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# Assessment of International Digital Economy and Society Index Using Entropy based TOPSIS Methods

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*Abstract:* **This paper assesses the International Digital Economy and Society Index (I-DESI) which measures the development of the digital economy. Based on the European Commission's I-DESI database of 45 countries from 2015 to 2018, the study compares criteria weights initially used for dimensions against new ones calculated using the Entropy method. Then, it recalculates the I-DESI using three different methods (Entropy, TOPSIS and Entropy-based TOPSIS) and finally compares countries rankings using Spearman's correlation and Kendall W test. Results show that calculated entropy weights and initial scoring ones diverge considerably. In entropy, "Integration of Digital Technology and Business" rises as an important dimension while the I-DESI scoring model selected "Human Capital" instead. "Use of Internet Services by Citizens" dimension has double the weight in entropy. Finally, comparisons of the four ranking methods show, on average, a very strong positive relationship between the I-DESI initial model and both TOPSIS and Entropy methods for the period 2015 to 2018, and a moderate positive one with the Entropy-based TOPSIS.**

*Keywords:* **Digital Economy Assessment, Entropy Method, I-DESI, Kendall's W, Spearman's Correlation, TOPSIS Method.**

## I. INTRODUCTION

According to researchers from the McKinsey Global Institute, the scope of global economic digitalization can be compared to the 18–19th century industrial revolution, which significantly altered the world power distribution system and hastened the industrialization of a number of countries [1].

The phrase "digital economy" was coined by Nicholas Negroponte (1995) of Massachusetts University. The World Economic Forum in 2017 viewed the future of the economy in its digitization. In order to speed progress, the Forum established targets for the adoption of the "digital economy and society." [2].

Several definitions exist for "digital economy". To cite a few, "the Digital Economy is the share of total economic output derived from a number of broad "digital" inputs. These digital inputs include digital skills, digital equipment (hardware, software and communications equipment) and the intermediate digital goods and services used in production. Such broad measures reflect the foundations of the digital economy [3]." According to a study commissioned by the European Parliament, it is "a complex structure of several levels/layers connected with each other by an almost endless and always growing number of nodes. Platforms are stacked on each other allowing for multiple routes to reach end-users and making it difficult to exclude certain players, i.e. competitors [4]."

In order to provide an overall assessment of the EU's progress toward a digital society and economy in comparison to non-EU economies, the International DESI (I-DESI) was created and first published in 2016 with the goal of replicating

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and extending on the outcomes of the European Commission's original (EU-only) DESI by identifying indicators that assess similar factors for non-EU countries [5].

The aim of this paper is to assess the I-DESI overall calculation method known as the scoring model, by using the Entropy method. First, the criteria weights are recalculated using the Entropy method and compared at dimension level to the initial I-DESI criteria weights. Then the study aims to assess the ranking proposed by the I-DESI methodology. To do so, three models were used to recalculate the I-DESI overall score and rank consequently countries' performance : Entropy based model, TOPSIS-based model and Entropy-based-TOPSIS model.

Remaining parts of this paper are structured as follows : Section 2 gives a brief literature review of the digital economy measurements, multiple-criteria decision methods in general then TOPSIS method in particular. Section 3 presents the research methodology adopted and describes the entropy and TOPSIS methods followed by Kendall's W test. Section 4 shows the application of the proposed methodology on the I-DESI data. Section 5 concludes this study.

## II. LITERATURE REVIEW

Information society indices that measure facets of digital economy development are an example of indices that are gaining prominence side by side of economic and social indices [2]. For the purpose of identifying priority investment sectors for the emergence of the digital market and supporting EU nations in improving digital productivity, the European Union created in 2015 the Digital Economy and Society Index (DESI) [6]. The Huawei firm examines digital economic developments through its global network interaction index (Global Connectivity Index (GCI)). They observe that the index's rise reflects an increase in the national economy's competitiveness, innovation, and productivity. The Digitization Index (DiGiX), which examines the variables, agent behavior, and institutions that enable a country to fully harness Information and Communication Technologies (ICTs) for enhanced competitiveness and welfare, is the next generally recognized attempt in the scientific literature [7]. It is a synthetic index that summarizes a state's 100 essential digital performance metrics. The DiGiX is organized around six major dimensions: infrastructure, enterprises' adoption, costs, households' adoption, regulation and contents [8]. Several more indexes one can find in literature like : the E-Readiness Index, the Knowledge Economy Index, Networked Readiness Index, Digital Access Index, Technology Achievement Index,..etc.

Decision-making is critical in economic policy because decision-makers strive to make decisions with the fewest negative repercussions. Over the last several decades, Multi-Criteria Decision Analysis has seen a tremendous amount of application. Its importance in several application fields has grown dramatically, particularly when new approaches emerge and existing ones improve [9]. The latter researchers identified eleven popular Multi-criteria decision-making (MCDM) approaches as follow : 1) Multi-Attribute Utility Theory (MAUT), 2) Analytic Hierarchy Process (AHP), 3) Fuzzy Set Theory, 4) Case-based Reasoning, 5) Data Envelopment Analysis, 6) Simple Multi-Attribute Rating Technique, 7) Goal Programming, 8) ELECTRE, 9) PROMETHEE, 10) Simple Additive Weighting, and 11) Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

MCDM techniques are effective tools for dealing with complicated challenges. They help managers and other decision-makers in weighing numerous factors and ranking various choices [10], [11]. MAUT was utilized in a real-world application by Ananda and Herath [12] to examine risk preferences in relation to forest land-use in Australia. Bentes et al. [13] applied AHP to prioritize performance aspects and indicators during the evaluation of the organizational performance of a Brazilian telecommunications business. Hermans, Brijs, Wets, and Vanhoof [14] evaluated metrics for road safety performance in various nations. Data envelopment analysis (DEA) is used to equip any country's policymakers with a model to help in prioritizing steps to improve the safety of their individual highways in the most efficient manner possible. ELECTRE has been used to solve problems in energy, economics, the environment, water management, and transportation [9]. Furthermore, an integrated model combining entropy and COPRAS methods was used for the selection of the best place in Turkey to hold the Olympic games [15].

In MCDM situations, the weighting procedure is carried out based on the relative relevance of each factor. This procedure is carried out in accordance with the performance of the target component. Alternative's data or the designer's experience can be used to calculate weights [11].

Without a doubt, the weights used may have a major impact on the units listed. In fact, a methodological note from the European Commission demonstrated that, in the case of the DESI, modifying the weights of specific indicators appears to impact the ranking of some of the countries examined, particularly those ranked in the middle [16]. Weighting methods

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found in the literature include No or Equal Weights, Budget Allocation Process (BAP), Analytic Hierarchy Process (AHP), Conjoint Analysis (CA). Because of the "subjectivity" aspect making the selection of weights more arbitrary, other statistical methods more "objective" are preferred [17], like Data Envelopment Analysis (DEA), Multiple linear regression analysis, Principal Component Analysis and Factor Analysis and Entropy method. Even though there are many methods for calculating the importance/weight of influential aspects of the digital economy, the entropy was selected due to the objectivity it provides and the simplicity of calculation.

Another objective of the current study as noted before is to rank countries and assess their digital economy performance. TOPSIS, an MCDM approach, was chosen for this purpose because it can compute the relative performance of each alternative efficiently. TOPSIS's simplicity allows for better comprehension and interpretation of its outcomes [10]. Hwang and Yoon promote TOPSIS as a valuable technique for dealing with many attribute decision making situations [18]. TOPSIS works on the notion of determining the optimum alternative based on the smallest distance from the positive ideal solution and the greatest distance from the negative ideal solution [19], [20].

The TOPSIS approach is enhanced by the entropy approach, which is used to fix more objectively the weight and decision outcome [21]. The entropy-based TOPSIS approach has recently gained popularity in a variety of applications. For example, Wang et al. presented an evaluation technique of symbiotic technology for the iron and steel sector [22]. Oluah et al. used entropy-based TOPSIS method for selecting Phase Change Material for Trombe Wall Systems [23]. Alao et al., using the waste stream of cities, applied it to select the optimal waste-to-energy technology [24].

## III. RESEARCH METHODOLOGY

Research methodology is based on the analysis of secondary data obtained from the European Commission website [25]. Analyzed data consists of I-DESI 4320 data points related to 24 indicators (criteria) across 45 countries covering the period of four years from 2015 to 2018. The I-DESI adopted a weighting system that reflects the relevance of dimensions as shown in TABLE II. The overall index is calculated following a bottom-up approach: indicators are aggregated into sub-dimensions and sub-dimensions into five dimensions, and dimensions into the overall index. The dimensions are : Connectivity, Human Capital, Use of Internet Services, Integration of Digital Technology and Digital Public Services. The top-level I-DESI score is calculated as follows [25]:

$$DESI = \sum_{i=1}^{5} a_i w_i,$$

where $a_i$ is the value of the ith indicator of the first level, $w_i$ is the weight (importance level) of the *ith* indicator.

To find out the best quantitative solution from the alternatives, the multi criteria decision making (MCDM) process provides a ranking solution of the countries. In this research paper, the entropy and TOPSIS methods were applied separately and jointly and results were compared with I-DESI ranking using Spearman correlation and Kendall W Test.

The decision matrix of MCDM problems included m alternatives and n criteria. The current study covers 45 alternatives (m=45 countries) and 24 criteria (n=24 indicators). xij(i=1; 2;...;m ; j=1; 2;...; n) elements in the decision matrix, which represents the performance score of the ith alternative to the jth criteria [11], [26].

### A. *Entropy Method*

The weight of all indicators is derived by information entropy based on the degree of index dispersion.

For a decision matrix B with m alternatives and n indicators:

**Step 1:** In matrix B, feature weight is of the jth alternatives to the jth factor:

$$p_{ij} = \frac{x_{ij}}{\Sigma_{i=1}^{m} x_{ij}}, \quad (1\leq i \leq m, 1\leq j\leq n) \qquad (1)$$

**Step 2:** The output entropy ej of the jth factor becomes

$$e_j = -k\Sigma_{i=1}^{m} p_{ij} \ln p_{ij} \quad ,( k = 1/\ln m, 1 \leq j \leq n ) \qquad (2)$$

**Step 3:** Variation coefficient of the jth factor: gj can be calculated as follows:

$$d_j = 1 - e_j , (1 \le j \le n) \quad (3)$$

**Step 4:** Calculate the weight of entropy wj:

$$w_j = g_j / \Sigma_{i=1}^{m} g_j, \qquad (1 \le j \le n) \quad (4)$$

**B. *TOPSIS Method***

The TOPSIS assessment process comprises six major steps, which are outlined below [27] :

**Step 1:** Calculate the normalized decision matrix A. The normalized value (aij) is calculated as:

$$a_{ij} = \frac{x_{ij}}{\Sigma_{i=1}^{m} (x_{ij})^2} , \quad (1\le i \le m, 1\le j \le n) \quad (5)$$

**Step 2:** Calculate the weighted normalized decision matrix:

$$V = (a_{ij} * w_j) \quad (6)$$

where wj is the weight of the ith criterion and

$$\Sigma_{i=1}^{n}, w = 1. \quad (7)$$

**Step 3:** Calculate the ideal solution V+ and the negative ideal solution V-

$$V^+ = \{v_1^+, v_2^+, .. v_n^+\} = \left\{(Max\ v_{ij} \mid j \in J), (Min\ v_{ij} \mid j \in J)\right\} \quad (8)$$

$$V^- = \{v_1^-, v_2^-, .. v_n^-\} = \left\{(Min\ v_{ij} \mid j \in J), (Max\ v_{ij} \mid j \in J)\right\} \quad (9)$$

**Step 4:** Calculate the separation measures, using the m dimensional Euclidean distance, where

$$S+ = \sqrt{\Sigma_{j=1}^{n} (V_{ij} - V^+)^2, where\ (1 \le i \le m, 1 \le j \le n)} \quad (10)$$

$$S- = \sqrt{\Sigma_{j=1}^{n} (V_{ij} - V^-)^2, where\ (1 \le i \le m, 1 \le j \le n)} \quad (11)$$

**Step 5:** Calculate the relative closeness to the ideal solution

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \ (1 \le i \le m, 1 \le j \le n) \quad (12)$$

where the larger is, Pi the closer the alternative is to the ideal solution.

**Step 6:** The larger TOPSIS value, the better the alternative.

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### C. *Kendall W Test*

Kendall's Coefficient of Concordance, W, is a measure of agreement among a group of (p) judges who have rank-ordered a set of (n) objects. It compares the ranking variability of the ranked objects to the maximum possible variability of the total ranks; a high ratio indicates agreement among ranking judges. Kendall W statistic can be calculated in two steps as follow [29]:

$$S = \sum_{i=1}^{n} (R_i - \underline{R})^2 \tag{13}$$

S is a sum-of-squares statistic over the row sums of ranks Ri. R is the mean of the Ri values. After that, Kendall's W statistic can be obtained from:

$$W = \frac{12S}{p^2(n^3 - n) - pT} \tag{14}$$

where n is the number of objects, p the number of judges. T is a correction factor for tied ranks [29]:

$$T = \sum_{k=1}^{m} (t_k^3 - t_k) \tag{15}$$

## IV. APPLICATION

The Entropy and TOPSIS methods were applied separately and jointly to the I-DESI data between 2015 and 2018. Thus, resulting in three ranking methods :

- Entropy method
- TOPSIS method (using initial I-DESI weights)
- Entropy-based TOPSIS method

The main objective is to assess the reliability of the I-DESI results. Computed results of the three ranking methods alongside the I-DESI data for 2018 are shown in TABLE I.

**TABLE I: COMPARISON OF THE CALCULATED SCORES & RANKINGS (2018)**

| Country | I-DESI Overall Index | | TOPSIS & Index Weighting Coef. | | Entropy | | Entropy based TOPSIS | |
|---|---|---|---|---|---|---|---|---|
| | Score % | Rank | Score % | Rank | Score% | Rank | Score % | Rank |
| Austria | 52 | 21 | 52 | 19 | 43 | 22 | 37 | 24 |
| Belgium | 49 | 22 | 47 | 23 | 45 | 21 | 42 | 20 |
| Bulgaria | 40 | 35 | 38 | 32 | 31 | 33 | 34 | 28 |
| Croatia | 35 | 43 | 28 | 44 | 26 | 39 | 28 | 33 |
| Cyprus | 47 | 25 | 40 | 30 | 32 | 32 | 26 | 38 |
| Czech Rep. | 47 | 25 | 48 | 22 | 45 | 20 | 48 | 15 |
| Denmark | 70 | 2 | 68 | 4 | 61 | 6 | 54 | 9 |
| Estonia | 57 | 15 | 56 | 16 | 50 | 16 | 48 | 14 |
| Finland | 68 | 3 | 68 | 3 | 63 | 5 | 56 | 8 |
| France | 57 | 15 | 59 | 13 | 47 | 18 | 39 | 22 |
| Germany | 58 | 13 | 58 | 14 | 55 | 13 | 57 | 7 |
| Greece | 40 | 35 | 34 | 38 | 24 | 41 | 18 | 44 |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hungary | 41 | 31 | 37 | 34 | 29 | 37 | 27 | 34 |
| Ireland | 60 | 10 | 63 | 7 | 60 | 7 | 66 | 3 |
| Italy | 38 | 38 | 31 | 41 | 33 | 31 | 36 | 26 |
| Lithuania | 44 | 29 | 41 | 27 | 42 | 24 | 44 | 18 |
| Latvia | 41 | 31 | 39 | 31 | 35 | 29 | 33 | 31 |
| Luxembourg | 62 | 8 | 61 | 8 | 56 | 10 | 53 | 11 |
| Malta | 48 | 23 | 47 | 24 | 40 | 25 | 37 | 25 |
| Netherlands | 68 | 3 | 69 | 2 | 69 | 2 | 71 | 2 |
| Poland | 36 | 42 | 34 | 39 | 31 | 34 | 33 | 30 |
| Portugal | 41 | 31 | 36 | 35 | 30 | 36 | 25 | 39 |
| Romania | 41 | 31 | 38 | 33 | 26 | 40 | 21 | 42 |
| Slovakia | 39 | 37 | 36 | 36 | 31 | 35 | 26 | 36 |
| Slovenia | 47 | 25 | 44 | 25 | 36 | 28 | 33 | 32 |
| Spain | 47 | 25 | 41 | 28 | 34 | 30 | 26 | 35 |
| Sweden | 65 | 6 | 65 | 6 | 64 | 4 | 58 | 6 |
| United Kingdom | 59 | 12 | 58 | 15 | 56 | 11 | 52 | 13 |
| Iceland | 62 | 8 | 59 | 12 | 59 | 9 | 59 | 7 |
| Norway | 64 | 7 | 61 | 9 | 56 | 12 | 46 | 14 |
| Switzerland | 66 | 5 | 67 | 5 | 69 | 1 | 75 | 1 |
| Republic of Serbia | 38 | 38 | 34 | 37 | 22 | 45 | 15 | 45 |
| Australia | 60 | 10 | 60 | 10 | 53 | 14 | 50 | 18 |
| Brazil | 37 | 40 | 33 | 40 | 27 | 38 | 26 | 35 |
| Canada | 55 | 18 | 50 | 20 | 47 | 19 | 41 | 22 |
| Chile | 35 | 43 | 30 | 43 | 24 | 43 | 22 | 41 |
| China | 48 | 23 | 42 | 26 | 38 | 27 | 36 | 25 |
| Israel | 58 | 13 | 60 | 11 | 60 | 8 | 54 | 8 |
| Japan | 57 | 15 | 54 | 17 | 50 | 17 | 43 | 20 |
| Korea, Republic of | 54 | 19 | 50 | 21 | 43 | 23 | 34 | 28 |
| Mexico | 37 | 40 | 31 | 42 | 24 | 42 | 22 | 40 |
| New Zealand | 54 | 19 | 54 | 18 | 50 | 15 | 47 | 17 |
| Russia Federation | 43 | 30 | 40 | 29 | 39 | 26 | 39 | 21 |
| Turkey | 34 | 45 | 28 | 45 | 23 | 44 | 19 | 43 |
| United States | 71 | 1 | 70 | 1 | 64 | 3 | 61 | 4 |

Results of dimension weights calculated by Entropy method are shown in TABLE II below side by side with I-DESI ones. Entropy method, on average, gives the highest weights to "Connectivity" (27%) and "Integration of Digital Technology and Business" (28%) dimensions while the I-DESI scoring model gives it to "Connectivity" (25%) and "Human Capital" (25%). Entropy method, on average, gives around double the weight to "Use of Internet Services by Citizens" dimension (20%) than to "Digital Public Services" (9%), while the scoring model weighs them the same (15%)

**TABLE II: ENTROPY WEIGHT COEFFICIENTS VS I-DESI COEFFICIENTS (2015-2018)**

| Dimensions | I-DESI | 2015 | | 2016 | | 2017 | | 2018 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Entropy | Diff | Entropy | Diff | Entropy | Diff | Entropy | Diff |
| Connectivity | 25% | 31% | 6% | 29% | 4% | 29% | 4% | 21% | -4% |
| Human Capital | 25% | 15% | -10% | 15% | -10% | 16% | -9% | 17% | -8% |
| Use of Internet Services by Citizens | 15% | 20% | 5% | 19% | 4% | 21% | 6% | 19% | 4% |
| Integration of Digital Technology by Businesses | 20% | 24% | 4% | 26% | 6% | 27% | 7% | 34% | 14% |
| Digital Public Services | 15% | 9% | -6% | 10% | -5% | 7% | -8% | 10% | -5% |

**D. *Spearman correlation***

The study of Spearman correlation applied to the three ranking methods and the I-DESI one indicates a very strong positive relationship between the TOPSIS method ($r_s$= 0.96), the Entropy method ($r_s$= 0.82) and the I-DESI initial method and also a moderate positive relationship with the Entropy-based TOPSIS method ($r_s$= 0.66) for the period 2015 to 2018. TABLE III summarizes the Spearman correlation ratios calculated.

**TABLE III: SPEARMAN CORRELATIONS BETWEEN RANKING METHODS (2015-2018)**

| **Spearman Correlation** | **I-DESI Ranking Method** | | | |
|---|---|---|---|---|
| **Method** | **2015** | **2016** | **2017** | **2018** |
| Entropy-based TOPSIS | 0.644 | 0.502 | 0.617 | 0.870 |
| Entropy | 0.786 | 0.731 | 0.797 | 0.953 |
| TOPSIS | 0.958 | 0.943 | 0.953 | 0.988 |

### E. *Kendall's W Concordance*

Kendall's concordance coefficient analysis demonstrates that the ranking of countries based on the values of the four ranking methods is very consistent with a confidence level of 99% (coefficient of concordance between 0.83 and 0.94). TABLE IV shows Kendall's W results.

**TABLE IV: KENDALL'S W CONCORDANCE BETWEEN RANKING METHODS (2015-2018)**

| Year | **2015** | **2016** | **2017** | **2018** |
|---|---|---|---|---|
| **Kendall's W** | 0.869 | 0.826 | 0.860 | 0.945 |

## V. CONCLUSION

The paper assesses the countries' ranking of the International Digital Economy and Society Index (I-DESI). The first objective was to compare criteria weights by using an objective method, the Entropy method was used. The results show that the Entropy method, on average, gives the highest weights to "Connectivity" (27%) and "Integration of Digital Technology and Business" (28%) dimensions while the I-DESI scoring model gives it to "Connectivity" (25%) and "Human Capital" (25%). Entropy method, on average, gives around double the weight to "Use of Internet Services by Citizens" dimension (20%) than to "Digital Public Services" (9%), while the I-DESI scoring model assigns the same weight to them (15%).

The second objective was to assess the I-DESI overall ranking model against three models : Entropy-based model, TOPSIS-based model and Entropy-based TOPSIS model. Comparing the four models, on average, results show a very strong positive relationship between the I-DESI initial model and TOPSIS based model ($r_s$= 0.96), the Entropy-based model ($r_s$= 0.82) and a moderate positive relationship with the Entropy-based TOPSIS model ($r_s$= 0.66) for the period 2015 to 2018. Lastly, the four ranking models agree to a large extent (Kendall's $w$ =0.87) on average for the same period.

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