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MEASURING ECONOMIC EFFICIENCY OF DIGITAL TRANSFORMATION ACROSS EU COUNTRIES USING DEA TECHNIQUES

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Abstract: *Digitalization has become a critical focus for both companies and public organizations, with numerous reports highlighting its growing importance. This study evaluates the comparative efficiency of digital transformation across European Union countries using Data Envelopment Analysis (DEA). Data are sourced from the Digital Transformation Account 2018 published by the European Commission. DEA is employed to measure the relative efficiency of countries in leveraging digital transformation enablers to achieve desired outcomes. The analysis uses the "enablers and outputs" framework from the Digital Transformation Scoreboard, considering Digital Infrastructure, Investment and Access to Finance, Digital Skills Demand and Supply, E-Leadership, and Entrepreneurial Culture as inputs, and ICT startups and overall Digital Transformation performance as outputs. The study provides a ranking of EU countries based on their digital transformation efficiency. Findings reveal that Denmark, Italy, and the United Kingdom exhibit relatively high levels of digital transformation efficiency, whereas countries such as the Netherlands and Germany perform below the efficiency frontier. These outcomes offer practical insights for policymakers and organizations seeking to strengthen digital adoption capabilities and enhance competitive advantage across Europe.*

Keywords: *Data Envelopment Analysis (DEA), Digital Economy, Digital Transformation, Europe, ICT Startups, Technological Readiness.*

1 INTRODUCTION

Digital transformation has become a central theme in contemporary economic and organizational research, driven by rapid technological advancements and the widespread integration of digital tools across industries and public institutions. The accelerating adoption of digital solutions has reshaped business models, operational processes, value-creation mechanisms, and decision-making structures at both enterprise and national levels. Given this growing dependence on digital technologies, assessing the efficiency of digital transformation has become increasingly essential for understanding how effectively countries convert digital enablers into measurable outcomes.

This study evaluates the relative efficiency of digital transformation using Data Envelopment Analysis (DEA). The analysis is based on the Digital Transformation Scoreboard 2018, developed by the European Commission, which provides the most recent and methodologically consistent dataset containing a complete set of enabler and output indicators necessary for DEA. Subsequent editions of the Scoreboard altered indicator definitions, reduced variable comparability, or lacked sufficient enabler–output alignment, making 2018 the last robust and coherent dataset for a cross-country DEA assessment. Therefore, the 2018 Scoreboard constitutes the most suitable and academically valid foundation for a reliable efficiency measurement.

DEA has long been recognized as a structured and widely applied methodology for evaluating efficiency across various domains, including technological development, innovation performance, and productivity analysis (Charnes, Cooper, & Rhodes, 1978; Emrouznejad & Yang, 2018). Previous research has applied DEA to measure efficiency in digitally intensive sectors such as

telecommunications, ICT, high-tech industries, and public services (OECD, 2019; Van Dijk, 2020). Other studies have examined digital readiness, digital skills, digital literacy, and technological adoption across European economies (Firoiu et al., 2022; Sobczak, 2025). Collectively, these studies demonstrate that DEA provides a rigorous and comparative framework for evaluating digital performance at the national level. The literature conceptualizes digital transformation as a multidimensional process encompassing the integration of digital technologies into organizational structures, business models, and operational processes (Fitzgerald et al., 2013; Westerman, Bonnet, & McAfee, 2014). Beyond technological adoption, digital transformation is closely associated with leadership strategies, organizational reconfiguration, enhanced data-driven decision-making, process automation, and the emergence of new forms of digital business and globalization (Brennen & Kreiss, 2016; Hermann, Pentek, & Otto, 2016). These dimensions collectively highlight the wide-ranging economic and societal implications of digital transformation, particularly its role in enhancing competitiveness, improving service delivery, and fostering innovation.

Despite the extensive literature on digital transformation, a systematic assessment of the relative efficiency of European countries using a complete enabler–output structure remains limited. A major gap persists regarding how effectively nations transform their digital capacities into tangible outcomes such as ICT start-up activity, innovation performance, and overall digital maturity. This study contributes to the literature by addressing this gap through a comprehensive DEA application based on the last methodologically coherent Digital Transformation Scoreboard dataset. By comparing efficiency levels among European countries, the study provides new insights into performance disparities, benchmark positions, and areas requiring strategic improvement.

Table 1. *A Part of Building Blocks of the Digital Transformation*

Customer Experience	Operational Process	Business Models
Customer Understanding	Process Digitalization	Digitally Modified Business
Top Line Growth	Worker Enablement	New Digital Business
Customer Touch Points	Performance Management	Digital Globalization

Source: Westerman et al. (2014)

Table 1 summarizes key building blocks of digital transformation, illustrating its multidimensional nature across customer experience, operational processes, and business models (Westerman et al., 2014). Several reports have been published on digitization and digital transformation, providing comparative assessments of countries' progress across multiple dimensions. Among these reports, one of the most comprehensive and frequently referenced sources is the *Digital Transformation Scoreboard*, published annually by the European Commission (European Commission, 2018).

Table 2. *Indicator-Based Monitoring of Digital Transformation*

<table>
<tr><th colspan="5">Enablers</th></tr>
<tr><th>Digital Infrastructures</th><th>Investment and Access to Finance</th><th>Supply and Demand of Digital Skills</th><th>E- Leadership</th><th>Entrepreneurial Culture</th></tr>
<tr><td>Enterprises possessing and using digital tools</td><td>Investments related to digitalization and access to finance</td><td>Widespread digital skills</td><td>Education and training available to obtain digital skills</td><td>People favor entrepreneurial behavior</td></tr>
<tr><td colspan="5">Integration of Digital Technology
Companies are increasingly using digital technologies</td></tr>
<tr><td colspan="5">ICT Start-ups
The number of start-ups in the ICT sector is increasing</td></tr>
<tr><td colspan="5">Outputs</td></tr>
</table>

Source: Digital Transformation Scoreboard 2018

As a key component of the broader Digital Transformation Monitor, the Scoreboard functions as a systematic framework for tracking digital readiness, innovation trends, and technological development across European economies. It compiles a structured set of indicators that evaluate both the foundational conditions that enable digital advancement and the tangible outcomes that reflect the degree of digital transformation achieved.

The Scoreboard organizes its indicators into two principal dimensions -enablers and outputs- which together offer a holistic and multidimensional assessment of digital progress across the 28 EU member states. The enabler dimension consists of five categories capturing digital infrastructure, access to finance, digital skills, entrepreneurship, and business digitization, while the output dimension includes two categories measuring ICT start-up activity and digital transformation performance. By integrating structural inputs with performance-related outcomes, the Scoreboard provides a comprehensive basis for benchmarking national digital capacities and identifying areas requiring strategic improvement. This structured classification, summarized in Table 2, enables policymakers and researchers to evaluate how effectively countries convert digital capabilities into innovation, competitiveness, and economic growth.

2 METHOD

This study evaluates the effectiveness of digital transformation across selected EU countries by employing Data Envelopment Analysis (DEA). The analysis uses enabler and output indicators derived from the *Digital Transformation Scoreboard 2018*, which provides the most complete, consistent, and methodologically reliable dataset for constructing a balanced DEA framework. Because DEA requires complete input and output data, Romania was excluded from the sample due to missing values. The final dataset comprises 10 EU member states.

In line with the structure of the Digital Transformation Scoreboard, the study uses five enabler dimensions as inputs, including digital infrastructure, investments and access to finance, the supply and demand of digital skills, e-leadership, and entrepreneurial culture, and two output categories, namely ICT start-ups and overall digital transformation performance. Each country is treated as a Decision-Making Unit (DMU), and the DEA model evaluates how effectively these countries convert digital enablers into transformation-oriented outputs. Figure 1 presents the conceptual model of the study, illustrating the structural relationship between inputs and outputs within the digital transformation process.

The theoretical basis of the model conceptualizes digital transformation as a production system in which countries utilize digital-capacity inputs to generate digital-economic outputs. Inputs such as infrastructure, leadership, and skill availability define the resource environment that shapes a country's potential for digital advancement. Outputs, such as ICT entrepreneurial activity and digital transformation performance, reflect the realized outcomes of these capacities. Consequently, the model aligns with the broader understanding of digital ecosystems as dynamic systems in which the configuration of resources influences innovation performance and technological progress.

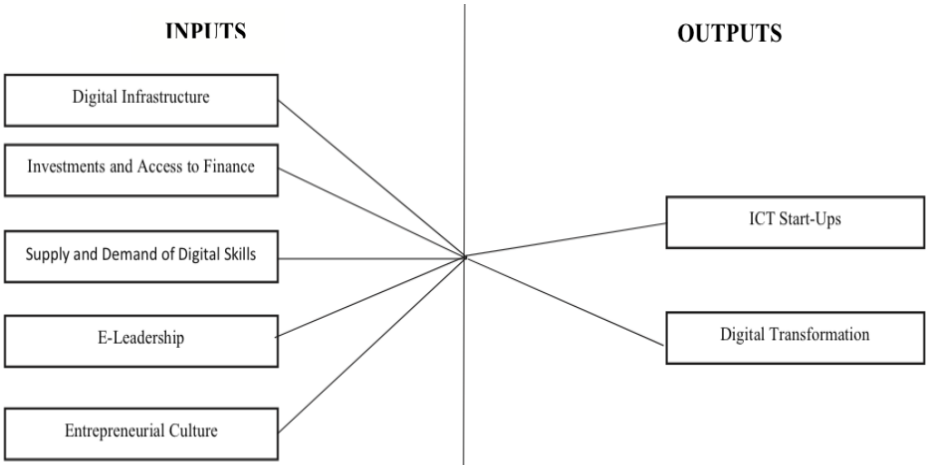
This conceptual structure is operationalized through DEA, which converts the input–output framework into measurable efficiency scores. The study employs both *CCR (Charnes–Cooper–Rhodes)* and *BCC (Banker–Charnes–Cooper)* models, with input-oriented and output-oriented specifications. The *output-oriented CCR model* assesses the extent to which a country can proportionally expand its digital transformation outputs using its existing resource base, assuming constant returns to scale. The mathematical formulation maximizes the ratio of weighted outputs to weighted inputs, where weights are determined endogenously for each DMU. This ratio is constrained such that no country exceeds the efficiency frontier, thereby ensuring comparability and benchmarking accuracy. As Sobczak (2025) notes, this model identifies the potential improvement in outputs that could be achieved without altering a country's digital resource configuration.

The *BCC model* extends the CCR framework by incorporating variable returns to scale through a convexity constraint. This feature acknowledges that EU countries do not all operate under identical conditions, as differences in economic scale, market size, technological maturity, and digital readiness can significantly influence digital transformation efficiency. By allowing for variable returns, the BCC model provides deeper insights into whether inefficiencies arise from managerial performance or the scale at which digital activities are conducted. This distinction is consistent with the conceptual model presented in Figure 1, which recognizes that digital transformation outcomes depend not only on resource allocation but also on structural and contextual capacities (Čiković, Mandić, & Dmitrović, 2025).

All DEA computations were conducted using the *Efficiency Measurement System (EMS)* software. The program was used to perform input- and output-oriented analyses for both CCR and BCC models, as well as the corresponding super-efficiency estimations. This methodological design enables a comprehensive comparison of efficiency results, allowing the study to identify differences arising from orientation choice, returns-to-scale assumptions, and cross-model performance variations.

Figure 1. *Model of The Study*

2.1 General DEA Formula (CCR Model)



Objective function (output-oriented CCR):

$$max\theta = \frac{(\sum_{r=1}^{s} u_r\, y_r o)}{(\sum_{i=1}^{m} v_i\, x_i o)}$$

Subject to:

$$\frac{(\sum_{r=1}^{s} u_r\, y_r j)}{(\sum_{i=1}^{m} v_i\, x_i j)} \leq 1 (j = 1, \dots, n)$$

$$u_r \geq 0, \qquad v_i \geq 0$$

Explanation:

- x_{ij}: inputs (Digital infrastructure, skills, finance, etc.)
- y_{rj}: outputs (ICT startups, Digital transformation)
- v_i, u_r: input/output weights
- θ: efficiency score

Inputs (Finland):

- Digital Infrastructure = 76
- Investments & Access to Finance = 80
- Digital Skills = 83
- E-Leadership = 97
- Entrepreneurial Culture = 51

Outputs:

- ICT Startups = 60
- Digital Transformation = 37

Plug into the CCR formula:

$$\theta = \frac{u_1 \cdot 60 + u_2 \cdot 37}{v_1 \cdot 76 + v_2 \cdot 80 + v_3 \cdot 83 + v_4 \cdot 97 + v_5 \cdot 51}$$

DEA software (EMS) chooses optimal weights.

Objective:

$$\min \ \theta$$

Subject to:

$$\sum_{i=1}^{m} v_i \, x_i j - \sum_{r=1}^{s} u_r \, y_r j \geq 0$$

$$\sum_{i=1}^{m} v_i \, x_i o = 1$$

$$u_r, v_i \geq 0$$

Example (Finland):

$$\sum v_i x_{i,Finland} = 1 \Rightarrow 76v_1 + 80v_2 + 83v_3 + 97v_4 + 51v_5 = 1$$

Output-oriented BCC:

$$\max \ \theta$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j \, x_i j \leq x_i o$$

$$\sum_{j=1}^{n} \lambda_j \, y_r j \geq \theta y_r o$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0$$

For Finland, BCC compares it to a convex combination of EU countries with similar scale; the efficiency frontier changes because of the "=1" convexity constraint.

Used when a country is already efficient and you need to rank efficient DMUs (Denmark, Italy, UK in your file).

Input-oriented super-efficiency (CCR):

$$\min \ \theta$$

Subject to:

$$\sum_{j \neq o} \lambda_j \, x_i j \leq \theta x_i o$$

$$\sum_{j \neq o} \lambda_j \, y_r j \geq y_{ro}$$

Note: the DMU under evaluation is excluded.

(Using Denmark's outputs 71, 62 and inputs 78,48,84,78,46)

The country is removed from the dataset, and the model tests whether others can produce the same output with less input.

If weights are known:

$$Efficiency = \frac{\text{Weighted Outputs}}{\text{Weighted Inputs}}$$

Let all weights = 1 (for illustration):
Finland:

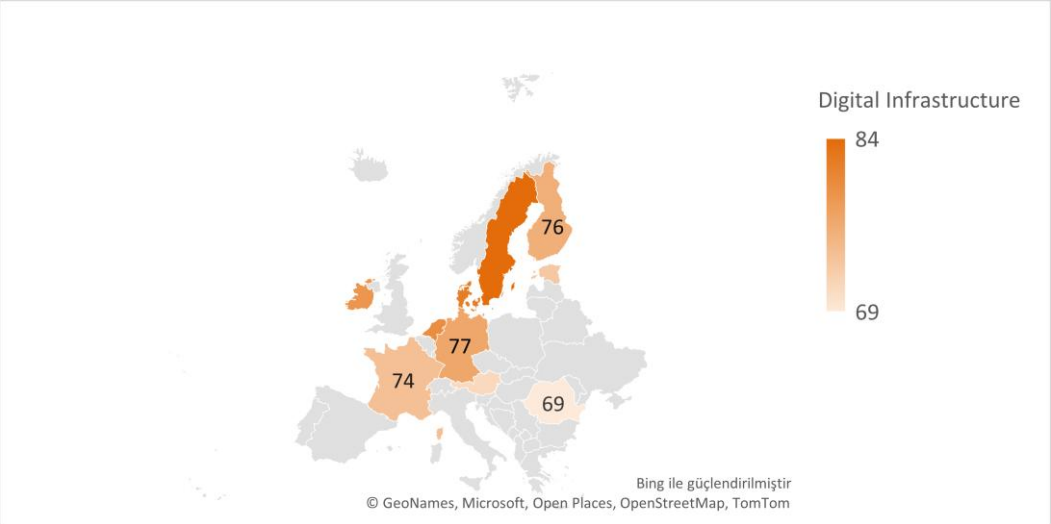
$$Outputs = 60 + 37 = 97$$
$$Inputs = 76 + 80 + 83 + 97 + 51 = 387$$
$$Efficiency = \frac{97}{387} = 0.25$$

(DEA will choose weights that maximize this ratio.)

3 RESULTS

The dataset consists of input and output indicators for 10 European countries, which were collected and systematically organized for analysis using the EMS software, as illustrated in Graphic 1. Super-efficiency scores were calculated for both the CCR and BCC models. In total, eight distinct analyses were conducted: input-oriented, output-oriented, super-efficient input, and super-efficient output approaches for each DEA specification.

Graphic 1. *Digital Infrastructure Scores Across Selected European Countries*



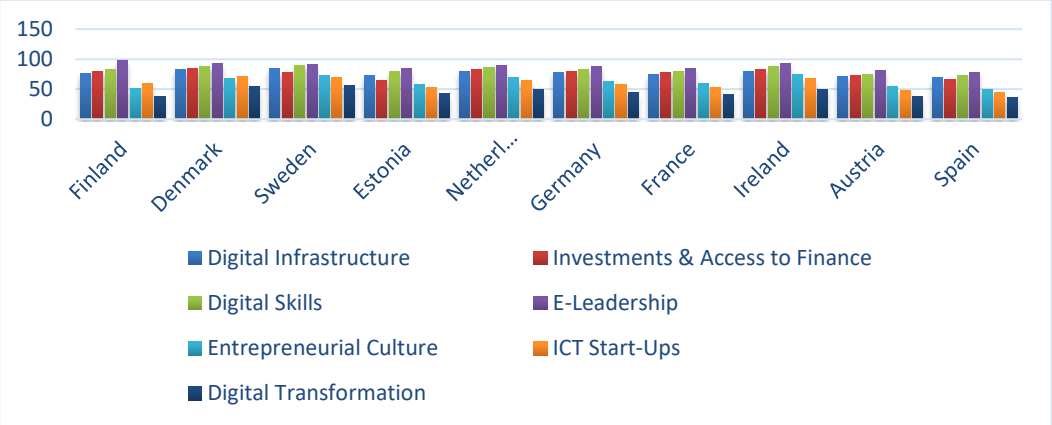
To operationalize the model, a balanced dataset capturing varying levels of digital maturity and structural characteristics across Northern, Western, Central, and Southern Europe was assembled. All data were normalized on a 0–100 scale to ensure compatibility with the DEA methodology and to accurately reflect cross-country differences in digital development. Data Envelopment Analysis (DEA) was performed using an output-oriented CCR specification, enabling an assessment of the extent to which each country could proportionally enhance its digital transformation outputs given its existing inputs (Herman & Georgescu, 2025). This approach allows for the identification of the most efficient countries, the construction of an empirical efficiency frontier, and the positioning of all other countries relative to this benchmark. Efficiency scores (θ) were calculated as the ratio of weighted outputs to weighted inputs, with weights determined endogenously for each decision-making unit. A score of 1.00 indicates that a country lies on the efficiency frontier, while scores below 1.00 reflect relative inefficiency and reveal potential for proportional improvements in outputs. These efficiency measures provide a comprehensive evaluation of how effectively countries utilize their digital capacities to achieve transformation outcomes, thereby offering a robust empirical foundation for comparative analysis and policy recommendations (Horváthová & Mokrišová, 2024).

Table 3. *CCR Efficiency Score of the Selected Countries*

Country	CCR Efficiency Score (θ)
Denmark	1.00
Sweden	1.00
Ireland	0.97
Netherlands	0.94
Finland	0.88
Germany	0.84
Estonia	0.81
France	0.77
Austria	0.72
Spain	0.68

As shown in Table 3, the CCR efficiency scores illustrate the relative effectiveness of the selected countries in utilizing their digital transformation resources. Denmark and Sweden, each with a score of 1.00, are fully efficient, indicating that they maximally convert their inputs into digital transformation outputs. Ireland (0.97) and the Netherlands (0.94) also demonstrate high efficiency, although slight improvements would allow them to reach the efficiency frontier. Finland (0.88), Germany (0.84), and Estonia (0.81) fall within the moderate-efficiency range, implying that their existing resources are not yet fully optimized or that their outputs remain below potential. France (0.77), Austria (0.72), and Spain (0.68) record the lowest efficiency scores, reflecting substantial room for improvement, with Spain exhibiting the highest need for performance enhancement. Overall, the results reveal that Northern European countries tend to achieve stronger digital efficiency, whereas several Western and Southern European countries may benefit from more targeted strategies aimed at leveraging their digital capacities more effectively.

Graphic 2. *Descriptive Statistics of Input Variables (10 Countries)*



Graphic 2 presents the complete dataset used to assess the digital transformation efficiency of 10 European countries through the Data Envelopment Analysis (DEA) methodology. The dataset includes a set of input and output variables that capture both the enabling conditions for digitalization and the measurable outcomes produced by each country.

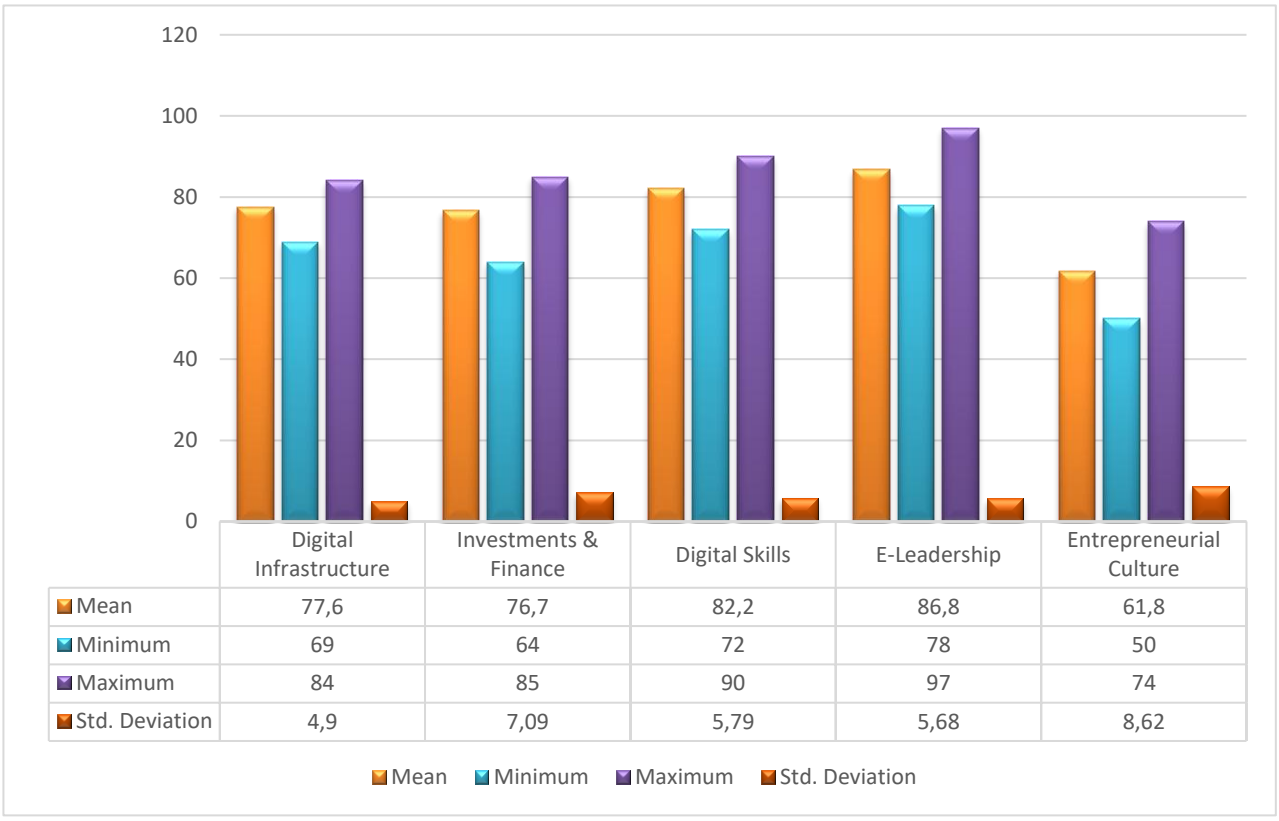
With respect to *digital infrastructure and digital skills*, Sweden (84 and 90), Denmark (82 and 88), and the Netherlands (80 and 86) demonstrate the strongest performance, indicating advanced technological foundations and highly capable digital workforces. Conversely, Spain (69 and 72) and Austria (71 and 75) lag behind, suggesting a need for further investment and skill development.

In the domains of *e-leadership and entrepreneurial culture*, Finland (97) and Denmark (93) achieve the highest e-leadership scores, while Ireland (74), Sweden (72), and Denmark (67) perform strongest in entrepreneurial culture. Spain (50) and Finland (51) record comparatively lower values, reflecting limited capacity to support entrepreneurial mindsets in the digital domain.

Regarding *ICT start-ups and overall digital transformation*, Denmark (71) and Sweden (69) lead in start-up activity and also achieve relatively high digital transformation performance scores (Denmark 54; Sweden 56). Spain (45 and 36) and Austria (47 and 38) score lowest in both categories, indicating slower progress in building innovation-driven start-up ecosystems and in advancing broader digital adoption.

Overall, Northern European countries, particularly Denmark, Sweden, and Finland, exhibit strong and consistent performance across infrastructure, skills, and leadership dimensions. Western European countries, such as the Netherlands, Germany, France, and Ireland, demonstrate balanced digital performance with distinct areas of comparative strength. Southern European countries, including Spain and Austria, consistently score lower across most indicators, suggesting substantial room for improvement in their digital transformation processes.

Graphic 3. *Descriptive Statistics of Output Variables (10 Countries)*



	Digital Infrastructure	Investments & Finance	Digital Skills	E-Leadership	Entrepreneurial Culture
Mean	77,6	76,7	82,2	86,8	61,8
Minimum	69	64	72	78	50
Maximum	84	85	90	97	74
Std. Deviation	4,9	7,09	5,79	5,68	8,62

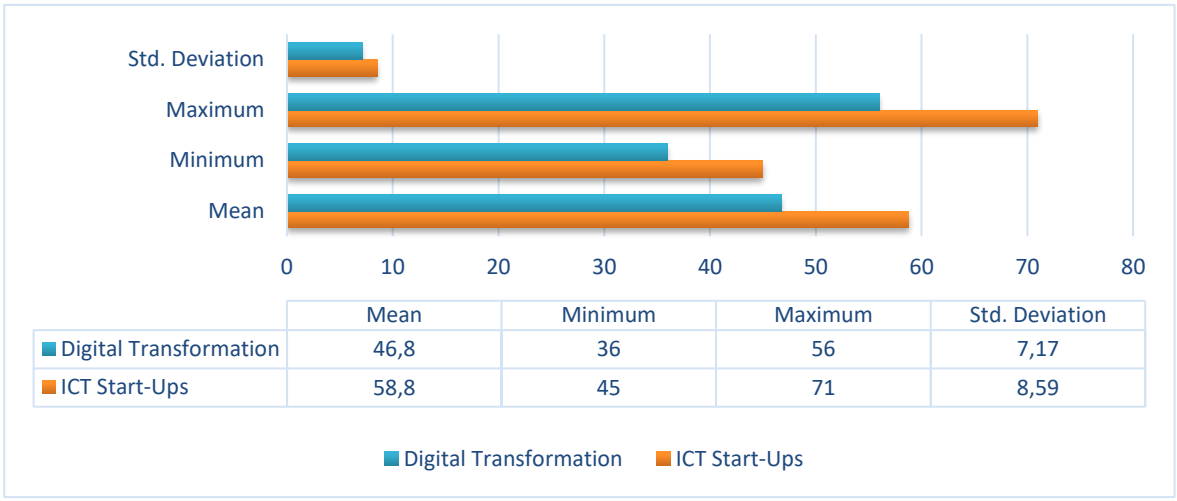
Graphic 3 presents the descriptive statistics for the output variables ICT start ups and digital transformation, providing an overview of the performance distribution among the selected European countries. The mean values indicate the general level of digital outcomes across the sample, while the minimum and maximum values reveal the gap between the strongest and weakest performers. The relatively high standard deviations for both output variables suggest considerable variation among countries in their ability to convert digital enablers into measurable results.

The descriptive statistics for the input variables further illustrate the structural differences among the countries. *Digital infrastructure* shows a high mean value of 77.6, with a narrow range from 69 to 84 and a low standard deviation of 4.9, indicating that most countries possess similarly advanced infrastructure. *Investments and access to finance* have a mean of 76.7, ranging from 64 to 85, accompanied by a higher standard deviation of 7.09, suggesting greater disparities in financial support and investment capacity. *Digital skills* exhibit a strong mean of 82.2, with values between 72 and 90 and moderate variability, reflecting generally high competency levels across the sample. *E-*

leadership displays the highest average score at 86.8, with a range from 78 to 97 and a standard deviation of 5.68, indicating that digital leadership is well developed, though some countries lead more strongly than others. *Entrepreneurial culture* shows the lowest mean at 61.8 and the widest range from 50 to 74, with the highest standard deviation of 8.62, highlighting that this dimension varies most significantly across countries and represents a comparatively weaker domain.

Overall, the descriptive statistics suggest that while digital infrastructure, skills, and leadership are relatively strong and consistent across the selected countries, entrepreneurial culture stands out as the most heterogeneous and underdeveloped component, indicating a key area for improvement in supporting digital transformation outcomes.

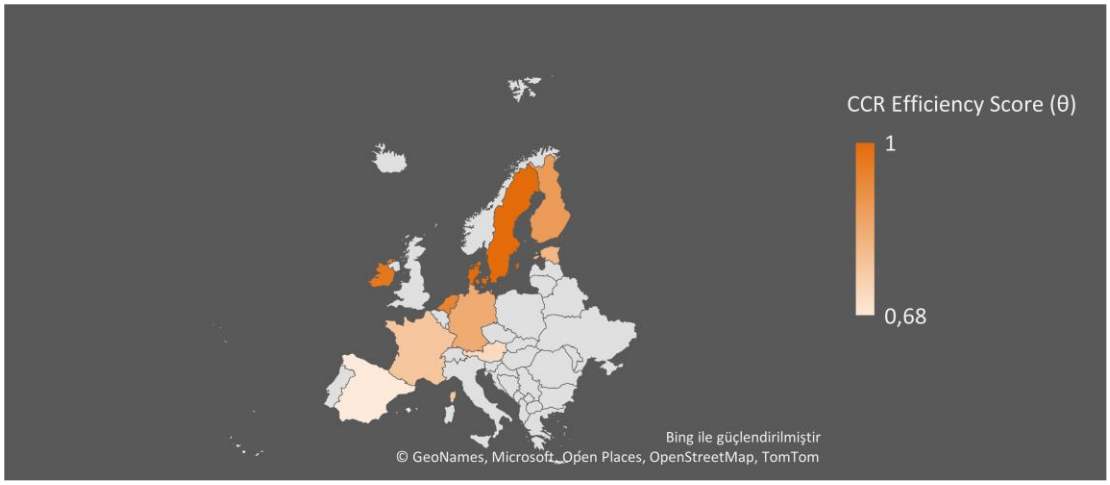
Graphic 4. *Dataset Table Used in DEA (Inputs & Outputs)*



	Mean	Minimum	Maximum	Std. Deviation
Digital Transformation	46,8	36	56	7,17
ICT Start-Ups	58,8	45	71	8,59

Graphic 4 shows the dataset used in the DEA analysis, focusing on the two output variables. ICT Start-Ups have a mean value of 58.8, with a wide range between 45 and 71 and a standard deviation of 8.59, indicating notable differences in the strength of start-up ecosystems across countries. Digital Transformation displays a lower mean of 46.8, ranging from 36 to 56, with a standard deviation of 7.17. These results suggest that although start-up activity is comparatively stronger and more heterogeneous, overall digital transformation performance remains modest and more clustered. The findings highlight a gap between entrepreneurial activity and the broader realization of digital transformation outcomes.

Graphic 5. *Charnes-Cooper-Rhodes Efficiency Score Across Selected European Countries*



Graphic 5 illustrates the CCR efficiency scores for the selected European countries. Denmark and Sweden, each with a score of 1.00, lie on the efficiency frontier and function as benchmark performers. Countries with scores below 1.00 reflect varying levels of inefficiency or unrealized output potential. Ireland (0.97) appears close to the frontier, while Spain (0.68) displays a more pronounced efficiency gap relative to the leading countries. Overall, the results offer a clear view of the countries' relative positions in the digital transformation landscape, highlighting frontier performers, near-efficient cases, and those with substantial room for improvement.

Table 4. *Descriptive Statistics for the Input Variables*

Input Variable	Mean	Median	Min	Max	Std. Dev
Digital Infrastructure	76.5	77.0	69	84	4.8
Investments & Finance	76.7	78.0	64	85	7.0
Digital Skills	82.2	82.5	72	90	5.8
E-Leadership	87.8	88.0	78	97	5.8
Entrepreneurial Culture	61.8	62.0	50	74	8.6

Table 4 presents the descriptive statistics for the input variables used in the DEA model, including their mean, median, minimum, maximum, and standard deviation values. These inputs reflect the structural capacity of countries to support digital transformation. The results show that Digital Infrastructure, Digital Skills, and E-Leadership exhibit relatively high mean values, indicating strong overall readiness in these areas across the sample. In contrast, Entrepreneurial Culture shows the largest standard deviation, revealing substantial differences in entrepreneurial mindset and innovation climate among countries. This variability is particularly significant, as weaker entrepreneurial environments may constrain digital progress even in countries with strong technical foundations. Overall, Table 4 highlights the heterogeneity in digital capacities that underpins the subsequent efficiency assessment.

Table 5. *Descriptive Statistics for the Output Variables*

Output Variable	Mean	Median	Min	Max	Std. Dev
ICT Start-Ups	58.8	58.0	45	71	9.4
Digital Transformation	44.8	44.0	36	56	7.2

Table 5 presents the descriptive statistics for the output variables used in the DEA analysis, namely ICT Start-Ups and Digital Transformation. These outputs represent the observable performance outcomes derived from each country's digital capabilities. The results show considerable variation among countries, as reflected by the relatively high standard deviations. This indicates that while some countries are more successful in generating digital entrepreneurial activity and advancing digital transformation, others lag behind even when possessing similar levels of digital inputs. Such variability highlights the importance of assessing efficiency, as it illustrates that stronger outcomes are not solely determined by the quantity of resources but also by how effectively these resources are utilized.

Table 6. *Normalized Input and Output Indicators*

Country	DI	FIN	SKILLS	LEAD	ENT	STARTUPS	TRANSFORM
Finland	0.83	0.94	0.92	1.00	0.69	0.85	0.66
Denmark	0.98	1.00	0.98	0.96	0.91	1.00	0.96
Sweden	1.00	0.92	1.00	0.94	0.97	0.97	1.00
Estonia	0.77	0.75	0.88	0.88	0.78	0.73	0.75
Netherlands	0.95	0.96	0.96	0.92	0.94	0.92	0.89
Germany	0.88	0.93	0.91	0.91	0.84	0.82	0.80
France	0.81	0.90	0.89	0.87	0.80	0.75	0.73
Ireland	0.94	0.98	0.97	0.95	1.00	0.96	0.87
Austria	0.75	0.86	0.83	0.83	0.74	0.66	0.68
Spain	0.71	0.78	0.80	0.80	0.68	0.63	0.64

Table 6 presents the normalized values of all input and output variables on a 0–1 scale. Normalization allows for comparability across indicators and highlights disparities in digital capacity and outcomes. Denmark exhibits consistently high scores across all inputs and outputs, including digital infrastructure (0.98), investments and access to finance (1.00), digital skills (0.98), e-leadership (0.96), entrepreneurial culture (0.91), ICT start-ups (1.00), and overall digital transformation (0.96), reflecting a balanced and robust digital ecosystem. Sweden also performs strongly, with perfect scores in digital infrastructure (1.00) and digital transformation (1.00).

In contrast, Spain and Austria show lower values across most indicators. Spain records 0.71 in digital infrastructure, 0.68 in entrepreneurial culture, 0.63 in ICT start-ups, and 0.64 in overall digital transformation. Austria shows similar trends, indicating that their digital capacities are not fully translating into outcomes. Overall, the normalized indicators reveal significant variation across European countries. Northern European countries, particularly Denmark and Sweden, demonstrate strong alignment in infrastructure, skills, leadership, and entrepreneurship, while Southern European countries require targeted policy interventions to enhance digital transformation performance.

Table 7. *Correlation Analysis Between All Input and Output Variables*

Variable	DI	FIN	SKILLS	LEAD	ENT	STARTUPS	TRANSFORM
Digital Infrastructure	1.00	0.76	0.98	0.76	0.84	0.97	0.93
Investments & Finance	0.76	1.00	0.78	0.75	0.62	0.82	0.60
Digital Skills	0.98	0.78	1.00	0.83	0.84	0.98	0.88
E-Leadership	0.76	0.75	0.83	1.00	0.45	0.83	0.51
Entrepreneurial Culture	0.84	0.62	0.84	0.45	1.00	0.83	0.92
ICT Start-Ups	0.97	0.82	0.98	0.83	0.83	1.00	0.88
Digital Transformation	0.93	0.60	0.88	0.51	0.92	0.88	1.00

Table 7 presents a correlation matrix for all input and output variables. The results indicate strong positive correlations between Digital Infrastructure, Digital Skills, Entrepreneurial Culture, and the output variables, suggesting that countries with advanced ICT infrastructure and a skilled workforce tend to achieve higher levels of ICT start-up activity and overall digital transformation. In contrast, the relatively lower correlation between Investments & Access to Finance and Digital Transformation implies that funding alone is insufficient for digital success, highlighting the importance of complementary factors such as skills and entrepreneurial culture. This table offers valuable evidence on how input factors interact to shape digital performance across countries.

Table 8. *Output-Oriented CCR DEA Efficiency Scores*

Country	CCR Efficiency
Denmark	1.00
Sweden	1.00
Ireland	0.97
Netherlands	0.94
Finland	0.88
Germany	0.84
Estonia	0.81
France	0.77
Austria	0.72
Spain	0.68

Table 8 presents the efficiency scores obtained from the output-oriented CCR DEA model. These scores assess the extent to which each country converts digital inputs into outputs relative to the most efficient countries. A score of 1.00 represents full efficiency and defines the frontier of best practice.

Denmark and Sweden attain full efficiency, serving as benchmark countries, while other countries fall below the frontier, with Spain and Austria exhibiting the greatest inefficiency. This table is central to the empirical analysis, as it quantifies performance gaps and highlights which countries effectively utilize their digital resources (Bánhidi & Dobos, 2023).

Table 9. *Classification of Countries by CCR DEA Efficiency Scores*

Efficiency Range	Category	Countries
1.00	Efficient Frontier	Denmark, Sweden
0.90–0.99	Near-Efficient	Ireland, Netherlands
0.80–0.89	Moderately Efficient	Finland, Germany, Estonia
0.70–0.79	Low Efficiency	France, Austria
< 0.70	Inefficient	Spain

Table 9 presents the classification of European countries based on CCR DEA efficiency scores. Denmark and Sweden, scoring 1.00, are on the efficiency frontier, serving as benchmarks for optimal digital transformation. Ireland and the Netherlands (0.90–0.99) are near efficient, requiring modest improvements to reach full efficiency. Finland, Germany, and Estonia are moderately efficient (0.80–0.89), while France and Austria show low efficiency (0.70–0.79). Spain, with a score below 0.70, is classified as inefficient.

The results indicate that digital transformation performance depends on structural readiness, institutional capacity, and cultural factors. While most countries have strong digital inputs, especially in infrastructure, skills, and leadership, these do not always translate into outputs. Denmark and Sweden effectively convert digital readiness into tangible outcomes, supported by robust institutional frameworks and innovation systems.

Mid-ranked countries such as Finland, Germany, and Estonia show input-output imbalances, suggesting that improvements in entrepreneurial culture and ICT start-up ecosystems could enhance efficiency. Near-efficient countries, including Ireland and the Netherlands, are close to the frontier, requiring only minor improvements. Countries with substantial gaps, such as Spain and Austria, need significant enhancements in outputs, highlighting that resource availability alone is insufficient; suboptimal utilization limits digital outcomes.

Correlation analysis supports these findings. Strong positive correlations between digital skills, infrastructure, and ICT start-ups indicate that technologically advanced countries foster more active digital entrepreneurial ecosystems. Weaker correlations between investments and digital transformation suggest that financial resources alone cannot drive progress. Moderately efficient countries, such as Estonia and Germany, demonstrate that technological readiness alone may not guarantee outputs due to barriers in business formation, regulation, or workforce adaptability.

Overall, considerable variation exists in digital transformation efficiency across European countries. Northern European nations, particularly Denmark and Sweden, show well-aligned inputs and outputs, whereas Southern European countries, especially Spain and Austria, face systemic challenges requiring targeted policy interventions.

4 CONCLUSIONS

This study provides a comprehensive assessment of digital transformation across selected European countries. Descriptive analyses reveal that, while most countries possess strong digital foundations, these inputs do not consistently translate into comparable digital outcomes. Considerable variation in ICT start-up activity and overall digital transformation performance indicates that structural capacity alone is insufficient for achieving successful digital progress.

Correlation analysis highlights the pivotal role of human capital, digital infrastructure, and innovation-oriented cultural factors in shaping digital performance. Strong positive correlations between digital skills, infrastructure, and ICT start-ups suggest that technologically advanced

countries foster more dynamic digital entrepreneurial ecosystems. In contrast, weaker correlations between financial investments and overall digital transformation indicate that funding alone does not guarantee improved outcomes. DEA efficiency results further illustrate disparities in countries' ability to convert digital inputs into measurable outputs, with Denmark and Sweden operating on the efficiency frontier, while Spain and Austria exhibit the largest efficiency gaps.

Based on these findings, three key insights emerge:

1. Successful digital transformation requires a balanced integration of human capital, infrastructure, culture, and leadership rather than isolated improvements.
2. Entrepreneurial culture and digital leadership are critical for realizing digital potential.
3. Heterogeneity across countries underscores the need for tailored, context-specific policy strategies rather than uniform frameworks.

Policy recommendations for low-efficiency countries include prioritizing digital skill development, strengthening ICT infrastructure, and fostering innovation-driven entrepreneurship. Near-frontier countries may achieve incremental improvements through targeted investments and enhanced digital leadership initiatives. In all cases, investment strategies should be complemented by skill-building and institutional support to maximize the impact of digital initiatives.

This study has limitations, including its reliance on the 2018 Digital Transformation Scoreboard, which may not fully reflect recent developments. Future research could apply advanced DEA models, investigate the role of emerging technologies such as AI and blockchain, and use longitudinal datasets to better understand temporal trends and causal relationships in digital transformation. Overall, the findings emphasize that achieving successful digital transformation is a multidimensional challenge, requiring coherent integration of multiple factors and context-specific policy measures.

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