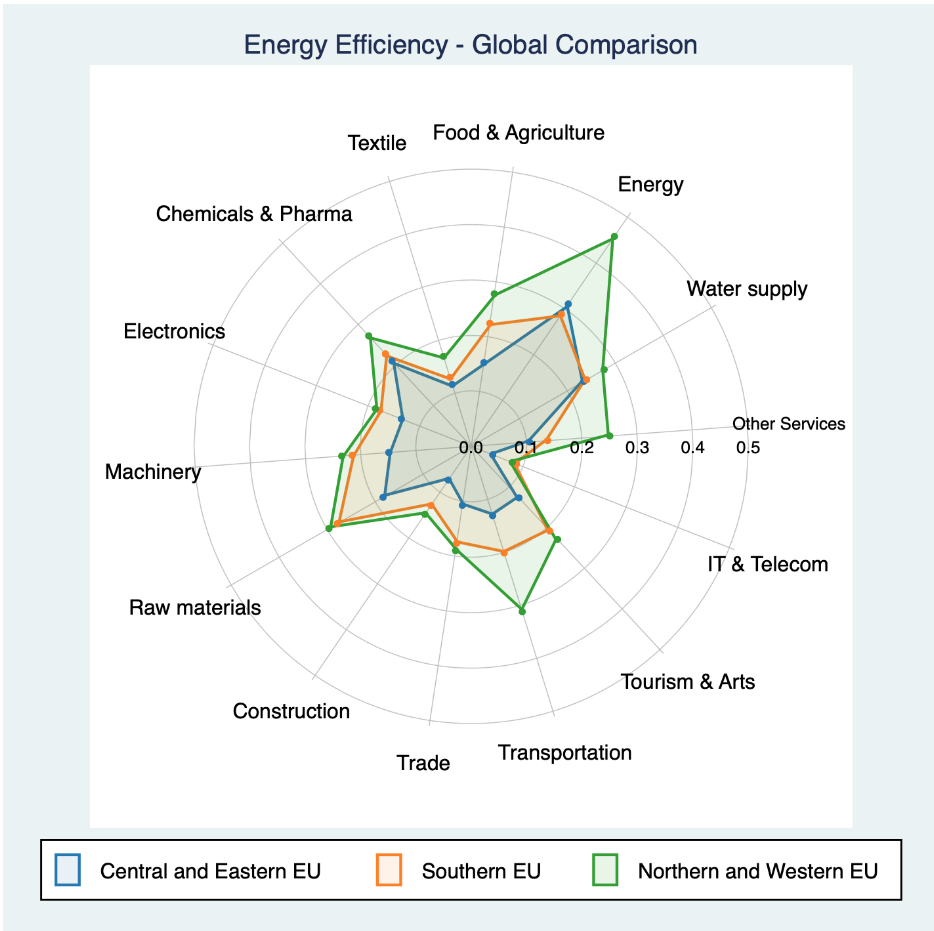

Figure 2: Energy efficiency estimated using the Meta-SFA method by 14-sector classification over 3 geographical regions in the EU. *Data: EIBIS.*

The graph below shows the density and the cumulative distribution for the energy efficiency estimations from the Meta-SFA.

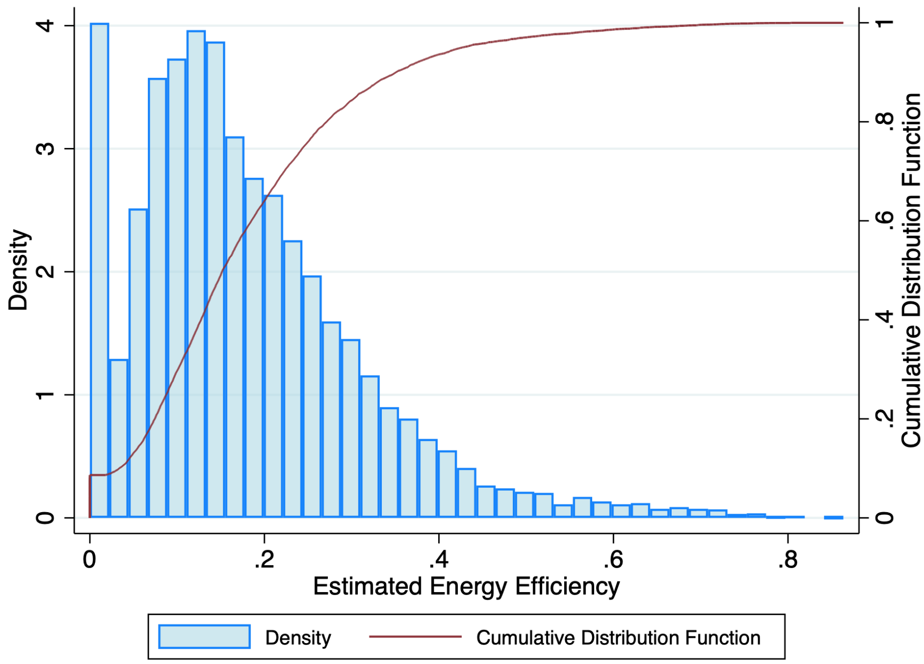

Figure 3: Energy efficiency estimated using the Meta-SFA method. *Data: EIBIS.*