How to rank universities from sustainability perspective?

Rebeka Lukman, Damjan Krajnc and Peter Glavič*

University of Maribor, Department of Chemistry and Chemical Engineering, Smetanova 17, SI–2000 Maribor

Abstract

This paper introduces a model, which would enable a comparison between universities regarding economic, social and environmental performances. The purpose is to provide simplified information about the qualities of the universities regarding sustainable development issues. This model enables a quick detection of the weaknesses, advantages and improvement options for universities. Indicators' weights were determined with an analytic hierarchy process (AHP). Results of the AHP have shown that the most important are research oriented indicators, followed by social and environmental ones.
The model has been tested on a sample of 35 top universities from the ARWU (Academic Ranking of World Universities) and Times ranking tables. As a result, a new ranking table has been designed, where more sustainable universities are placed in the higher positions. In addition, correlations have been carried out between indicators and ranking tables. Only a medium correlation exists between the ARWU and a Sustainability University Ranking (SUR) table. Regarding the indicators, a high correlation between *h*-indices and highly cited researchers exists, while there is an insignificant correlation between a low student to staff ratio and the graduation rate.

Keywords: university ranking, research, educational and environmental indicators, sustainability index.

* Corresponding author. Tel.: + 386 2 2294 455, Email: rebeka.lukman@uni-mb.si, Fax: + 386 2 2527 744

1 Introduction

Over the course of the last two decades higher education ranking tables have emerged, offering information about the quality of higher education institutions. But these ranking tables differ in the number and nature of indicators, as well as the ways the data are obtained (Enserink, 2007). Marginson (2007) argues that ranking tables conceal a whole array of methodological problems and anomalies. It is often unclear why a particular indicator was chosen, by whom it was decided, and how open and reflective the decision process was. For example, the Academic Ranking of World Universities (ARWU) ranking table uses objective data, measured quantitatively. On the other hand, Times Higher Education Supplement (THES) ranking table relies heavily on subjective evaluations by experts and recruiters, presenting 50 % of the final score. Enserink (2007) argues that this peer review is very controversial. Researchers from the Leiden University carried out a correlation between rankings based on subjective evaluations and counting citations – an accepted measure of scientific impact. The results showed that there was no correlation (R^2 = 0,005) (van Raan, 2005). This has fostered doubts about the credibility of the THES ranking table (Enserink, 2007). The same doubts exist regarding the U.S. News ranking table. ARWU and Webometrics ranking tables have avoided this kind of criticism, because both take into consideration objectively accessible data.

Nowadays, universities are exhaustively compared from the educational or research perspective, such as student to staff ratio, number of citations, or number of scientific publications. In contrast, the implication of environmental issues has received little or no attention, although many environmental problems, such as pollution, climate change, and non-sustainable consumption exist.

In our paper, a new ranking table is proposed, covering all three perspectives of sustainable development: research, development, and investment (economic perspective), education and student services (social perspective), and the environmental perspective.

2 Evaluation of ranking tables from the environmental perspective

In the field of world ranking tables, the most influential are the ARWU and THES ones (Dill and Soo, 2005; Jesenšek, 2006). An analysis of well known ranking tables (American, British, Asia, Canadian, Chinese, German and Spanish), reveals common indicators, Table 1. The common indicators are reputation, presented through scientific publications, financial means and student selection. On the other hand, specific indicators, typical for only one ranking table can be found. Such indicators are rents, or commuting possibilities identified in the CHE ranking table. The ranking table, which differs from the others, is Webometrics, including indicators such as: number of pages recovered from four search engines: Google, Yahoo, Live Search and Exalead or the total number of unique external links received (inlinks) by a site. Table 1 reveals that designers of ranking tables more often stress the importance of research and academic reputation, followed by educational indicators, whereas environmental issues are not embraced.

3 A conceptual model for sustainability ranking

To design a ranking table it is necessary to merge various information (indicators) into more condense one (an index). During the index development process, complex information about systems is transformed into simpler information containing numerical fractions useful for stakeholders and decision-makers (Krajnc and Glavič, 2005).

The methodology presented in Fig. 1 has been followed, in order to develop a new ranking table. Indicators have been selected covering various aspects of university performance, based on the principle of objectivity and quantitative expression. Furthermore, indicators have been grouped and judged according to their positive or negative impacts on the particular group (sub-index). Finally indicators have been weighted, using an analytic hierarchy process (AHP) and normalized in order to obtain the final ranking (index).

3.1 Hierarchy levels

The proposed ranking uses a comprehensive, evaluated model, based on the research, educational, and environmental performances of numerous universities. The final rank (A) is composed of sub-indices: research (B_1), educational (B_2) and environmental (B_3), while the lower level consists of various indicators (C_i), Figure 2. The selection of indicators is based on objectivity, quantity, and representation in other ranking tables, while adding environmental and some other indicators.

3.1.1 Research dimension

The *research dimension* includes the following indicators:

- **Patents** (C_1), expressed as number per staff. The data have been obtained from Esp@cenet, an online service for searching patents (Esp@cenet, 2008).
- **Research expenditure** (C_2) is expressed in EUR per student on an annual basis. These data have been obtained on the Internet (Google search engine and web pages of universities).
- **Highly cited researchers** (HiCi) (C_3) is expressed as a fraction of the top score citations in percentage, provided from Top 500 university ranking (ARWU, 2007).
- ***h*-index** (C_4) quantifies both the actual scientific productivity and the apparent scientific impact of a scientist. The data have been obtained at the Web of Science (2007), where the *h*-index has been counted and normalized by the number of academic staff.
- **SCI** index (C_5) has been extracted from the Top 500 University ranking. It embraces the total number of articles indexed in Science Citation Index-expanded and Social Science Citation Index in 2006.
- **Annual expenses for computers and/or library** per student (C_6). The data for this indicator have been searched via Internet with the Google search engine.

3.1.2 Educational dimension

The educational dimension embraces the following indicators:

- **Student / academic staff ratio** (C_7) The data for this indicator were obtained on the Internet, QS Top Universities (2008), Wikipedia and universities' web pages.
- **Graduation rate** (C_8) is an indicator determined by the fraction of students in a university attaining their educational goal. The data for this indicator were obtained from the Internet using Google search engine.
- **Presence on the web** (C_9) is taken from data obtained by Webometrics (2008).
- **Foreign student's rate (mobility)** (C_{10}) shows the tendency of a university to internationalize. The data were obtained via the Internet.

3.1.3 Environmental dimension

The environmental dimension includes the following indicators:

- **Voluntary environmental agreements** or **commitments** (C_{11}) in order to obtain information about activities within community and global environments.
- S**ustainability** oriented **courses** (C_{12}) and **sustainability** oriented **programmes** (C_{13}), providing information about curriculum and trends within education and sustainability.
- **Sustainability vision** and **mission** (C_{14})
- S**ustainability office**, **manager**, **council** or **consultant** (C_{15}).

The data for this group of indicators were obtained via the Internet, using the Google search engine and on the universities' web pages.

3.2 Weighting

Weighting of the data can have a significant impact on the resulting value of the index (Parris and Kates, 2003; Mayer, 2008). In determining the weight of each indicator, AHP has been employed to calculate the contributions of each indicator to the various sub-indices. This method was developed by Saaty and decomposes the decisional process in a hierarchy of criteria, sub-criteria, and alternatives, through a set of weights that reflect the relative importance of alternatives (Saaty, 1980; Saaty, 2000).

In the weighting process, the selected indicators are compared pair-wise, with respect to a specific element in the immediate upper level. A judgmental matrix is formed and used for computing the priorities of the corresponding indicators (Ramanathan, 2001). It has been agreed Saaty (1980; 2000) that the priorities of criteria can be estimated by finding the principal eigenvector of the matrix, λ_{max}. Once the judgmental matrix, comparing criteria with respect to the goal is obtained, the consistency of the judgments is determined by a consistency ratio (R_c), Eq 1.

$$R_C = \frac{I_C}{R_I} \qquad (1)$$

where R_I values of randomly generated matrices (Table 2) have been provided by Saaty (1980, 2000). I_C is a consistency index, calculated from Eq. (2):

$$I_C = \frac{\lambda_{max} - N}{N - 1} \qquad (2)$$

where λ_{max} presents the calculated eigenvalue, and N is the order of the judgment matrix.

Questionnaires with pair-wise comparisons were sent to 40 experts and 16 of them from various countries (USA, UK, The Netherlands, Slovenia, and Sweden) answered. They were asked to estimate a preference factor for each pair of indicators by following the Saaty's scale from 1 to 9. Each expert entered his/her judgments and made a distinction. They compared all the 15 selected indicators. The relative weights of indicators in each group were estimated following the AHP model. Building on the procedure, the first order judgment matrix has been set up. The calculation results are presented in Table 3, showing that the results have satisfactory consistency (R_C = 0,008). The contribution of the third level to the second level is based on the same principle, Table 4. Once the individual priorities of the indicators are available, they are aggregated to obtain final priorities of the sub-indices, $w(B_j)$. The final priority of an indicator C_i with respect to A is calculated as follows:

$$w(C_{i,j})_A = \sum_{ij}^{N} \left[w(C_i)_{B_j} w(B_j)_A \right] \qquad (3)$$

where $w(C_i)_{B_j}$ is the local priority of C_i with respect to B_j, and $w(C_{i,j})_A$ is a local priority of indicators i in a group j with respect to A.

3.3 Normalization

Indicators include a wide range of data, which tend to differ within their range of values and measurement units. Therefore, it is necessary to standardize these values using a certain aggregation method, so that their range of variability is constant (Mayer, 2008). A suitable normalization procedure was used (Eqs. 4 and 5):

$$C^{+}_{\mathrm{N},ij} = \frac{C^{+}_{ij} - C^{+}_{\mathrm{min},j}}{C^{+}_{\mathrm{max},j} - C^{+}_{\mathrm{min},j}} \tag{4}$$

$$C^{-}_{\mathrm{N},ij} = 1 - \frac{C^{-}_{ij} - C^{-}_{\mathrm{min},j}}{C^{-}_{\mathrm{max},j} - C^{-}_{\mathrm{min},j}} \tag{5}$$

where $C^{+}_{\mathrm{N},ij}$ is the normalized indicator *i* of type “more is better”, for indicator group *j*, and $C^{-}_{\mathrm{N},ij}$ is the normalized indicator *i*, of type “less is better”, for indicator group *j*. One of the advantages of the proposed indicator, normalization is the clear compatibility of different indicators (Krajnc and Glavič, 2005).

3.4 Aggregation

The principle shown in Eqs. (6) and (7) was used for aggregation:

$$B_j = \sum_{ij}^{N} w(C_{i,j})_{B_j}\, C^{+}_{\mathrm{N},ij} + \sum_{ij}^{N} w(C_{i,j})_{B_j}\, C^{-}_{\mathrm{N},ij} \tag{6}$$

$$\sum_{ij}^{N} w(C_{ij})_{B_j} = 1, \quad w_{ji} \geq 0 \tag{7}$$

where B_j represents groups of indicators (research, educational, environmental) *j*, while $w(C_i)_{B_j}$ is the weighting of the indicator *i* from group *j*, reflecting its importance, and *N* is the number of indicators considered.

In order to rank universities, a final composite rank A has to be developed which embraces all the three dimensions. It can be calculated from Eq. (8).

$$A = \sum_{j}^{N} w(B_j)_A \, B_j = \sum_{ij}^{N} w(C_{ij})_A \, C_{ij} \tag{8}$$

where $w(B_j)_A$ is a factor representing the weight given to group j of index A.

4. Results

A sample of 35 universities from ARWU 2007 and THES 2007 ranking tables were considered, in order to evaluate and compare their performance from the three perspectives of sustainability (research, educational, and environmental), and to test the developed index. Allowing for the fact that universities do not post data on the internet every year, the latest available data (during the research) was taken into consideration.

The results of the pair-wise comparisons and the importance of indicators are presented in Table 4. Based on opinions of the 16 experts, the more important are economically-oriented indicators: patents, expenditure for research, library and ICT, followed by highly cited researchers and their number of publications in SCI, SSCI and A&HCI journals.

Indicators have different units; therefore, normalization using the Eqs. 4 and 5 is needed. In order to obtain the value of a sub-index (Table, 5), the normalized value of each indicator was multiplied by its corresponding weight, as given in Table 4. Sub-indices were used to aggregate the values of each contributing group (research, educational, environmental), respectively (Eqs. 5 and 6). A final rank A was calculated, according to Eq. 7 (Table 6).

Some universities have been randomly chosen in order to present them on the graph, based on the “triangle method” (Xiang-mei, 2005). A triangular diagram is produced, Figure 3, when connecting the three dimensions of the universities together. Each angle shows research, educational or environmental information about the university. Universities can be characterized by three main groups with respect to their quality and characteristics:

- R (research universities), where the R angle is upward
- E (educational universities), where the E angle is the highest
- EN (environmentally-oriented universities), where the EN angle is dominating.

The overall comparison of the universities from excellent to very good and good is presented in Figure 3. For example, Figure 3 reveals that Harvard is an E-peak university, even though its R and EN are above the 35-average. The University of California, San Francisco is an E-peak university with R far above average and EN below average, while King's College, London is an EN-peak university with all the three characteristics below average. The averages for each of the three dimensions can be calculated, respectively. Thus, a deviation from the average practice can be observed. The results reveal the opportunities for universities, their room for improvement, and their place in comparison with other universities. In other words, it shows whether a specific university is in the forefront, where it might be lagging behind or what needs to be improved in order to achieve a better position.

4.1 Correlations between ranking tables and indicators

Correlation between randomly-chosen indicators and ranking tables, were carried out. The results of the correlation between ARWU and SUR (Sustainable University Ranking), and THES and SUR are presented in Table 7. The results show that medium correlation exists between ARWU and SUR ranking tables while, on the other hand, the correlation between THES and SUR could be denoted as 'low'. A medium correlation with the ARWU ranking table is a consequence of emphasising research dimensions in both ranking tables. On the other hand, insufficient correlation with THES is the result of the subjectively-obtained data in THES.

A correlation can also be determined between indicators of the various ranking tables, e.g. between *h*-indices and highly cited researchers, research expenditure and *h*-indices. (Table 8). Table 8 shows a high correlation between highly cited researchers and *h*-indices, and between *h*-indices and researchers awarded with Nobel Prizes and Fields Medals. In our study, a medium correlation between *h*-indices and research expenditure exists. This correlation is reasonable, especially regarding engineering, science and medicine-oriented universities, where research equipment represents a huge expenditure. Also, a medium correlation exists between *h*-indices and presence on the web. There is a low correlation between patents and highly cited researchers, indicating an insufficient share of knowledge transfer to the industrial environment. Surprisingly, there is insignificant correlation between a wishful low student to staff ratio and the graduation rate. Other correlations could also be investigated.

5 Discussions and Conclusion

The purpose of this new raking method is to provide simplified information about the qualities of universities in respect to the three various perspectives (research, educational and environmental). Furthermore, it enables quick realization of potential weaknesses or advantages regarding a particular university and its potential for improvement. The proposed method is flexible and enables the inclusion of additional indicators. In this case, the AHP process has to be repeated using a pair-wise comparison of indicators.

The first limitation of this methodology is in the number of indicators considered, which are objective, obtained from universities' web pages, and accessible. The environmental indicators, such as CO_2 and other air emissions, source reduction, waste management, land use, consumption to name a few are not represented in the study, because universities, especially in Europe are rarely publishing them. Therefore, a need exists for standardizing indicators for universities.

The second limitation of the ranking table can be the determination of the indicator weights, which are mostly based on the personal opinions of experts. Better results could be obtained if the study included more experts from different fields, while using the AHP process to check the consistency of the answers.

It should be noted that the proposed university ranking is an attempt to evaluate universities from a more objective perspective. Clearly, further studies are needed to improve this ranking, especially in the field of selecting indicators and weights, and determining indicators for evaluation of art and humanities-oriented universities, including indicators embracing monographs, textbooks, and the pedagogic-didactic ability of the teaching staff.

Nomenclature

Symbols

A composite sustainable development index for universities, 1
B sub-index
B_j sub-index of group j of indicators
C_i basic indicator i, 1
C_i^+ indicator whose increasing value has a positive impact in the SD of a university
C_i^- indicator whose increasing value has a negative impact in the SD of a university
C_{max}^+ indicator of positive performance compared to the maximum value of all the universities
C_{max}^- indicator of negative performance compared to the maximum value of all the universities
C_{min}^+ indicator of positive performance compared to the minimum value of all the universities
C_{min}^- indicator of negative performance compared to the minimum value of all the universities
$C_{\mathrm{N},i}$ normalized basic indicator, i
C_{N}^+ normalized indicator whose increasing value has positive impact on the SD of universities
C_{N}^- normalized indicator whose increasing value has negative impact on the SD of universities
I_{c} consistency index, 1
N order of the judgment matrix
R_{c} consistency ratio, 1
R_{I} random index, 1
w weight (importance) of an indicator
λ_{max} eigenvalue of the matrix

Indices

i sustainable development indicator
j group of sustainable development indicators, j = research, educational or environmental

Acronyms

AHP – Analytic Hierarchy Process
ARWU – Academic Ranking of World Universities
A&HCI – Arts & Humanities Citation Index
CHE – Centre for Higher Education Development
EUR – Euro
GDP – Gross Domestic Product
ICT – Information and Communication Technology
SCI – Science Citation Index
SSCI – Social Sciences Citation Index
SUR – Sustainability University Ranking
THES – Times Higher Education Supplement
UK – United Kingdom
USA – The United States of America

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TABLES

Table 1. League tables from the sustainability perspective.

Indicators	**Ranking tables**						
	Asia's best universities	Meclean's best universities	ARWU ranking	CHE ranking	THES ranking	Webometrics ranking	US News Best colleges
Research and academic reputation							
• Publications	✓		✓	✓	✓	✓	
• Research expenses	✓	✓		✓			✓
• Library and equipment	✓	✓		✓			
Education							
• Student/staff ratio				✓	✓		✓
• Graduation rate		✓		✓			✓
• International students		✓		✓	✓		
• Presence on the web						✓	
• Employment rate	✓			✓			
Environmental performance							

Table 2: The average consistencies of random matrices (R_I values)

Size	1	2	3	4	5	6	7	8	9	10
$\boldsymbol{R_I}$	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Table 3: Contribution by groups of indicators (B) to the total rank (A).

	B_1	B_2	B_3	Weight (w)
B_1	1	2	3	0.5438
B_2	1/2	1	2	0.3172
B_3	1/3	1/2	1	0.1390

$\lambda_{max} = 3{,}0092$, $I_c = 0{,}0046$, $R_c = 0{,}008 < 0{,}1$

Table 4: The order of hierarchy of C (indicators) to hierarchy B (groups of indicators) and A (rank).

C_i	Indicator	$w(C_i)_{B_1}$	$w(C_i)_{B_2}$	$w(C_i)_{B_3}$	$w(C_{i,j})_A$
C_1	Patents	0,3096	-	-	0,1684
C_2	Research expenditure	0,2605	-	-	0,1416
C_3	Highly cited researchers	0,1519			0,0826
C_4	Hirsch indices	0,1195	-	-	0,0649
C_5	SCI	0,1101	-	-	0,0599
C_6	Expenses for ICT and/or library	0,0484	0,3212	-	0,1282
C_7	Student/staff ratio	-	0,2769	-	0,0878
C_8	Graduation rate	-	0,2360	-	0,0749
C_9	Presence on the web	-	0,1007	0,0658	0,0412
C_{10}	Mobility	-	0,0652	0,0655	0,0298
C_{11}	Voluntary environmental agreements, commitments,	-	-	0,2032	0,0282
C_{12}	Sustainability oriented courses	-	-	0,2020	0,0225
C_{13}	Sustainability oriented programmes	-	-	0,1616	0,0281
C_{14}	Office, council or manager for sustainable development	-	-	0,1542	0,0214
C_{15}	Sustainability vision, mission	-	-	0,1477	0,0205
	SUM	**1,0000**	**1,0000**	**1,0000**	**1,0000**

Table 5: Sub-indices and their ranks in a new ranking table

UNIVERSITY	B_1	Rank	B_2	Rank	B_3	Rank
Harvard Univ	0,429	2	0,861	2	0,603	7
Stanford	0,418	3	0,825	3	0,588	10
MIT	0,397	5	0,713	5	0,600	9
Yale Univ	0,332	6	0,769	4	0,652	2
UC San Francisco	0,533	**1**	0,558	14	0,336	25
Princeton Univ	0,279	9	0,893	**1**	0,387	22
Caltech	0,403	4	0,712	6	0,271	27
Duke Univ	0,265	11	0,562	13	0,692	**1**
Pennsylvania Univ	0,268	10	0,646	8	0,396	21
Cornell	0,263	14	0,598	12	0,500	15
Univ California, Berkeley	0,265	12	0,522	20	0,611	6
Imperial Coll London	0,240	16	0,552	16	0,600	8
Columbia Univ	0,263	13	0,666	7	0,239	29
Cambridge Univ	0,188	23	0,625	9	0,623	3
John Hopkins Univ	0,287	7	0,535	17	0,431	16
Chicago Univ	0,232	18	0,523	19	0,586	11
Oxford Univ	0,186	24	0,617	11	0,255	28
Univ Michigan - Ann Arbor	0,201	20	0,506	22	0,423	17
Washington Univ - St Louis	0,143	28	0,623	10	0,338	24
Univ California Los Angeles	0,253	15	0,382	26	0,418	18
TokyoUniv	0,140	29	0,533	18	0,502	14
Univ California San Diego	0,282	8	0,341	30	0,374	23
Univ Wisconsin Madison	0,211	19	0,438	24	0,416	19
Northwestern Univ	0,180	25	0,557	15	0,223	31
Univ Washington	0,234	17	0,387	25	0,397	20
Univ Toronto	0,198	21	0,331	31	0,515	13
Australian National Univ	0,148	27	0,359	29	0,622	4
Univ Urbana Champaign	0,132	32	0,377	27	0,541	12
McGill Univ	0,138	30	0,372	28	0,310	26
ETH Zurich	0,093	33	0,501	23	0,186	32
Univ Hong Kong	0,091	34	0,298	33	0,619	5
University Coll London	0,161	26	0,311	32	0,184	33
Carnegie Mellon	0,135	31	0,508	21	0,125	34
Kyoto Univ	0,197	22	0,262	34	0,095	35
King's Coll London	0,032	35	0,161	35	0,229	30

Table 6: A new ranking table of the selected universities.

RANK	*A*	UNIVERSITY
1	0,590	Harvard
2	0,571	Stanford
3	0,526	Massachusetts Inst Technology
4	0,515	Yale Univ
5	0,513	Univ California San Francisco
6	0,489	Princeton Univ
7	0,483	California Inst Techn (Caltech)
8	0,419	Duke Univ
9	0,406	Pennsylvania Univ
10	0,402	Cornell Univ
11	0,395	Univ California, Berkeley
12	0,389	Imperial Coll London
13	0,388	Columbia Univ
14	0,387	Cambridge Univ
15	0,386	John Hopkins Univ
16	0,373	Chicago Univ
17	0,333	Oxford Univ
18	0,329	Univ Michigan – Ann Arbor
19	0,322	Washington Univ – St Louis
20	0,317	Univ California Los Angeles
21	0,315	Tokyo Univ
22	0,314	Univ California San Diego
23	0,311	Univ Winsconsin Madison
24	0,306	Northwestern Univ
25	0,305	Univ Washington
26	0,284	Univ Toronto
27*	0,281	Australian National Univ
28	0,267	Univ Illinois Urbana Champaign
29	0,251	Carnegie Mellon Univ
30	0,236	McGill Univ
31	0,236	ETH Zurich
32*	0,230	Hong Kong Univ
33*	0,212	Univ Coll London
34*	0,204	Kyoto Univ
35*	0,095	King's Coll London

*not all the data were available

Table 7: The correlation between ranking tables.

Ranking tables	Correlation coefficient
ARWU and SUR	0,6711
THES and SUR	0,3418

Table 8: Selected correlations between various indicators.

Indicators compared	Correlation coefficient
HiCi and *h*-indices	0,7131
h-indices, and Nobel Prizes and Fields Medals	0,7059
h-indices and research expenses	0,6020
h-indices and presence on the web	0,5873
Patents and HiCi	0,2985
Student / Staff Ratio, and graduation rate	0,0650

FIGURE CAPTURES

Figure 1: A methodology for determining the final ranks of universities.
Figure 2: Hierarchical structure of the final index for university ranking.
Figure 3: Triangular diagram: comprehensive comparison of randomly-selected universities.

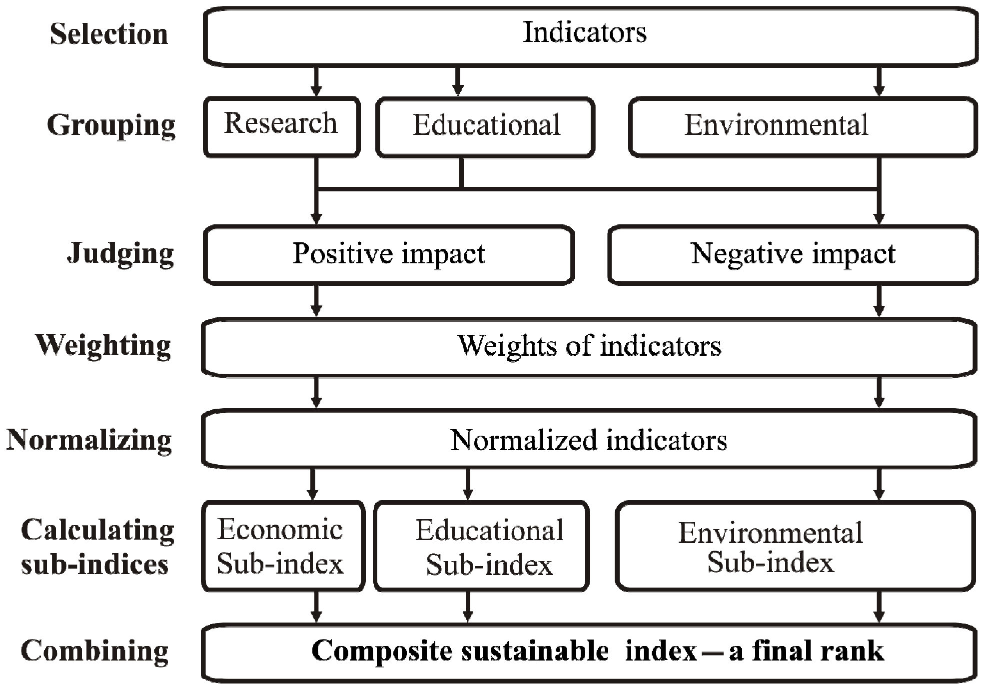


Figure 1: A methodology for determining the final ranks of universities.

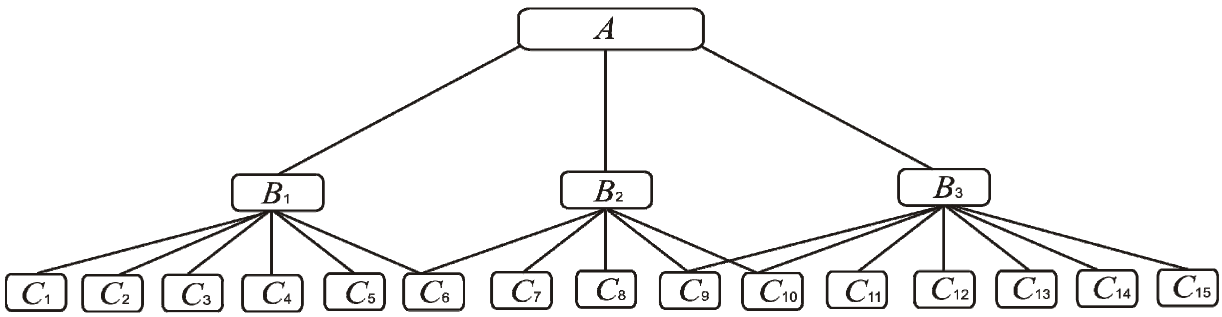
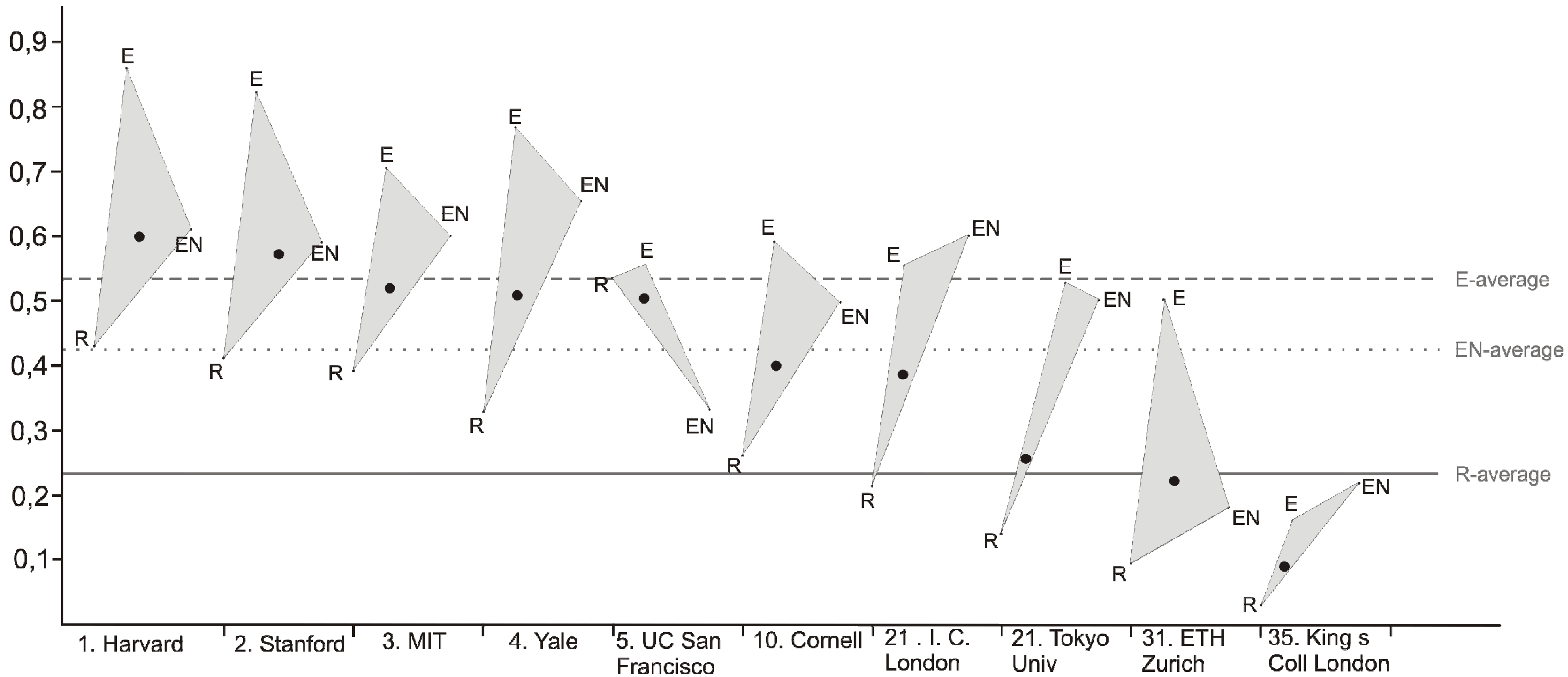


Figure 2: Hierarchical structure of the final index for university ranking.



Legend:

- • overall rank of a university
- R research performance
- E educational performance
- EN environmental performance

Figure 3: Triangular diagram: comprehensive comparison of randomly-selected universities.