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Measuring ICT-opportunity index using generalized data envelopment analysis

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Abstract Information and Communication Technology (ICT) is an important structural part of modern society. This is why countries strive for constant progress in ICT. Information Technology Development Index (IDI) ranks countries' performance in terms of ICT infrastructure and uptake. It aims to provide an objective international performance evaluation based on quantitative indicators and benchmarks. The results for this metric help policymakers monitor trends, identify areas for policy action, and compare their ICT developments. Bearing this in mind, the main purpose of this paper is to introduce a generalized DEA method that incorporates decision makers' preferences and offers a new perspective on measuring the ICT development index. In addition, preferred solutions are introduced depending on preferential information and improvement axis. Since the opinions of the decision-makers have been applied to reach the preferred solution, more realistic results are obtained. The results show that these solutions are a subset of efficient solutions. A total of 11 IDI indicators are identified based on International Telecommunication Union data. Assessments and rankings were performed using the DEA output-oriented model without input and the cross-efficiency model. In addition, for low-level countries, using preferred solutions, realistic targets are set following the preferential information of decision-makers to reach higher levels.

Keyword: IDI Index, Data Envelopment Analysis, Preferred Solutions, Cross Efficiency.

1 Introduction

Information and communication technology (ICT) is an extended term for information technology (IT) that stresses the role of unified communications and the integration of telecommunications (telephone lines and wireless signals), computers as well as the necessary software, and their storage and the audio-visual systems, which enable all users to access, store, transmit, and manipulate information.

With World Summit on the Information Society (WSIS) in 2005, rapid growth has occurred in access and use of ICT around the world. However, the potential impact of ICT is

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still limited because of the digital divide between countries and communities. The International Telecommunication Union (ITU) provides an annual report on ICT acquisition and measures the extent of the digital divide between regions and countries through the presentation of the ICT Index (ICT-DI). The purpose of this indicator is to transform the technology gap into technology development for the whole world, especially in backward or marginalized countries [1, 2].

The rapid expansion of ICT is of crucial importance for economic growth for many reasons: The use of this technology enables various participants in economic and social life to have quick and easy access to information and knowledge [3]. ICT also enables companies to communicate faster and better so they reduce production costs and improve productivity [4].

A credible assessment of the state of development of ICT at the national level is crucial because of the extent to which a nation's ICT is a significant driver of social and economic change. The Information Technology Development Index (IDI) and related data collection provide researchers with a good platform to use different methods to measure the extent of the digital divide and to monitor how the discrepancy evolved.

Ghaffari et al. examined the impact of ICT development on the demand for ICT services and infrastructures across Iran. According to their results, as household size increases, the demand for ICT increases, and the user skill and knowledge subgroup has the greatest impact on increasing the investment in ICT infrastructure [5]. Zhang and Li investigated the direct effect of regional ICT access on individuals' entrepreneurial performance and the interaction effect between regional ICT access and guanxi in the context of Chinese business and economy. Drawing upon a matched large-scale dataset, they found that regional ICT access in terms of access to the Internet, fixed phone, and mobile phone had a significant impact on performance [6]. Another study investigates whether the relationship between financial development and economic growth depends on the level of development of the ICT sector. The results indicate that ICT diffusion has a positive and significant impact on economic growth, and the impetus of financial development can be strengthened by enhancing ICT infrastructure [7].

Bamary et al. presented an ICT Performance Evaluation Model based on Meta-Synthesis Approach. They identify the dimensions and indicators of ICT performance evaluation and suggested a model for assessing it in organizations. They designed a questionnaire and this questionnaire answered by ICT experts and managers to determine the importance of each of the indicators of the model. They showed that the proposed ICT performance evaluation model has three dimensions: strategic, quality, and sustainability [8]. Hosseinzadeh and Mozayani analyzed the effect of ICT expansion on energy consumption of urban households in Iran using the Panel Data method and GLS model during the period 2008-2015 and in the form of provincial data. They showed that in some models, a significant reducing effect of ICT on energy expenditure was observed [9].

Shao et al. showed that ICT factors can influence national health outcomes of a country over time and ICT social impact can play an important partial mediating role between them [10]. Laddha et al. examined the impact of information communication technology on labor productivity. The research findings showed that ICT affects the labor productivity, and investing in Information Communication Technology is necessary to increase the labor productivity [11]. Chandio et al. examine the effects of technological development (through fertilizer and pesticide use) and information and communication technology (ICT) on cereal production in four ASEAN countries (Indonesia, Malaysia, the Philippines, and Thailand) from 1991 to 2018. The results demonstrated that the development of technology and information and communication technology plays an important role in increasing grain production and ensuring food security in selected ASEAN countries [12]. Shaleh et al, investigate the impact of ICT on farmers' pesticide used. The results indicated that Farmers who has access on the ICT tend to use lower pesticide that the farmers who did not use the ICT [13].

Existing literature on the digital or ICT divide and its effects shows that econometric techniques (e.g., regression analysis) are widely used, and descriptive statistics are commonly used in most studies. Some studies have also used factor analysis. Only one attempt has been made to develop and measure a single ICT development index (except that used by ITU) using non-parametric linear programming to accurately measure digital division.

Emrouznejad et al. measured the ICT index using a DEA model and compared it with the ICT index [14]. One of the disadvantages of their model was its failure to differentiate between countries that had achieved full efficiency, and several countries were ranked one and thus did not have a complete ranking of countries. In addition, traditional DEA models fail to apply decision-makers' preferences and give the same priority to all output (or input) indicators.

In this paper, a generalized DEA model is introduced. The developed model incorporates decision-makers' preferences and evaluates units accordingly. The main idea of this study is to incorporate the preferences of decision-makers. To this end, a preferred solution is introduced. Since the opinions of the decision-makers have been applied to reach the preferred solution, more realistic results are obtained. The rest of the paper is organized as follows:

Section 2 presents the IDI index and the ICT Opportunity Index. Section 3 provides a brief discussion of DEA and ranking efficient units using the across-efficiency model. A generalized CCR output-oriented model without input is also presented that incorporates decision-makers' preferences. Section 4 presents the case study and results.

2 IDI index

The IDI is scored by three sub-indexes of access, use, and skill, each having a specific weight in determining IDI [15]. Each sub-index represents a specific step, and the sub-index may change over time as ICT technologies evolve and move from one step to another. The score of the IDI index varies from 0 to 10. The IDI index is calculated as follows. Each index is first standardized using an ideal value or reference index. Then, the index is weighted according to the table below, and calculated using the formulas presented. Finally, the scores calculated for the three sub-indexes of access, use, and skill with the assigned weights determine the overall IDI score for each country.

The first index measures development in terms of access to ICT facilities and infrastructure. The ICT access component consists of five sub-indexes: (A) Fixed telephone subscriptions per 100 inhabitants, (B) mobile cellular telephone subscriptions per 100 inhabitants, (C) international Internet bandwidth per Internet user, (D) percentage of households with a computer, and (E) percentage of households with Internet access. The second index is the ICT utilization index, which consists of three sub-indexes: (F) percentage of individuals using the Internet, (G) fixed (wired)-broadband Internet subscriptions per 100 inhabitants, and (H) active mobile-road band subscriptions per 100 inhabitants. The third index is the ICT Skills Component Index, which consists of three sub-indexes: (I) adult literacy rate, (J) tertiary gross enrolment ratio, and (K) tertiary gross enrolment ratio.

Table 1 Calculating the IDI index

Indexes	Ideal value*	Standardized value	Weight	calculation formula
ICT access sub-index	--	--	0.4	L=Y1+ Y2+ Y3+ Y4+ Y5
A	60	Z1=A/60	0.2	Y1= Z1*0.2
B	120	Z2=B/120	0.2	Y2= Z2*0.2
C	962216	Z3=log(C)/log(962216)	0.2	Y3= Z3*0.2
D	100	Z4=D/100	0.2	Y4= Z4*0.2
E	100	Z5=E/100	0.2	Y5= Z5*0.2
ICT use sub-index	--	--	0.4	M=Y6+Y7+Y8
F	100	Z6=F/100	0.33	Y6= Z6*0.33
G	60	Z7=G/60	0.33	Y7= Z7*0.33
H	100	Z8=H/100	0.33	Y8= Z8*0.33
ICT skills sub-index	--	--	0.2	N=Y9+Y10+Y11
I	100	Z9=I/100	0.33	Y9= Z9*0.33
J	100	Z10=J/100	0.33	Y10= Z10*0.33
K	100	Z11=K/100	0.33	Y11= Z11*0.33
ICT Development Index (IDI)				((L*0/4)+(M*0/4)+(N*0/2))*10

*The ideal values for the indices a, b, c, and g are obtained by adding twice the standard deviation to the mean values of the indexes.
**The logarithmic scale was used to eliminate the effect of large values and off-limits data on values.

ICT-OI is generally accepted as a statistical tool for tracking the digital divide by measuring the relative level of ICT across economies and regions over time. It is based on the dual concepts of a country's production capacity and consumption and therefore depends on the country's information density (a fraction of the country's total capital and labor force, representing production capacity) and its use (ICT consumption flow). Technically speaking, the ICT opportunity is measured as follows:

The purpose of this study is to present a non-parametric method for measuring the ICT development index using data made available by the International Telecommunication Union. Using DEA, we assess the efficiency of countries and determine the new ranking of countries.

The 2007 ICT-OI split world economies into four major groupings depending on the degree to which a country had ICT access and use: high levels (7 and above), upper levels (5 to 7) medium levels (3 to 5), and low levels (less than 3). Moreover, equivalently, for the DEA-OI: high levels (90 and above), upper levels (80 to 90) medium levels (70 to 80), and low levels (less than 70).

3. Methodology

Data Envelopment Analysis (DEA) is a data-oriented approach for a relative evaluation of the performance of a group of entities referred to DMUs. It was introduced by Charnes, Cooper, and Rhodes based on Farrell's pioneering work [16].

An output-oriented DEA model with input variables ($x_1, \ldots, x_m$) and output variables ($y_1, \ldots, y_s$) with n decision-making units ($j = 1, \ldots, n$) is presented in Eq. (1).

$$
\begin{aligned}
& Max \sum_{r=1}^{s} u_r y_{r\circ} \\
& s.t: \sum_{i=1}^{m} v_i x_{i\circ} = 1 \\
& \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0; \quad j = 1, \dots, n \\
& u_r \ge 0 \qquad v_i \ge 0
\end{aligned} \tag{1}
$$

Where u_r is the weight associated with output r, and v_i is the weight associated with input i. Usually, in the DEA method, there should be at least one input and at least one output for all the units. But in many cases, we have only inputs or only outputs. Okniński and Radziszewski showed that the DEA method can be also applied when the unit's activity is represented by output or input only. If the analyzed units are defined by outputs only, then the DEA method can be used to show which units have the best outputs in this case. To do so, it is enough to assume that the values of all the inputs are the same and equal e.g. one [17]. Eq. (1) can be expressed as follows:

$$
\begin{aligned}
& \max \sum_{r=1}^{s} u_r y_{ro} \\
& \sum_{r=1}^{s} u_r y_{rj} \le 1, \quad j = 1, \dots, n, \\
& u_r \ge 0, \quad r = 1, \dots, s.
\end{aligned} \tag{2}
$$

The CCR envelopment model without any input for the unit DMU_0 is:

$$
\begin{aligned}
& \max \theta_o \\
& \sum_{j=1}^{n} \lambda_j y_{rj} \ge \theta_o y_{ro}, \quad r = 1, \dots, s, \\
& \lambda_j \ge 0, \quad j = 1, \dots, n.
\end{aligned} \tag{3}
$$

The optimal solution to Eq. (3) is θ^*. The score $\theta^* = 1$ represents efficiency, and values greater than 1 reveal the presence of inefficiency. The following problem defines the production possibility set for the DMU_0:

$$
\begin{aligned}
& \max [\textstyle\sum_{j=1}^{n} \lambda_j y_{1j}, \dots, \sum_{j=1}^{n} \lambda_j y_{sj}] \\
& \lambda_j \ge 0, \quad j = 1, \dots, n.
\end{aligned} \tag{4}
$$

A basic assumption in the DEA is that no input or output takes priority over the rest. But in practice, there are generally one or more decision-makers who have preferences for some of their inputs or outputs. The problem presented in Eq. (4) can be considered a multi-objective problem (MOP) in which each output of the DEA model corresponds to an objective of the following multi-objective problem:

$$
\begin{aligned}
& \max f(x) = [f_1(x), \dots, f_s(x)] \\
& s.t: \ x \in \Omega
\end{aligned} \tag{5}
$$

Where $\Omega \subseteq R^s$ is a feasible set in the decision space. The feasible set is displayed in the target space $f(\Omega)$. The concept of optimality in a single objective problem (SOP) is not directly applicable to MOP. For this reason, a classification of the solutions is introduced in terms of Pareto optimality, according to the following definitions [18]:

Definition 1. Suppose $x, x^* \in \Omega$. Vector x* dominates vector x (denoting this relationship $x^* \succ x$) if the x* is no worse than x in all objectives and x* is strictly better than x in at least one objective.

Definition 2. A solution $x^* \in \Omega$ is the Pareto optimal solution of MOP if and only if there is no other $x \in \Omega$ which dominates x*.

In this study, we consider the case where there is partial preferred information for some outputs (in DEA) or objectives (in MOP). That is, the exact weight of the outputs or objectives is not known, but there is some partial preferential information about them. The partial preferential information is indicated by $\Lambda \subseteq \Delta^{s-1}$ where $\Delta^{s-1} = \{w \in R_+^s \mid \sum_{r=1}^{s} w_r = 1\}$. In certain cases, we consider situations in which Λ is a polyhedron with extreme points $w^1, w^2, ..., w^k$.

Definition 3. Suppose $f(x), f'(x) \in f(\Omega)$, a vector f(x) dominates another vector $f'(x)$ with respect to $\Lambda \subseteq \Delta^{s-1}$(denoting the relationship $f(x) \succ_\Lambda f'(x)$) if $wf(x) > wf'(x)$ for all $w \in \Lambda$. Moreover, a vector f(x) is said to weakly dominate another vector $f'(x)$ with respect to $\Lambda \subseteq \Delta^{s-1}$, and denote $f(x) \geq_\Lambda f'(x)$, if $wf(x) \geq wf'(x)$ for all $w \in \Lambda$.

Definition 4. A feasible point $x^* \in \Omega$ is $\Lambda -$efficient, if $f(x^*)$ is not dominated by any $f(x) \in f(\Omega)$ with respect to $\Lambda \subseteq \Delta^{s-1}$.

Theorem 1. The set of $\Lambda -$efficient points is a subset of efficient points.

Proof. Suppose $x^* \in \Omega$ is $\Lambda -$efficient but not efficient. So there exists a x member of the efficient set such that $f(x) > f(x^*)$. So we have:

$$\forall w \in \Delta^{s-1}: \; wf(x) > f(x^*) \tag{6}$$

Since $\Lambda \subseteq \Delta^{s-1}$, we conclude that Eq. (6) ($f(x) \succ f(x^*)$) is true for every $w \in \Lambda$. This means that x^* is not $\Lambda -$efficient, which contradicts the assumption. □

In the next step, we will introduce the preferred solution. This solution combines the idea of $\Lambda -$efficient and the improvement axis. The improvement axis plays a different role from the preferred information and provides a direction for improving more desirable possible target values.

Definition 5. The feasible solution $x \in \Omega$ is a preferred solution of a multi-objective problem with preferential information if $f(x) \geq_\Lambda t^* p$, where $p \in R_+^s$ is the improvement axis and t^* is obtained from Eq. (7)

$$t^* = \max\{t \in R_+ \mid \exists x \in \Omega, \; f(x) \geq_\Lambda t.p\} \tag{7}$$

Theorem 2. The preferred solutions are a subset of the $\Lambda -$ efficient solutions.

Proof. Let $x \in Y$ and suppose on the contrary that $f(\bar{x}) \geq_\Lambda f(x)$, indicating that $f(\bar{x}) \geq_\Lambda f(x)$ is dominated with respect to Λ. Then:

$$w^h f(\bar{x}) > w^h f(x) \geq w^h t^* p \;; h = 1, ..., k \tag{8}$$

Since $p \in R_+^s$, then for each $w \in \Lambda$ we have $wp > 0$ and there is a small enough ϵ> 0, such that

$$\varepsilon w^h p < w^h (f(\bar{x}) - t^* p) \quad \forall h = 1,\dots,k$$

$$\Rightarrow w^h f(\bar{x}) > w^h (t^* + \varepsilon) p \quad \forall h = 1,\dots,k$$

And this contradicts (7). □

The following theorem shows that preferred solutions depend both on $w \in \Lambda$ and $p \in R_+^s$.

Theorem 3. Suppose $w \in \Lambda$ and $p \in R_+^s$ then $Y = \arg\max_{x\in\Omega} \varphi(f(x))$.

$$\varphi(f(x)) = \min\left\{\frac{w^1 f(x)}{w^1 p},\dots,\frac{w^k f(x)}{w^k p}\right\}$$

Proof. From the definition of the preference equations, we have:

$$t^* = \max\{t \in R_+ \mid \exists x \in \Omega, f(x) \geq_\Lambda tp\}$$
$$= \max\{t \in R_+ \mid \exists x \in \Omega, w^h f(x) \geq w^h tp; h = 1,\dots,k\}$$
$$= \max\{t \in R_+ \mid \exists x \in \Omega, \frac{w^h f(x)}{w^h p} \geq t;\ h = 1,\dots,k\}$$
$$= \max\{t \in R_+ \mid \exists x \in \Omega, \varphi(f(x)) = t\}$$

□

Corollary 1. Suppose $w \in \Lambda$ and $p \in R_+^s$ then $x^* \in Y$ if and only if there exists t^* such that (t^*, x^*) is an optimal solution to the following problem:

$$\begin{aligned} &\max t \\ &s.t: w^h f(x) \geq w^h tp\ ;\ h = 1,\dots,k, \\ &x \in \Omega. \end{aligned} \tag{9}$$

Now consider model (4). For DMU$_o$ and with the partial information set, $\Lambda \subseteq \Delta^{s-1}$, and the improvement axis, $p = y_o \in R_+^s$, we can construct a linear problem and obtain a measure of $\Lambda-$efficient for DMUo. In this case, $\varphi(f(x))$ will be as follows:

$$\min\left\{\frac{\sum_{j=1}^{n}(\sum_{r=1}^{s} w_r^1 y_{rj})\lambda_j}{\sum_{r=1}^{s} w_r^1 y_{ro}},\dots,\frac{\sum_{j=1}^{n}(\sum_{r=1}^{s} w_r^k y_{rj})\lambda_j}{\sum_{r=1}^{s} w_r^k y_{ro}}\right\}$$

Therefore, we introduce the CCR output-oriented model without any input with preferred information for DMUo as follows:

$$\begin{aligned} &\max t_o \\ &s.t: \frac{\sum_{j=1}^{n}(\sum_{r=1}^{s} w_r^h y_{rj})\lambda_j}{\sum_{r=1}^{s} w_r^h y_{ro}} \geq t_o ; h = 1,\dots,k, \\ &\lambda_j \geq 0\ ,\ j = 1,\dots,n. \end{aligned} \tag{10}$$

In the above problem, DMU0 is $\Lambda-$efficient if $t_o = 1$; otherwise, if $t_o > 1$ it is inefficient. For inefficient units, we define an $\Lambda-$efficient target as $\left(\sum_{j=1}^{n}\lambda_j^* y_{1j},\ldots,\sum_{j=1}^{n}\lambda_j^* y_{sj}\right)$.

The efficiency score calculated using DEA models for several units is 1. These units cannot be ranked using classic DEA models. Fully ranking DMUs is a traditional and important topic in DEA. There is a body of works in this area [19], [20], [21].

In various types of ranking methods, cross-efficiency approaches receive much attention from researchers because they evaluate DMUs by using self and peer evaluation [22].

Cross-efficiency typically involves two stages: The self-evaluation stage where the DEA scores are calculated using the constant return to scale (CRS) and the coefficients obtained from the first stage are used to obtain cross-efficiency for each DMU [23].

Step 1: Suppose the DMU_d is evaluated by the CRS model. Then its efficiency score (self-evaluation) is calculated by the following DEA model:

$$\max E_{dd} = \frac{\sum_{r=1}^{s} u_{rd} y_{rd}}{\sum_{i=1}^{m} v_{id} x_{id}} \tag{11}$$

$$s.t: E_{dj} = \frac{\sum_{r=1}^{s} u_{rj} y_{rj}}{\sum_{i=1}^{m} v_{ij} x_{ij}} \qquad (j = 1,2,\ldots,n)$$

$$u_{rj} \geq \circ \qquad r = 1,2,\ldots,s$$

$$v_{ij} \geq \circ \qquad i = 1,2,\ldots,m$$

where v_{id} and u_{rd} denote the weights of input i and output r from DMU_d, respectively.

Step 2: Using the weights obtained from DMU_d in the above model, the cross-efficiency of DMUj is obtained as follows:

$$E_{dj} = \frac{\sum_{r=1}^{s} u_{rj}^* y_{rj}}{\sum_{i=1}^{m} v_{ij}^* x_{ij}} \qquad (d, j = 1,2,\ldots,n)$$

For (j = 1, ..., n) DMU_j, an average of all (d=1,...,n), E_{dj},

$$\bar{E}_j = \frac{1}{n}\sum_{d=1}^{n} E_{dj}$$

It is intended as an efficiency score for DMU_j.

4 Case Study and Results

Given the potential benefits that ICTs can provide in transforming a nation's economy and its citizens' well-being, assessing ICT developments has been the object of much academic and policy attention in the past decade. To increase the convergence between high- and low-income countries by bridging the digital divide, there is a necessity to accurately measure it.

In this section, we apply the CCR output-oriented model without input to performance assessment and target setting in a situation where preferential information is available. As an example, the ICT-opportunity index is measured in a preference situation. The data used to measure different indexes were taken from the ITU's IDI, where an IDI value is shown. For the DEA formulation, the reference set consists of 176 countries, for which 11 outputs; (A) Fixed telephone subscriptions per 100 inhabitants, (B) mobile cellular telephone subscriptions per 100 inhabitants, (C) international Internet bandwidth per Internet user, (D) percentage of households with a computer, and (E) percentage of households with Internet access. The second index is the ICT utilization index, which consists of three sub-indexes: (F) percentage of individuals using the Internet, (G) fixed (wired)-broadband Internet subscriptions per 100 inhabitants, and (H) active mobile-road band subscriptions per 100 inhabitants. The third index is the ICT Skills Component Index, which consists of three sub-indexes: (I) adult literacy rate, (J) tertiary gross enrolment ratio, and (K) tertiary gross enrolment ratio, without any inputs are considered.

Decision makers have preferences over their outputs as follows. They considered the importance of B, E, and F equally. Moreover, they considered the importance of A, C, D, G, H, I, J and K equally. In addition, the DM considers 1 unit of outputs B, E, and F no less than two times the importance of a unit of outputs A, C, D, G, H, I, J, and K, and no more than three times the importance of a unit of outputs A, C, D, G, H, I, J and K. The preferences of the DMs are represented by the set of information:

$$\Lambda = \{ w \in \Delta^{10} \mid w_{B,E,F} \geq 2w_{A,C,D,G,H,I,J,K},$$
$$w_{B,E,F} \leq 3w_{A,C,D,G,H,I,J,K} \}$$

The extreme points of Λ are:

$$w^1 = (\frac{1}{14},\frac{2}{14},\frac{1}{14},\frac{1}{14},\frac{2}{14},\frac{2}{14},\frac{1}{14},\frac{1}{14},\frac{1}{14},\frac{1}{14},\frac{1}{14})$$

$$w^2 = (\frac{1}{17},\frac{3}{17},\frac{1}{17},\frac{1}{17},\frac{3}{17},\frac{3}{17},\frac{1}{17},\frac{1}{17},\frac{1}{17},\frac{1}{17},\frac{1}{17})$$

The results obtained when performing the traditional output-oriented CCR without input model (3) and the generalized CCR output-oriented model without input (10) are shown in Table 2. In this study, data from ITU sub-indexes from 176 countries are used. These countries are located in five regions: Africa, America, Arab States, Asia & Pacific, CIS (Commonwealth of Independent States), and Europe containing 38, 35, 19, 34, 10, and 40 countries, respectively. For ICT-OI comparisons, we grouped these countries into four low, medium, upper, and high categories/scales.

The efficiency scores estimated with the DEA model indicated that the efficiency score of some units is 1(100 %). Sexton's cross-efficiency method was used for ranking. The results are added to the last column of the table.

Table 2 Ranking of countries by ITU and DEA

IDI Rank	Economy	Region	IDI Value	DEA Score	DEA Rank	ICT-OI scale	DEA-OI scale	Λ -DEA Score	Λ -DEA-OI scale	Cross-DEA Score
1	Iceland	Europe	8.98	100	1	High	High	100	High	100.19
2	Korea (Rep.)	Asia &Pacific	8.85	100	3	High	High	100	High	100.16
3	Switzerland	Europe	8.74	100	2	High	High	100	High	100.18
4	Denmark	Europe	8.71	100	4	High	High	100	High	100.14
5	United Kingdom	Europe	8.65	100	12	High	High	99.97	High	100.06
6	Hong Kong, China	Asia &Pacific	8.61	100	6	High	High	100	High	100.12
7	Netherlands	Europe	8.49	100	14	High	High	99.98	High	100.04
8	Norway	Europe	8.47	100	5	High	High	100	High	100.13
9	Luxembourg	Europe	8.47	100	16	High	High	99.94	High	100.02

IDI Rank	Economy	Region	IDI Value	DEA Score	DEA Rank	ICT-OI scale	DEA-OI scale	^ -DEA Score	^ -DEA-OI scale	Cross-DEA Score
10	Japan	Asia &Pacific	8.43	100	13	High	High	99.97	High	100.05
11	Sweden	Europe	8.41	100	8	High	High	100	High	100.10
12	Germany	Europe	8.39	100	9	High	High	100	High	100.09
13	New Zealand	Asia &Pacific	8.33	100	10	High	High	99.96	High	100.08
14	Australia	Asia &Pacific	8.24	100	7	High	High	100	High	100.11
15	France	Europe	8.24	100	15	High	High	99.93	High	100.03
16	United States	America	8.18	100	11	High	High	100	High	100.07
17	Estonia	Europe	8.14	100	17	High	High	99.89	High	100.01
18	Singapore	Asia &Pacific	8.05	99.89	18	High	High	99.83	High	---
19	Monaco	Europe	8.05	99.95	19	High	High	99.62	High	---
20	Ireland	Europe	8.02	98.56	20	High	High	98.74	High	---
21	Austria	Europe	8.02	97.43	26	High	High	97.37	High	---
22	Finland	Europe	7.88	98.4	22	High	High	98.32	High	---
23	Israel	Europe	7.88	98.45	21	High	High	96.35	High	---
24	Malta	Europe	7.86	95.31	28	High	High	94.26	High	---
25	Belgium	Europe	7.81	97.12	29	High	High	97.83	High	---
26	Macao, China	Asia &Pacific	7.80	97.85	23	High	High	97.46	High	---
27	Spain	Europe	7.79	97.32	27	High	High	96.57	High	---
28	Cyprus	Europe	7.77	96.52	34	High	High	97.34	High	---
29	Canada	America	7.77	91.45	51	High	High	91.73	High	---
30	Andorra	Europe	7.71	92.36	50	High	High	90.42	High	---
31	Bahrain	Arab States	7.60	94.69	45	High	High	91.53	High	---
32	Belarus	CIS	7.55	94.65	46	High	High	92.43	High	---
33	Slovenia	Europe	7.38	97.65	25	High	High	96.32	High	---
34	Barbados	America	7.31	96.87	32	High	High	95.32	High	---
35	Latvia	Europe	7.26	95.39	42	High	High	93.75	High	---
36	Croatia	Europe	7.24	96.25	39	High	High	95.63	High	---
37	St. Kitts and Nevis	America	7.24	97.69	24	High	High	97.47	High	---
38	Greece	Europe	7.23	95.24	44	High	High	95.83	High	---
39	Qatar	Arab States	7.21	95.36	43	High	High	94.27	High	---
40	United Arab Emirates	Arab States	7.21	96.67	33	High	High	96.83	High	---
41	Lithuania	Europe	7.19	97.01	31	High	High	97.17	High	---
42	Uruguay	America	7.16	96.36	35	High	High	95.42	High	---
43	Czech Republic	Europe	7.16	97.1	30	High	High	94.75	High	---
44	Portugal	Europe	7.13	96.3	38	High	High	95.53	High	---
45	Russian Federation	CIS	7.07	95.63	41	High	High	95.12	High	---
46	Slovakia	Europe	7.06	96.31	37	High	High	96.73	High	---
47	Italy	Europe	7.04	95.68	40	High	High	92.14	High	---

IDI Rank	Economy	Region	IDI Value	DEA Score	DEA Rank	ICT-OI scale	DEA-OI scale	Λ -DEA Score	Λ -DEA-OI scale	Cross-DEA Score
48	Hungary	Europe	6.93	94.36	47	Upper	High	91.24	High	---
49	Poland	Europe	6.89	94.31	48	Upper	High	95.58	High	---
50	Bulgaria	Europe	6.86	96.32	36	Upper	High	95.21	High	---
51	Argentina	America	6.79	93.69	49	Upper	High	94.32	High	---
52	Kazakhstan	CIS	6.79	91.12	53	Upper	High	86.43	Upper	---
53	Brunei Darussalam	Asia &Pacific	6.75	89.63	57	Upper	Upper	87.35	Upper	---
54	Saudi Arabia	Arab States	6.67	87.36	65	Upper	Upper	84.21	Upper	---
55	Serbia	Europe	6.61	89.54	58	Upper	Upper	88.32	Upper	---
56	Chile	America	6.57	90.32	54	Upper	High	88.41	Upper	---
57	Bahamas	America	6.51	86.89	70	Upper	Upper	83.22	Upper	---
58	Romania	Europe	6.48	91.32	52	Upper	High	86.12	Upper	---
59	Moldova	CIS	6.45	86.54	71	Upper	Upper	81.32	Upper	---
60	Costa Rica	America	6.44	84.96	80	Upper	Upper	79.23	Medium	---
61	Montenegro	Europe	6.44	89.39	59	Upper	Upper	90.41	Upper	---
62	Oman	Arab States	6.43	88.81	61	Upper	Upper	83.42	Upper	---
63	Malaysia	Asia &Pacific	6.38	87.91	63	Upper	Upper	90.32	High	---
64	Lebanon	Arab States	6.30	85.36	77	Upper	Upper	81.42	Upper	---
65	Azerbaijan	CIS	6.20	86.91	69	Upper	Upper	82.54	Upper	---
66	Brazil	America	6.12	83.21	84	Upper	Upper	86.37	Upper	---
67	Turkey	Europe	6.08	84.87	81	Upper	Upper	82.45	Upper	---
68	Trinidad & Tobago	America	6.04	79.65	98	Upper	Medium	75.87	Medium	---
69	TFYR Macedonia	Europe	6.01	87.63	64	Upper	Upper	82.56	Upper	---
70	Jordan	Arab States	6.00	84.85	82	Upper	Upper	85.58	Upper	---
71	Kuwait	Arab States	5.98	90.31	55	Upper	High	88.57	Upper	---
72	Mauritius	Africa	5.88	86.31	76	Upper	Upper	84.56	Upper	---
73	Grenada	America	5.80	84.1	83	Upper	Upper	81.57	Upper	---
74	Georgia	CIS	5.79	85.3	78	Upper	Upper	87.12	Upper	---
75	Armenia	CIS	5.76	84.98	79	Upper	Upper	79.38	Medium	---
76	Antigua & Barbuda	America	5.71	87.35	66	Upper	Upper	84.56	Upper	---
77	Dominica	America	5.69	79.36	99	Upper	Medium	81.28	Upper	---
78	Thailand	Asia &Pacific	5.67	87.3	68	Upper	Upper	90.37	High	---
79	Ukraine	CIS	5.62	88.9	60	Upper	Upper	90.47	High	---
80	China	Asia &Pacific	5.60	90.2	56	Upper	Upper	89.87	Upper	---
81	Iran (I.R.)	Asia &Pacific	5.58	86.32	75	Upper	Upper	85.89	Upper	---
82	St. Vincent and the Grenadines	America	5.54	83.18	86	Upper	Upper	79.56	Medium	---
83	Bosnia and Herzegovina	Europe	5.39	78.32	106	Upper	Medium	77.46	Medium	---
84	Colombia	America	5.36	87.34	67	Upper	Upper	84.45	Upper	---
85	Maldives	Asia	5.25	86.34	74	Upper	Upper	85.78	Upper	---

IDI Rank	Economy	Region	IDI Value	DEA Score	DEA Rank	ICT-OI scale	DEA-OI scale	^ -DEA Score	^ -DEA-OI scale	Cross-DEA Score
		&Pacific								
86	Venezuela	America	5.17	79.12	102	Upper	Medium	81.72	Upper	---
87	Mexico	America	5.16	88.36	62	Upper	Upper	87.93	Upper	---
88	Suriname	America	5.15	81.36	90	Upper	Upper	79.72	Medium	---
89	Albania	Europe	5.14	86.37	73	Upper	Upper	86.45	Upper	---
90	Seychelles	Africa	5.03	81.35	91	Upper	Upper	82.75	Upper	---
91	Mongolia	Asia &Pacific	4.96	82.37	87	Medium	Upper	81.87	Upper	---
92	South Africa	Africa	4.96	79.98	96	Medium	Medium	80.03	Upper	---
93	Cape Verde	Africa	4.92	79.35	100	Medium	Medium	77.95	Medium	---
94	Panama	America	4.91	80.96	92	Medium	Upper	81.36	Upper	---
95	Uzbekistan	CIS	4.90	81.97	89	Medium	Upper	79.46	Medium	---
96	Peru	America	4.85	82.17	88	Medium	Upper	81.36	Upper	---
97	Ecuador	America	4.84	86.39	72	Medium	Upper	87.12	Upper	---
98	Jamaica	America	4.84	79.14	101	Medium	Medium	80.19	Upper	---
99	Tunisia	Arab States	4.82	78.36	104	Medium	Medium	77.44	Medium	---
100	Morocco	Arab States	4.77	80.64	94	Medium	Upper	78.61	Medium	---
101	Philippines	Asia &Pacific	4.67	78.12	108	Medium	Medium	77.36	Medium	---
102	Algeria	Arab States	4.67	76.32	111	Medium	Medium	75.74	Medium	---
103	Egypt	Arab States	4.63	83.20	85	Medium	Upper	81.56	Upper	---
104	St. Lucia	America	4.63	77.36	110	Medium	Medium	74.53	Medium	---
105	Botswana	Africa	4.59	78.25	107	Medium	Medium	75.36	Medium	---
106	Dominican Rep.	America	4.51	73.65	121	Medium	Medium	72.35	Medium	---
107	Fiji	Asia &Pacific	4.49	75.36	113	Medium	Medium	76.75	Medium	---
108	Viet Nam	Asia &Pacific	4.43	69.22	142	Medium	Low	71.29	Medium	---
109	Kyrgyzstan	CIS	4.37	78.35	105	Medium	Medium	81.22	Medium	---
110	Tonga	Asia &Pacific	4.34	74.44	117	Medium	Medium	72.88	Medium	---
111	Indonesia	Asia &Pacific	4.33	79.88	97	Medium	Medium	77.83	Medium	---
112	Bolivia	America	4.31	78.99	103	Medium	Medium	80.18	Upper	---
113	Paraguay	America	4.18	80.36	95	Medium	Upper	77.27	Medium	---
114	Gabon	Africa	4.11	74.69	116	Medium	Medium	75.22	Medium	---
115	Libya	Arab States	4.11	75.21	114	Medium	Medium	72.43	Medium	---
116	Ghana	Africa	4.05	69.33	140	Medium	Low	72.72	Medium	---
117	Sri Lanka	Asia &Pacific	3.91	77.8	109	Medium	Medium	73.82	Medium	---
118	Namibia	Africa	3.89	72.14	125	Medium	Medium	69.98	Low	---
119	El Salvador	America	3.82	80.66	93	Medium	Upper	78.47	Medium	---
120	Belize	America	3.71	74.99	115	Medium	Medium	71.32	Medium	---
121	Bhutan	Asia &Pacific	3.69	75.97	112	Medium	Medium	71.25	Medium	---

IDI Rank	Economy	Region	IDI Value	DEA Score	DEA Rank	ICT-OI scale	DEA-OI scale	^ -DEA Score	^ -DEA-OI scale	Cross-DEA Score
122	Timor-Leste	Asia &Pacific	3.57	72.37	124	Medium	Medium	69.22	Low	---
123	Palestine	Arab States	3.55	69.69	138	Medium	Low	61.56	Low	---
124	Guyana	America	3.44	73.2	123	Medium	Medium	71.46	Medium	---
125	Guatemala	America	3.35	71.69	127	Medium	Medium	69.32	Low	---
126	Syria	Arab States	3.34	69.11	145	Medium	Low	67.52	Low	---
127	Samoa	Asia &Pacific	3.30	71.36	130	Medium	Medium	69.21	Low	---
128	Cambodia	Asia &Pacific	3.28	74.36	118	Medium	Medium	73.21	Medium	---
129	Honduras	America	3.28	73.36	122	Medium	Medium	69.26	Low	---
130	Nicaragua	America	3.27	71.3	131	Medium	Medium	72.46	Medium	---
131	Côte d'Ivoire	Africa	3.14	69.2	143	Medium	Low	64.39	Low	---
132	S. Tomé & Principe	Africa	3.09	70.8	133	Medium	Medium	68.46	Low	---
133	Lesotho	Africa	3.04	71.68	128	Medium	Medium	68.24	Low	---
134	India	Asia &Pacific	3.03	73.98	119	Medium	Medium	69.22	Low	---
135	Myanmar	Asia &Pacific	3.00	70.36	134	Medium	Medium	67.23	Low	---
136	Zimbabwe	Africa	2.92	69.5	139	Low	Low	65.43	Low	---
137	Cuba	America	2.91	67.32	151	Low	Low	64.52	Low	---
138	Kenya	Africa	2.91	71.94	126	Low	Medium	68.23	Low	---
139	Lao P.D.R.	Asia &Pacific	2.91	66.58	154	Low	Low	63.96	Low	---
140	Nepal	Asia &Pacific	2.88	67.99	148	Low	Low	64.23	Low	---
141	Vanuatu	Asia &Pacific	2.81	69.19	144	Low	Low	65.36	Low	---
142	Senegal	Africa	2.66	70.3	135	Low	Medium	68.57	Low	---
143	Nigeria	Africa	2.60	71.2	132	Low	Medium	68.53	Low	---
144	Gambia	Africa	2.59	69.3	141	Low	Low	65.12	Low	---
145	Sudan	Arab States	2.55	71.38	129	Low	Medium	68.32	Low	---
146	Zambia	Africa	2.54	66.32	156	Low	Low	63.56	Low	---
147	Bangladesh	Asia &Pacific	2.53	68.32	147	Low	Low	65.29	Low	---
148	Pakistan	Asia &Pacific	2.42	73.90	120	Low	Medium	69.76	Low	---
149	Cameroon	Africa	2.38	67.75	150	Low	Low	64.36	Low	---
150	Mozambique	Africa	2.32	70.19	136	Low	Medium	69.23	Low	---
151	Mauritania	Arab States	2.26	66.34	155	Low	Low	63.25	Low	---
152	Uganda	Africa	2.19	64.28	163	Low	Low	61.88	Low	---
153	Rwanda	Africa	2.18	64.29	161	Low	Low	62.56	Low	---
154	Kiribati	Asia &Pacific	2.17	67.96	149	Low	Low	64.53	Low	---
155	Mali	Africa	2.16	67.2	152	Low	Low	63.55	Low	---

IDI Rank	Economy	Region	IDI Value	DEA Score	DEA Rank	ICT-OI scale	DEA-OI scale	Λ -DEA Score	Λ -DEA-OI scale	Cross-DEA Score
156	Togo	Africa	2.15	70.1	137	Low	Medium	68.37	Low	---
157	Solomon Islands	Asia &Pacific	2.11	66.98	153	Low	Low	63.47	Low	---
158	Djibouti	Arab States	1.98	68.92	146	Low	Low	64.27	Low	---
159	Afghanistan	Asia &Pacific	1.95	65.25	157	Low	Low	62.36	Low	---
160	Angola	Africa	1.94	64.32	160	Low	Low	61.46	Low	---
161	Benin	Africa	1.94	63.28	166	Low	Low	61.45	Low	---
162	Burkina Faso	Africa	1.90	64.19	164	Low	Low	62.36	Low	---
163	Equatorial Guinea	Africa	1.86	62.76	168	Low	Low	60.77	Low	---
164	Comoros	Arab States	1.82	64.29	162	Low	Low	61.43	Low	---
165	Tanzania	Africa	1.81	65.13	158	Low	Low	63.28	Low	---
166	Guinea	Africa	1.78	63.25	167	Low	Low	62.57	Low	---
167	Malawi	Africa	1.74	62.58	169	Low	Low	61.11	Low	---
168	Haiti	America	1.72	64.39	159	Low	Low	62.27	Low	---
169	Madagascar	Africa	1.68	61.29	171	Low	Low	60.13	Low	---
170	Ethiopia	Africa	1.65	61.99	170	Low	Low	60.27	Low	---
171	Congo (Dem. Rep.)	Africa	1.55	61.12	172	Low	Low	60.17	Low	---
172	Burundi	Africa	1.48	60.95	174	Low	Low	60.01	Low	---
173	Guinea-Bissau	Africa	1.48	60.34	175	Low	Low	60.04	Low	---
174	Chad	Africa	1.27	60.25	176	Low	Low	60.05	Low	---
175	Central African Rep.	Africa	1.04	63.98	165	Low	Low	62.19	Low	---
176	Eritrea	Africa	0.96	61.01	173	Low	Low	60.17	Low	---

Source: Author's computation for DEA results and the rest is of ITU.

The results showed that Iceland, Korea (Rep.), and Switzerland were ranked the highest, and Chad, Central African Rep., and Eritrea had the lowest ranks, respectively. Whereas the DEA results showed that the high-rating countries were Iceland, Switzerland, and Korea (Rep.). On the other hand, Burundi, Guinea-Bissau, and Chad have the lowest ratings. Furthermore, the rankings for both the ICT-OI and DEA-OI were also closer, if not the same in some cases. To further validate our model, we ran a correlation test and found a very high correlation between the ICT-OI and DEA-OI, with a correlation coefficient of 0.85.

Under the ICT-OI scale, 45 countries (25.6%) have achieved a high level of ICT access and use, while 54 (30.7%) and 53 (30.1%) from DEA-OI and $\Lambda-$DEA-OI scales are at this level. It is noteworthy that all three scales showed that none of the African countries is at a high-level ICT access. Given the high percentages of all three scales at the top level and the absence of African countries at this level, it can be said that policymakers in African countries should take a big step toward improving ICT and addressing the existing shortcomings and weaknesses.

For upper levels, the results are slightly different. 18.7%, 22.7%, and 21% of countries are at this level for ICT-OI, DEA-OI, and $\Lambda-$DEA-OI scales, respectively. The results showed that 26.1%, 23.8%, and 17.6% of countries are in the medium level for ICT-OI, DEA-OI, and $\Lambda-$DEA-OI scales, respectively. According to ICT-OI, no European country is at this level, while DEA-OI and $\Lambda-$DEA-OI scales show that a European country, Bosnia and Herzegovina, is at this level. A high percentage of American countries are also at this level.

The results showed that 23.3%, 25.6%, and 31.2% of countries are at the low level for ICT-OI, DEA-OI, and $\Lambda-$DEA-OI scales, respectively. All three scales showed that no European and CIS country is at this level, and few American countries are at this level. This level also includes most African countries. According to Table 2, the distribution of economies to their scale level and DEA, DEA, and IDI comparisons are presented in Figure 1:

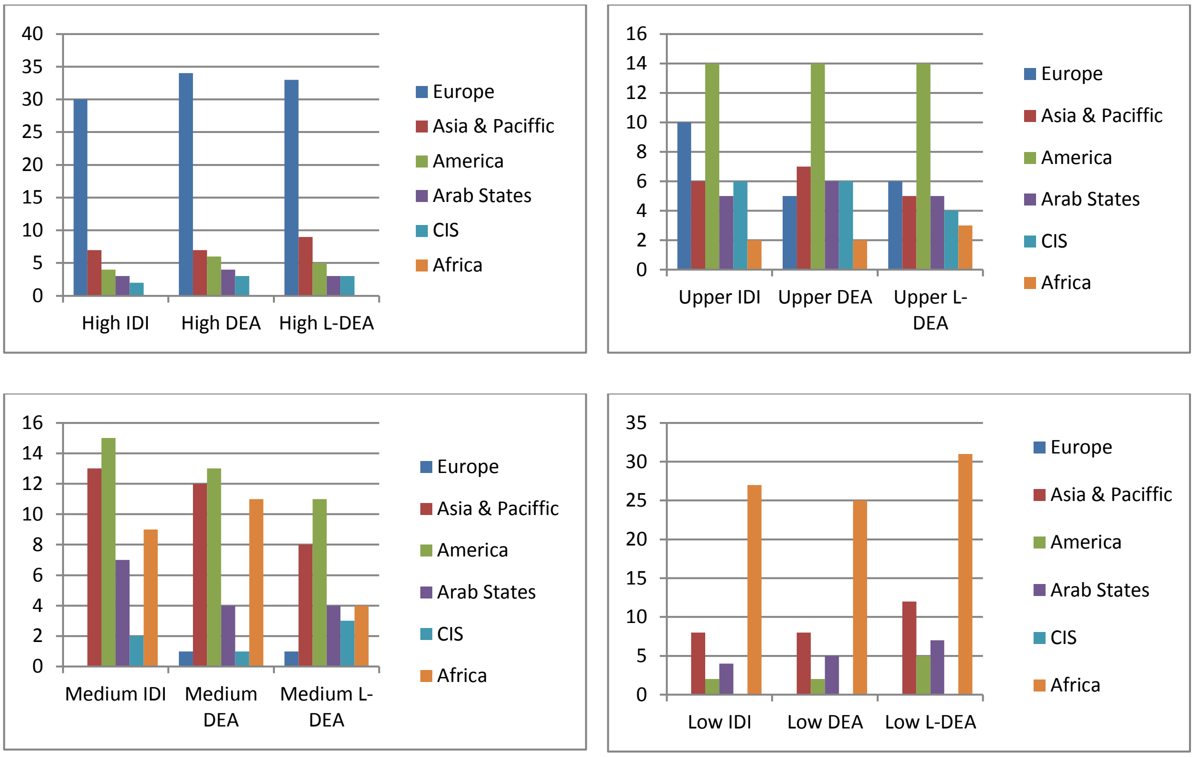

Fig. 1 Distribution of economies to their scale level ad DEA, $\Lambda-$DEA, and IDI comparisons

As can be seen, the difference between the two DEA-OI and $\Lambda-$DEA-OI scales at the high level is very small (0.6%), but gradually when we reach the low level, the difference between the two scales increases significantly (5.6%). For example, there is a significant difference between the DEA-OI and $\Lambda-$DEA-OI scales for African countries at medium and low levels. The reason for this difference is the exercise of decision makers' preferences as they paid more attention to mobile cellular telephone subscriptions per 100 inhabitants, the percentage of households with internet access, and the percentage of individuals using the internet (B, E, and F) indexes than other indexes, and this shows that in lower level countries, these three indexes are much more effective than in high-level countries. This reflects the fact that as the preferences of decision-makers and their partial information about the importance of indexes change, so do the levels of countries, thus affecting the ranking of countries. This is important from the perspective that these preferences can play a key role in countries' ICT policies.

Benchmarking was originally developed as a management tool to help individual businesses to identify their strengths and weaknesses compared to competitors and assist them to identify ways to improve their relative performance. In the context of national competitiveness, benchmarking is a tool to increase national performance by improving design and political practices.

Therefore, countries need to identify ways to improve their performance in addition to awareness of their performance to achieve their predetermined goals and future progress. The data in Table 2 show that almost all African countries are at a low level and have very poor performance. Therefore, politicians in these countries need to define the outlook for each of the indexes to achieve high performance and levels. In this section, the four inefficient and low-level countries (Eritrea, Guinea-Bissau, Chad, and Burundi) are targeted using the DEA model as shown in Table 3.

Table 3 Target setting for indexes

Indexes	Eritrea		Guinea-Bissau		Chad		Burundi	
ICT access sub-index	Original	Target	Original	Target	Original	Target	Original	Target
A	0.9	46.4	0.00	28.6	0.10	42.7	0.18	36.6
B	7.2	129.5	70.2	130.3	44.5	125.5	48.04	136.2
C	3600.5	534065.9	4706.6	219818.2	3761.8	251338.1	6083.2	525609.3
D	3.3	84.2	2.78	92.4	3.3	83.4	3.36	92.6
E	1.9	94.8	2.20	90.5	3.50	88.5	3.50	90.4
ICT use sub-index								
F	1.18	91.7	3.76	91.3	5.00	81.1	5.17	91.3
G	0.01	37.2	0.04	37.7	0.07	34.7	0.04	33.4
H	0.00	113.6	6.89	123.9	9.51	117.3	8.30	116.2
ICT skills sub-index								
I	3.90	12.21	2.90	12.69	2.30	12.9	3.00	12.38
J	30.55	106.6	32.64	121.6	22.40	97.3	42.48	116.4
K	2.57	84.4	2.50	77.8	3.45	88.6	4.41	73.8

5 Conclusion

IDI ranks countries' performance in terms of ICT infrastructure and uptake. It aims to provide an objective international performance evaluation based on quantitative indicators and benchmarks. It is a relevant tool for monitoring and comparing the ICT development level and progress made by countries at the international level. The results for this metric help policymakers monitor trends, identify areas for policy action, and compare their ICT developments.

In this study, we developed a new plan, a generalized output-oriented DEA model, for measuring the IDI index. This model incorporates the preferences of decision-makers. Besides, preferred solutions were introduced and it was shown that these solutions are a subset of efficient solutions. These solutions were used to set realistic targets following the preferential information of decision-makers. The proposed model was implemented in 176 countries with 11 indexes and countries were ranked according to their efficiency score. Since traditional DEA models do not distinguish between efficient units, the cross-efficiency method was used to rank countries.

Government policymakers can use the results to identify the technology policies and digital divide offsets of governments. By understanding their positions in global ICT, they can detect their strengths and weaknesses. Low-income countries should also strive to improve their underlying networks and continually upgrade their education and skills to achieve high-level status and benefit from ICT. Incorporation managers' preferences for ICT indexes are taken for future work.

Given the important role of ICT in development and the achievement of international goals, it is necessary to produce accurate and updated statistics to understand various aspects of the digital divide and identify those who are excluded from the information society and lagging. The national and international statistical community should then multiply its efforts to enhance the dissemination of high-quality ICT statistics, especially in developing countries.

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