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Artificial Intelligence Adoption in Small Enterprises Across Europe: A Comparative and Efficiency-Based Evaluation with Policy Implications for Türkiye

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Abstract:

This paper assesses the efficiency of AI adoption among small enterprises in Türkiye and 30 peer EU and EU-neighborhood countries using data envelopment analysis (DEA) for 2021 and 2023. The results reveal pronounced cross-country heterogeneity and sizable scale inefficiencies: efficiency scores differ markedly between CRS and VRS specifications, while orientation choices matter little. For Türkiye, near-unity VRS scores alongside much lower CRS scores indicate high pure technical efficiency but a persistent scale gap relative to frontier economies. These findings underline the need to prioritize scalable and inclusive AI diffusion among small firms rather than merely expanding generic digital capacity.

Key Words: artificial intelligence, small enterprises, data envelopment analysis (DEA), efficiency, scale effects, EU, Türkiye

1. Introduction

Artificial Intelligence (AI) is increasingly recognized as a catalyst for productivity, competitiveness, and innovation across the enterprise landscape. However, substantial variation persists across countries, particularly among small enterprises (10–49 employees), regarding not only the level of AI adoption but also the efficiency with which enabling conditions are translated into actual uptake.

This timely study focuses exclusively on small enterprises and evaluates how effectively they convert digital, financial and institutional capacities into AI use at firm level. The analysis covers 31 European and neighboring countries, including EU member states, Türkiye and non-EU economies such as Norway, Serbia and Bosnia and Herzegovina, providing a comparative benchmarking framework for small-enterprise AI adoption across the wider European region (see Table 1).

Table 1. Country Coverage of the Dataset

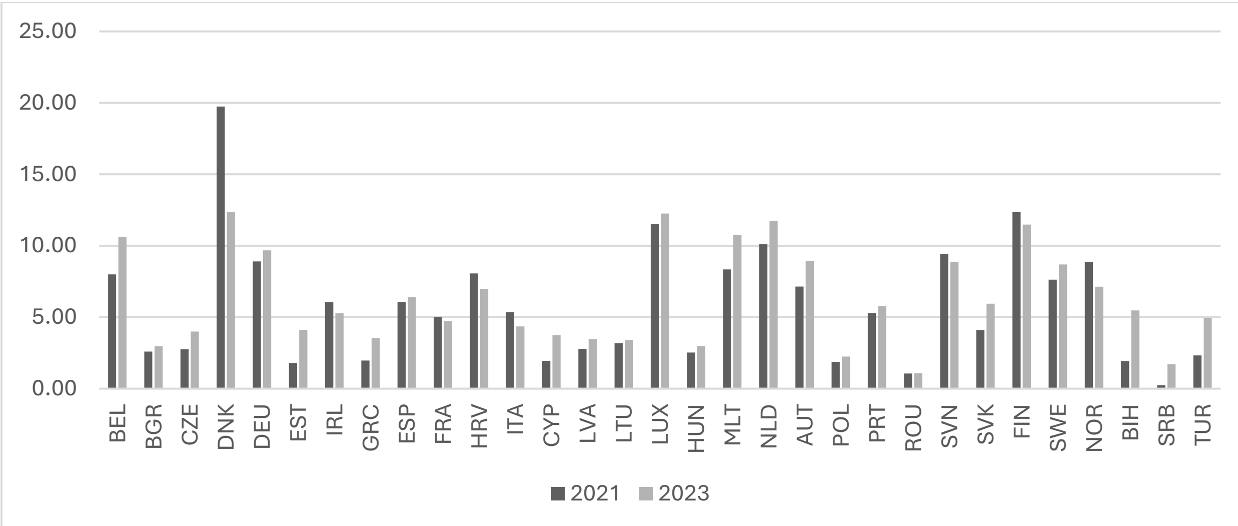
Abbreviation (iso3)	Country Name
BEL	Belgium
BGR	Bulgaria
CZE	Czechia
DNK	Denmark
DEU	Germany
EST	Estonia
IRL	Ireland
GRC	Greece
ESP	Spain
FRA	France
HRV	Croatia
ITA	Italy
CYP	Cyprus
LVA	Latvia
LTU	Lithuania
LUX	Luxembourg
HUN	Hungary
MLT	Malta
NLD	Netherlands
AUT	Austria
POL	Poland
PRT	Portugal
ROU	Romania

SVN	Slovenia
SVK	Slovakia
FIN	Finland
SWE	Sweden
NOR	Norway
BIH	Bosnia and Herzegovina
SRB	Serbia
TUR	Türkiye

To provide an initial descriptive overview, we first examine cross-country variation in our main outcome variable, namely the share of small enterprises using at least one AI technology. As shown in Figure 1, the raw adoption rates for 2021 and 2023 already reveal a highly heterogeneous landscape. In 2021, the share of small enterprises using at least one AI technology ranges from 0.24% in Serbia and 1.06% in Romania to almost 20% in Denmark and above 10–12% in Finland, Luxembourg and the Netherlands. By 2023, the cross-country mean increases only modestly, but the pattern shifts: some early leaders, such as Denmark and Finland, record slightly lower adoption rates, while others, notably Türkiye (from 2.33% to 4.95%), Bosnia and Herzegovina and Estonia, more than double their small-enterprise AI usage.

However, these descriptive differences do not tell us whether countries with higher adoption are genuinely performing better or simply benefiting from more favorable structural and institutional conditions. As discussed in the data and methodology section, countries differ markedly in their underlying enablers of AI diffusion, so a simple comparison of adoption rates would conflate outcomes with these underlying endowments. By embedding the single adoption indicator as the output in a DEA framework and conditioning on the relevant enablers, we move from levels to efficiency: we can distinguish between countries whose higher AI usage among small enterprises is largely driven by more abundant resources and those that achieve comparatively high adoption given a similar input mix. In this way, DEA reveals relative performance gaps and latent catching-up potential, as in Türkiye's case between 2021 and 2023, that would remain hidden in a purely descriptive comparison of adoption rates.

Figure 1. The Share of Small Enterprises that use at least one AI Technology (10–49 employees)



Source: EuroStat (2025)

The paper is structured as follows. The next section reviews the relevant literature and positions of our contribution. Section 3 sets out the data and the DEA-based methodological framework. Section 4 presents and discusses empirical results. Section 5 concludes and elaborates the main policy implications.

2. Literature Review

Unlike Ionascu (2025), who employs Principal Component Analysis (PCA) and K-means Clustering with an emphasis on pattern identification rather than efficiency or firm-size differentiation, this study offers a novel contribution by applying Data Envelopment Analysis (DEA) to evaluate how effectively countries transform enabling conditions into AI adoption specifically within small enterprises. In contrast to broader SME-level or large-firm-focused analyses, such as those by Drago et al. (2025) and Arroyabe et al. (2024), our approach uniquely centers on small firms and introduces a comparative benchmarking perspective.

3. Methodology and Analysis

The study investigates the question: “How efficiently do small enterprises across countries utilize their available resources to adopt AI technologies, and what does a comparative analysis reveal about Türkiye's position and change in efficiency between 2021 and 2023?”

Our empirical application draws on Eurostat enterprise survey data (Eurostat, 2025) and World Development Indicators (World Bank (2025)) for 2021 and 2023. Although 2024 data show a decline in AI usage by small enterprises in Türkiye (TurkStat (2024); Eurostat (2025)), these figures are descriptively used due to data structure limitations. Nonetheless, this trend reinforces the urgency of evaluating efficiency and policy responsiveness, particularly in Türkiye’s digital trajectory.

For each year, we estimate separate output-oriented Data Envelopment Analysis (DEA) models using the Banker, Charnes, and Cooper (BCC) specification (Banker et al., 1984), which assumes variable returns to scale (VRS). In addition, we estimate alternative models, input-oriented and output-oriented Charnes, Cooper, and Rhodes (CCR) specifications (Charnes et al., 1978), which assume constant returns to scale (CRS), to assess the robustness of our results. All DEA models are implemented in Stata (Ji and Lee, 2009).

Our DEA model uses a single output: the share of small enterprises that use at least one AI technology, and seven inputs capturing key structural and institutional enablers: internet usage, log-transformed secure internet servers per million people, domestic credit to the private sector, gross fixed capital formation, urbanization, the share of the labor force with advanced education, and computer, communications and other services as a share of commercial services imports (See Table 2 for the variables and their data sources).

Table 2. Variables and Data Sources

Variable Name	Input & Output Type	Source
SmallEnterpriseAI (the share of small enterprises that use at least one AI technology)	output	Eurostat (2025) & TurkStat (2024)
Computer, communications and other services (% of commercial service imports)	input	World Bank (2025)
Domestic credit to private sector (% of GDP)	input	World Bank (2025)
Individuals using the Internet (% of population)	input	World Bank (2025)
Labor force with advanced education (% of total working-age population with advanced education)	input	World Bank (2025)
Urban population (% of total population)	input	World Bank (2025)
GFCF_percentGDP	input	World Bank (2025)
Log Secure Internet servers (per 1 million people)	input	World Bank (2025)

This approach allows us to assess how effectively countries transform these structural and institutional enablers into AI uptake among small enterprises. DEA enables us to compare not only the observed level of adoption, but also the efficiency with which countries use internet access, secure digital infrastructure, credit, investment, human capital, urbanization and ICT-related service imports, thereby capturing relative performance gaps across countries.

In the baseline specification, the single output captures realized AI adoption by small enterprises, while the seven inputs proxy the main enabling factors: digital infrastructure, financing and investment conditions, human capital, the degree of urbanization and openness to ICT service imports.

4. Results

Our baseline DEA model is specified under constant returns to scale (CRS) and input orientation. As a robustness check, we re-estimated the model under variable returns to scale (VRS). The efficiency scores differ noticeably between the CRS and VRS specifications, pointing to the presence of scale inefficiencies across countries. By contrast, changing the orientation from input to output (under both CRS and VRS) yields efficiency scores and rankings that are virtually identical to those of the CRS input-oriented model, indicating that our main findings are not sensitive to the choice of orientation.

Table 3. Input & Output Oriented DEA (BCC & CCR for 2021)

	Orientation (Input)				Orientation (Output)	
	Charnes–Cooper–Rhodes (CCR)		Banker, Charnes ve Cooper (BCC)		Charnes–Cooper–Rhodes (CCR)	
Country	Rank	DEA Efficiency for 2021	Rank	DEA Efficiency for 2021	Rank	DEA Efficiency for 2021
BEL	11	0.674085	20	0.971714	10	0.674085
BGR	21	0.306269	11	1	21	0.306269
CZE	23	0.276836	22	0.959938	23	0.276836
DNK	1	1	1	1	1	1
DEU	10	0.693184	18	0.983515	9	0.693184
EST	29	0.164891	31	0.927782	29	0.164891
IRL	4	0.998662	5	1	3	0.998662
GRC	24	0.272232	12	1	24	0.272232
ESP	15	0.440536	25	0.951349	15	0.440537
FRA	20	0.316425	28	0.931659	20	0.316425
HRV	7	0.81316	3	1	6	0.81316
ITA	13	0.466829	6	1	13	0.466829
CYP	30	0.149295	29	0.930045	30	0.149295
LVA	19	0.375195	13	1	19	0.375195

LTU	16	0.430397	10	1	16	0.430397
LUX	5	0.848344	4	1	4	0.848344
HUN	22	0.285591	19	0.980449	22	0.285591
MLT	8	0.793627	7	1	7	0.793627
NLD	9	0.719209	27	0.93518	8	0.719209
AUT	12	0.564134	24	0.953929	11	0.564134
POL	26	0.212696	15	1	26	0.212696
PRT	18	0.383486	23	0.955724	18	0.383486
ROU	28	0.175555	14	1	28	0.175555
SVN	1	1	1	1	1	1
SVK	17	0.391856	8	1	17	0.391856
FIN	6	0.845619	21	0.968472	5	0.845619
SWE	14	0.456285	26	0.937823	14	0.456285
NOR	3	1	30	0.928451	12	0.5241
BIH	25	0.257598	9	1	25	0.257598
SRB	31	0.0279984	16	1	31	0.0279984
TUR	27	0.21269	17	0.996608	27	0.21269

Using an input-oriented DEA model with CRS (CCR), Türkiye's efficiency score in 2021 is 0.213, placing the country 27th out of 31. This implies that, given its current levels of digital infrastructure, financial development, human capital, urbanisation and ICT-related service imports, Türkiye could in principle achieve the same level of AI adoption among small enterprises with roughly 79% fewer inputs, or, equivalently, could almost quintuple its current level of AI adoption at the existing input levels. When we allow for variable returns to scale (BCC), Türkiye's efficiency score increases to 0.997 and its rank improves to 17th, indicating that pure technical efficiency is high and that most of the inefficiency observed under CRS is driven by scale effects. In other words, AI adoption among small enterprises in Türkiye is relatively efficient compared to countries with a similar input mix, but the overall ecosystem remains far from the global frontier in terms of scale and diffusion.

In 2023, the cross-country pattern is broadly consistent with the 2021 results, but average efficiency levels are higher. Under the input-oriented CRS (CCR) specification, several countries lie on the efficiency frontier ($\theta = 1$), including Denmark, Luxembourg, Malta, the Netherlands, Finland, Slovenia and Belgium. A second group of countries – such as Austria, Germany, Ireland and Croatia – record relatively high efficiency scores ($\theta \gtrsim 0.80$), while Bulgaria, Poland, Serbia and Romania remain among the least efficient performers, with scores between 0.19 and 0.35. Re-estimating the model under VRS (BCC) again produces a large number of fully efficient units ($\theta = 1$), confirming that a substantial part of the dispersion observed under CRS reflects scale differences rather than pure technical inefficiency. As in 2021, the output-oriented CRS model yields exactly the same efficiency scores as the input-oriented CRS model, with only minor rank differences due to ties, indicating that the results are not sensitive to the choice of orientation.

Table 4. Input & Output Oriented (BCC & CCR for 2023)

	Orientation (Input)				Orientation (Output)	
	Charnes–Cooper–Rhodes (CCR)		Banker, Charnes ve Cooper (BCC)		Charnes–Cooper–Rhodes (CCR)	
Country	Rank	DEA Efficiency for 2021	Rank	DEA Efficiency for 2021	Rank	DEA Efficiency for 2021
BEL	7	1	8	1	1	1
BGR	28	0.348364	16	1	28	0.348364
CZE	23	0.438086	25	0.960498	23	0.438086
DNK	1	1	1	1	1	1
DEU	9	0.912619	6	1	9	0.912619
EST	25	0.413828	30	0.935516	25	0.413828
IRL	10	0.832302	13	1	10	0.832302
GRC	17	0.587172	14	1	17	0.587172
ESP	18	0.584251	26	0.957986	18	0.584251
FRA	24	0.43651	28	0.95389	24	0.43651
HRV	11	0.797704	10	1	11	0.797704
ITA	22	0.44162	24	0.970812	22	0.44162
CYP	26	0.379124	31	0.92692	26	0.379124
LVA	20	0.491755	15	1	20	0.491755
LTU	21	0.45693	20	0.99473	21	0.45693
LUX	1	1	1	1	1	1
HUN	27	0.370082	23	0.97779	27	0.370082
MLT	1	1	1	1	1	1
NLD	5	1	5	1	1	1
AUT	8	0.985575	9	1	8	0.985575
POL	29	0.288565	18	1	29	0.288565
PRT	16	0.592833	22	0.980626	16	0.592833
ROU	31	0.190272	19	1	31	0.190272
SVN	1	1	1	1	1	1
SVK	14	0.697328	21	0.993953	14	0.697328
FIN	6	1	7	1	1	1
SWE	13	0.733598	27	0.955821	13	0.733598
NOR	15	0.628535	29	0.940145	15	0.628535
BIH	12	0.789605	11	1	12	0.789605
SRB	30	0.220778	17	1	30	0.220778
TUR	19	0.579755	12	1	19	0.579755

For Türkiye, the input-oriented CRS efficiency score in 2023 is 0.580, with a rank of 19th out of 31 countries. This implies that, given its 2023 levels of digital infrastructure, financial development, human capital, urbanisation and ICT-related service imports, Türkiye could in principle achieve the same degree of AI adoption among small enterprises with about 42% fewer inputs, or, equivalently, could increase AI adoption by a factor of roughly 1.7 at current input levels. Under the VRS (BCC) specification, Türkiye becomes fully efficient ($\theta = 1$) and its rank improves to 12th, indicating that, once scale effects are taken into account, Türkiye's small-enterprise AI adoption is technically efficient relative to countries with a similar input mix. The remaining gap to the global frontier is therefore largely a matter of scale and diffusion rather than a lack of technical capability.

Comparing 2021 and 2023 reveals a substantial improvement in Türkiye's performance. The input-oriented CRS efficiency score rises from 0.213 in 2021 (27th place) to 0.580 in 2023 (19th place). Scale efficiency, approximated by the ratio of the CRS to the VRS scores, increases from about 0.21 (0.213/0.997) to around 0.58 (0.580/1.000), suggesting that Türkiye has moved significantly closer to the global frontier in terms of the scale at which its small-enterprise AI ecosystem operates. At the same time, pure technical efficiency – already very high in 2021 ($\theta\_VRS \approx 0.997$, rank 17) – reaches full efficiency ($\theta\_VRS = 1$, rank 12) by 2023. Taken together, these results indicate that Türkiye has not only maintained strong technical performance but has also reduced part of its scale-related inefficiency over time, although a sizeable gap to the leading group of countries remains in terms of the overall diffusion and depth of AI use among small enterprises.

Table 5. Peer (reference) countries for Türkiye based on λ-weights in DEA models, 2021 and 2023

2021			2023		
Input Oriented		Output Oriented	Input Oriented		Output Oriented
CCR	BCC	CCR	CCR	BCC	CCR
DNK (.0764574) SVN (.0871263)	DNK (.118034)	DNK (.0764574) SVN (.0871264)	LUX (.174497) MLT (.0185196) SVN (.294097)	SVN (.557432)	LUX (.182886) SVN (.304935)

Note: λ-values are shown in parentheses.

Table 5 reports the peer (reference) countries for Türkiye in each DEA specification. A country appears in the table whenever its λ-weight in Türkiye's row is strictly positive; λ-values are shown in parentheses. In 2021, under the CRS (CCR) models with both input and output orientation, Türkiye is benchmarked against Denmark (DNK) and Slovenia (SVN), while under the VRS (BCC) input-oriented model Denmark remains the sole peer. This indicates that Türkiye's virtual benchmark in 2021 is essentially a convex combination of two Northern and Central European frontier economies with very high levels of small-enterprise AI adoption and strong digital infrastructures.

By 2023, the composition of Türkiye's reference set changes. Under the CRS input-oriented model, Luxembourg (LUX), Malta (MLT) and Slovenia (SVN) emerge as peers, with Luxembourg and Slovenia carrying the largest λ-weights, while under the VRS input-oriented model Slovenia becomes the dominant benchmark ($\lambda = 0.557$). The CRS output-oriented model again highlights

Luxembourg and Slovenia as Türkiye's reference countries. Taken together, these patterns suggest a gradual convergence of Türkiye's small-enterprise AI profile towards that of small, highly digitalized European economies such as Slovenia and Luxembourg, while Slovenia stands out as a persistent benchmark across years and model specifications.

5. Conclusions and Policy Implications

This study has examined the efficiency of AI adoption among small enterprises in Türkiye and a group of peer countries from European Union using a DEA-based benchmarking framework. The results reveal a nuanced picture. On the one hand, Türkiye's pure technical efficiency is high: under the VRS (BCC) specification, small-enterprise AI adoption is almost fully efficient in 2021 and reaches full efficiency by 2023, indicating that, given its input mix, Türkiye is broadly comparable to its peers in how it translates digital infrastructure, finance and human capital into AI use. On the other hand, the CRS (CCR) results underscore a persistent scale gap. Although Türkiye's CRS efficiency score rises from 0.213 in 2021 to 0.580 in 2023, the country still remains well below the global frontier, implying sizeable untapped potential in scaling up AI adoption across the small-firm segment.

This tension between high technical efficiency and significant scale inefficiency becomes even more salient when considered alongside the observed drop in AI usage in 2024. While the DEA results suggest that the underlying ecosystem has become more capable and that part of the scale-related inefficiency has been reduced over time, the subsequent decline in actual AI adoption points to a misalignment between capacity and realized outcomes. In other words, the system has built up the ingredients for more widespread and effective AI use, but small enterprises are not consistently converting this potential into sustained adoption. This divergence highlights the need to move beyond generic digitalization narratives and to focus on the specific frictions that prevent small firms from embedding AI into their everyday operations.

Against this background, Türkiye's declining performance in realized AI use among small enterprises, as evidenced by the 2024 drop in usage, highlights the urgent need for strategic policy realignment. The findings of this study, based on a DEA-driven efficiency benchmarking framework, underscore the importance of targeting support toward more resource-effective and inclusive AI adoption pathways, rather than simply expanding infrastructure or offering broad, untargeted incentives. Policy interventions should be designed to close the gap between potential and actual AI use, especially for smaller and more vulnerable firms.

Key policy recommendations include:

- Enhancing access to AI tools and digital infrastructure for small enterprises through financial incentives, shared platforms or public–private partnerships. This includes lowering the fixed costs of adoption by promoting "AI-as-a-service" models, common data and cloud platforms, and sector-specific solution bundles tailored to small firms.
- Implementing targeted AI awareness and skill-development programmes, specifically designed for the operational realities of small firms and their workforce. Rather than

generic training, these programmes should focus on concrete use cases, simple decision-support tools and low-entry-cost applications that directly address productivity, cost reduction and market access constraints faced by small enterprises.

- Embedding AI-readiness and AI-usage metrics into national digital transformation strategies, ensuring that these frameworks are sensitive to firm size, sectoral context and technological absorptive capacity. Monitoring should not only track infrastructure and investment, but also the actual diffusion and intensity of AI use among micro and small firms.
- Strengthening coordination and learning mechanisms between leading frontier countries and latecomers, as revealed by the DEA benchmark structure. Peer learning from countries that appear as reference units (benchmarks) for Türkiye can help identify concrete program designs, regulatory tweaks and support schemes that have proven effective in scaling AI adoption among small firms.

Taken together, these conclusions and policy implications suggest that Türkiye is no longer primarily constrained by a lack of digital or financial capacity, but by the scaling, diffusion and institutionalization of AI use in the small-enterprise segment. The DEA framework employed here not only informs Türkiye's policy agenda; it also offers a replicable model for other emerging economies facing similar digital transformation challenges among small firms, providing a systematic way to diagnose where inefficiencies lie and how targeted policy interventions can unlock more inclusive and efficient AI adoption.

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