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

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The big picture: Key Takeaways

Positive Impact of Energy E ciency:

- Boosts nancial performance, including pro tability and Total Factor Productivity (TFP).

Energy E ciency varies widely by sector and region:

- US rms roughly match EU energy performance, but some EU countries and sectors appear to be leading this trend, showing the need for customized policies.

Dual Focus on E ciency and Productivity:

- This approach ensures long-term sustainability and competitiveness by aligning climate goals with productivity improvements.

Towards a net-zero economy

We need to transition to a net-zero economy to ensure a sustainable future (Bonsu 2020).

Reducing carbon emissions to zero is essential to ght climate change (Rootzæn et al. 2020; Colding et al. 2022).

Everyone, including individuals, communities, and businesses, needs to take actior (Hamann et al. 2023).

Businesses should lead by using energy-saving technologies (Dieperink, Brand, an Vermeulen 2004).

Some industries might face economic challenges during this transition (Madureira 2012).

This study aims to help make the transition fair and economically sound (Noman et al. 2024).

Why it matters? Bridging the knowledge gap

Utilizing unique rm-level data to bridge the knowledge gap on energy metrics and pro tability.

- Importance of distinguishing between e ciency and productivity, particularly in assessing their impact on pro tability (Coelli et al. 2005; Fried, Lovell, and Schmidt 2008; Grosskopf 1993; Kumbhakar, Denny, and Fuss 2000).
- Energy e ciency and energy productivity are often used interchangeably, but accurate estimation is crucial for competitiveness (Dimitropoulos 2007; Kumbhakar, Horncastle, and Wang 2015).
- The methods used in this study ensure di erences between e ciency and productivity are accounted for when exploring their e ect on nancial performance.

Research Questions:

How do energy e ciency and productivity a ect rms' economic performance?
What is the nature of the relationship between energy metrics and pro tability across di erent sectors?

Why care about energy e ciency and economic performance?

Cost Savings: Lower energy use cuts operational costs, boosting pro ts.

Environmental Impact: Reduces greenhouse gases and pollutants, ensuring sustainable resource use.

Competitiveness: Reduces costs and enhances reputation, fostering growth.

Risk Management: Mitigates risks from energy price volatility and supply disruptions.

Innovation: Drives advancements in e cient technologies.

Stakeholder Value: Enhances stakeholder value and informs sustainable policies.

Understanding the nexus

Strategic Imperative and Collective Goal :

- Transition to net-zero is crucial for a sustainable future (Bonsu 2020).
- Reducing carbon emissions to net-zero is a shared responsibility (Rootzen et al. 2020; Colding et al. 2022).
- Corporations should adopt energy-saving innovations (Hamann et al. 2023; Dieperink et al. 2004).

Challenges related to measuring Energy Transition at rm level :

- E ciency Concerns: Economic impact and potential obsolescence for lagging rms (Madureira 2012).
- Important Distinction: E ciency and productivity are di erent and impact pro tability in their respective unique ways (Coelli et al. 2005; Dimitropoulos 2007).
- Labour Productivity: Energy e ciency investments can improve labour productivity (Romm 1995; Kalantzis & Niczyporuk 2022).

Impact on nancial performance

- Energy e ciency and productivity enhance rm pro tability (Cantore et al. 2016; Fan et al. 2017).

Data used in this study

Main variables

Source: European Investment Bank Investment Survey (EIBIS) - Data since 2016

Sample: Over 12K EU rms + 1K in the US (country, sector, rm size levels)

Focus: Investment activities, nancing needs, climate-related challenges and responses

Methodology: Strati ed sampling from Bureau van Dijk ORBIS database

Data for Analysis: Cross-sectional for 2023

Variables Collected:

- Firm-speci c: age, size, turnover, xed assets, employees, total investment, pro t, energy e ciency investments, energy spending (2023)
- Sector-speci c:

  14-sector (energy, food & agriculture, textile, chemicals & pharmaceuticals, electronics, machinery, raw materials, construction, trade, transportation, tourism & arts, IT & telecommunications, other services, water supply)

Measuring energy e ciency - Input distance function (IDF)

Methodology: IDF based on Stochastic Frontier Analysis (SFA)

- Widely recognized for evaluating e ciency
- Decomposes deviations from the frontier:
  - Random error (v_i)
  - Technical ine ciency (u_i)

Model: Stochastic frontier analysis based on Shephard's distance function

$$\ln E = \beta_0 + \sum_{i=1}^{N} \beta_i \ln Y_i + \sum_{i=1}^{N} \gamma_i \ln X_i + \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1}^{N} \delta_{ij} \ln X_i \ln X_j + v_i \quad u_i$$

- $\ln y_i$: Turnover
- $\ln x_i$: Vector of other inputs (capital and labour)
- $\ln E_i$: Energy spending
- , , : Technological parameters

How does it look like in practice?

(a) Input Distance Function

(b) Meta vs. Group E ciency*

*TFEE = Total-Factor Energy E ciency within Group, while Meta-TFEE = TFEE TGR, where Meta-TFEE is the TFEE across the Economy & TGR is the Technology Gap Ratio

Measuring energy productivity - Malmquist Productivity Index

Introduced by Caves et al. (1982), refined by Färe et al. (1992, 1994) and Ray & Desli (1997) - Based on Shephard's distance function

Decomposition: Splits productivity change into efficiency change and technological change

Methodology: Non-parametric method adhering to DEA standards, assumes constant returns to scale (Emrouznejad & De Witte, 2010; Färe, Grosskopf & Roos, 1998)

MPI Calculation:

$$MI_{(x;y)} = \frac{D_t(x_{t+1}; y_{t+1})}{D_{t+1}(x_{t+1}; y_{t+1})} \quad \sqrt{\frac{D_t(x_t; y_t)}{D_{t+1}(x_t; y_t)} \quad \frac{D_t(x_{t+1}; y_{t+1})}{D_{t+1}(x_{t+1}; y_{t+1})}}$$

- D_t, D_{t+1}: Distance functions at times t and $t+1$
- $(x; y)$: Input and output vectors

Tracking productivity changes

Estimation Approach: Follow Du, Huang & Chen (2018) using the Malmquist method

De nition:

$$\text{MEPI} = \text{TECH} \quad \text{TECCH}$$

- MEPI: Malmquist Energy Productivity Index
- TECH: Energy e ciency change
- TECCH: Technological change

Insight: MEPI estimation assesses the Best Practice Gap change, indicating how far estimated EP indices are from the best practice scenario.

Unveiling the link between energy e ciency and economic performance

In order to investigate the relationship between energy performance and economic performance, the following Logit and OLS Fixed E ects Models are used:

$$Y_i = \quad _i + \quad \text{EnergyPerformance} + \sum_{k=1}^{n} \quad ^k \quad X_i^k + "_i$$

Y_i represents either Pro tability $_i$ or ln TFP $_i$ (Levinsohn & Petrin, 2003)

EnergyPerformance variable is changed to Group TFEE, Meta TFEE or Malmquist Energy Productivity Index (MEPI) for each model.

X_i^k includes all control variables, we control for size, sector and country FE

$_i$ captures the rm speci c xed e ects (i.e., everything that varies between rms but is constant overtime)

"$_i$ is the error term

Exploring the causal link

We use the 2SLS - IV method to investigate the impact of energy performance on economic performance

We run separate regressions for Group and Meta TFEE (energy e ciency) and MEPI (energy productivity) as explanatory variables, while separately considering pro tability and TFP as dependent variables.

We use industry averages of energy performance indicators excluding each examined observation as an instrument.

Additionally, as a robustness check we take rms' perception of energy regulation as a major obstacle to recovery from energy shocks.

Estimated Energy E ciency by region: Group vs. Meta

Robustness check

CEE = Central and Eastern Europe, SE = Southern EU, WN = Western and Northern EU, US = United States

Global comparison: Estimated Meta-SFA TFEE by region & sector

CEE = Central and Eastern Europe, SE = Southern EU, WN = Western and Northern EU, US = United States

Tech Divide: assessing sectoral disparities across 14 EU sectors

E ects of energy performance on economic performance

VARIABLES	(1) TFP	(2) TFP	(3) TFP	(4) Pro tability	(5) Pro tability	(6) Pro tability
Group TFEE	0.32***			0.19***		
	(0.007)			(0.035)		
Meta TFEE		0.62***			0.41***	
		(0.008)			(0.047)	
MEPI			0.07***			0.23***
			(0.008)			(0.043)
Observations	6,437	6,437	2,321	6,687	6,687	2,451
Country FE	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES
Size	YES	YES	YES	YES	YES	YES

Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p< 0.1

2SLS IV: E ects of energy performance on economic performance

Robustness check First stage

VARIABLES	(1) TFP	(2) TFP	(3) TFP	(4) Pro tability	(5) Pro tability	(6) Pro tability
Group TFEE	0.24***			0.02***		
	(0.011)			(0.002)		
Meta TFEE		0.63***			0.02***	
		(0.012)			(0.003)	
MEPI			0.07***			0.01***
			(0.010)			(0.001)
Observations	6,437	6,437	2,321	6,432	6,432	2,380
R-squared	0.472	0.721	0.398	0.159	0.161	0.215
Country FE	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES
Size	YES	YES	YES	YES	YES	YES

Testing for heterogeneous e ects

VARIABLES	(1) TFP	(2) TFP	(3) TFP	(4) Pro tability	(5) Pro tability	(6) Pro tability
Energy spending intensity (log)	-0.04***	-0.02***	-0.04***	-0.04***	-0.03***	-0.05**
	(0.002)	(0.001)	(0.002)	(0.012)	(0.008)	(0.018)
Group TFEE	0.20***			0.17**		
	(0.010)			(0.070)		
Group TFEE ES intensity (log)	0.01***			0.02		
	(0.002)			(0.016)		
Meta TFEE		0.52***			0.32***	
		(0.012)			(0.102)	
Meta TFEE ES intensity (log)		0.02***			0.01	
		(0.002)			(0.018)	
MEPI			0.06***			0.32**
			(0.018)			(0.132)
MEPI ES intensity (log)			0.01**			0.03
			(0.004)			(0.031)
Observations	6,437	6,437	2,317	6,687	6,687	2,446
Country FE	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES
Size	YES	YES	YES	YES	YES	YES

Key insights and implications

Energy performance has a positive and statistically signi cant e ect on economic performance (pro tability and TFP).

Strength of Relationship:

- MEPI generates lower coe cients compared to Meta TFEE.
- Suggests energy e ciency indicators may capture additional factors.
- Emphasizes the importance of measuring EP alongside EE.
- Relevant for formulating policy intervention and EE investments.

TFEE Indicators:

- Show a more pronounced positive e ect on TFP than on pro tability.

Sectoral Homogeneity:

- Some sectors are more homogeneous.
- Meta TFEE allows improved cross-sectoral assessments.
- Takes into account the Technological Gap Ratio (TGR).

US Firms roughly match EU overall energy e ciency performance, but many EU countries lead in sectors like energy and agriculture.

Further insights and future research

For energy-intensive rms, improving energy e ciency and productivity signi cantly boosts Total Factor Productivity (TFP).

Di erent metrics (Meta TFEE, MEPI, Group TFEE) show varying impacts of energy intensity on performance and pro tability, highlighting the need for global sector-speci c policies and rm strategies.

Future research should explore alternative measures of Energy Productivity (EP), such as breaking down Total Factor Productivity (TFP) into energy and non-energy components.

Investigating country-level technological di erences using advanced methods like Latent Class Stochastic Frontier Analysis (SFA) or Bayesian SFA while controlling for country xed e ects could o er deeper insights.

Appendix

Main Variables from EIBIS

Variable	Question in EIBIS or formula	Obs.
Capital	What is the rm's total investment spend across all these areas?*	12,600
Labour	How many people does your rm employ either full or part time?	12,832
Wages	How much was the spend on wages (gross, i.e. including bene ts)?	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
Pro t or loss	Was there a pro t or a loss before tax, or a break-even?	12,334
Pro t %	Pro t or loss (EBIT) as % of turnover in 5 categories of % ranges	10,990
Pro t (cont.)	Pro t 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 x total investment in euros / 100	10,349
Energy costs	Are energy costs a major obstacle to investment activities?	12,087
Avail. of nance	Is availability of nance 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 rm set and monitor targets for its own GHG emissions?	11,911
Total assets	Value of total xed assets (incl. tangible assets & intangible assets)	11,241
Size (categ.)	Company size (Micro, Small, Medium, Large)	12,087

Return

*The main areas: Infrastructure, Machinery, R&D, IT, Training, Restructuring

Does higher energy spending intensity diminish EE?

Return

(c) Group TFEE

(d) Meta TFEE

Note: We control for size as well as for each country-sector by generating a group variable

First SLS: E ects of energy performance on TFP & pro tability .
IV = industry averages of energy performance indicators.

First Stage Least Squares VARIABLES	(1) Group TFEE	(2) Meta TFEE	(3) MEPI
Industry average Group TFEE (IV)	0.02** (0.008)		
Industry average Meta TFEE (IV)		0.04*** (0.002)	
Industry average MEPI (IV)			0.02** (0.012)
Observations	6,735	6,735	2,462
R-squared	0.538	0.676	0.093
Country FE	YES	YES	YES
Sector FE	YES	YES	YES
Size	YES	YES	YES

We take industry averages of energy performance indicators as the instrument.

Standard errors in parentheses *** p < 0.01, ** p < 0.05, * p< 0.1

Return

2SLS: E ects of energy performance on TFP & pro tability . Robustness Check with IV = Energy regulation as a major obstacle.

First stage

VARIABLES	(1) TFP	(2) TFP	(3) TFP	(4) Pro tability	(5) Pro tability	(6) Pro tability
Group TFEE	0.75***			0.03**		
	(0.230)			(0.030)		
Meta TFEE		0.53***			0.02***	
		(0.081)			(0.020)	
MEPI			0.37*			0.03
			(0.202)			(0.021)
Constant	1.91***	2.18***	2.23***	0.12***	0.13***	0.11***
	(0.164)	(0.041)	(0.114)	(0.022)	(0.010)	(0.012)
Observations	6,437	6,437	2,321	6,687	6,687	2,451
Country FE	NO	NO	NO	NO	NO	NO
Sector FE	YES	YES	YES	YES	YES	YES
Size	YES	YES	YES	YES	YES	YES

Return

We take rm's perception of energy regulation as a major obstacle to recovery from energy shocks.

First SLS: E ects of energy performance on TFP & pro tability . IV = Energy regulation as a major obstacle.

Second stage

First Stage Least Squares VARIABLES	(1) Group TFEE	(2) Meta TFEE	(3) MEPI
Major obstacle: Energy regulatory frameworks (IV)	-0.01***	-0.01***	-0.02**
	(0.004)	(0.003)	(0.008)
Constant	0.69***	0.52***	0.58***
	(0.018)	(0.014)	(0.037)
Observations	6,735	6,735	2,463
R-squared	0.629	0.661	0.090
Country FE	YES	YES	YES
Sector FE	YES	YES	YES
Size	YES	YES	YES

Return

We take rm's perception of energy regulation as a major obstacle to recovery from energy shocks as the instrument.

Estimated EE by country - ranked by weighted average