Journal of Cleaner Production 18 (2010) 619–628

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

University ranking using research, educational and environmental indicators

Rebeka Lukman*, Damjan Krajnc, Peter Glavič

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

ARTICLE INFO

Article history:
Received 17 April 2009
Received in revised form
28 July 2009
Accepted 12 September 2009
Available online 17 September 2009

Keywords:
University ranking
Research
Educational and environmental indicators
Sustainability index

ABSTRACT

This paper introduces a model, which is enabling a comparison between universities regarding research, educational and environmental performances; the mission of university fits the sustainability idea. The purpose of the paper is to improve the methodology and indicators of the existing ranking tables. The three dimensional index, which provides simplified information about the quality of universities, has been developed. It enables quick detection of the weaknesses, strengths and opportunities for universities. Weights of indicators were determined using the 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 proposed model has been tested on a sample of 35 top universities from the ARWU (Academic Ranking of World Universities) and Times ranking tables and a new ranking table – the Three dimensional University Ranking (TUR) has been developed. In addition, correlations between indicators and ranking tables have been carried out. There is only a medium correlation between the ARWU and TUR. Regarding the indicators, a high correlation with Hirsch indices and Highly Cited Researchers exists, while there is an insignificant correlation between the low student to staff ratio and the graduation rate.

1. Introduction

University ranking tables are a global phenomenon [1] with more than 25 years of history. Rankings began in 1983, when the US News and World report started to publish the annual America's best colleges review. It spawned the development and publication of more and more ranking tables from numerous countries across the world. Over the last two decades, higher education ranking tables have emerged not only from the private and media-based sectors, but also from professional associations and governments [2]. The goals of ranking tables include: (1) directing an entrant to higher educational programmes, (2) evaluating the phenomena of the international higher education market, (3) introducing market directions for universities at national levels, (4) enhancing sound and positive competition for students, professors, and the funders of universities [3]. Ranking tables also offer information about the quality and other characteristics of higher education institutions, influencing the students' matriculation. In many countries higher education presents a financial burden for students, their parents, and scholarship foundations. When students are granted a scholarship, it is important for them to receive high quality education and other complementary services, thus influencing their future employment possibilities.

The designers and publishers of ranking tables have the intention to objectively assess the quality of each university. Most rankings start by collecting university data that are believed to be indicators of quality. After allocating a different, predetermined weight to each indicator, they are added-up to give a total score that determines a university's rank. There are vast differences between the methodologies used in ranking tables, as well as the number and nature of indicators employed [4].

There is much criticism about ranking methodologies. Marginson [5] argues that ranking tables conceal a whole array of methodological problems (e.g. weighing) and anomalies, regarding the indicators. University ranking requires a specific definition and quality criteria for indicators developed in order to assess a university's performance. As a result of methodological problems and usage of various indicators, overall rankings and ranking tables differ. It is often unclear why a particular methodology or indicator was chosen, how well it was founded, by whom it was decided and how open and reflective the decision process was [6]. Regarding the indicators, the Academic Ranking of World Universities (ARWU) ranking table uses objective data, measured quantitatively, but the winners are a particular kind of science-oriented universities. Times Higher Education Supplement (THES) ranking table relies heavily on subjective evaluations by experts and recruiters,

* Corresponding author. Tel.: +386 2 2294 455; fax: +386 2 2527 744.
E-mail address: rebeka.lukman@uni-mb.si (R. Lukman).

0959-6526/$ – see front matter
doi:10.1016/j.jclepro.2009.09.015

Nomenclature

Symbols

A	three dimensional index for universities, 1
B	sub-index
B_j	sub-index of group j of indicators
C_i	indicator i, 1
C_i^+	indicator whose increasing value has a positive impact on the final rank of a university
C_i^-	indicator whose increasing value has a negative impact on the final rank 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
$C_{N,I}$	normalized basic indicator, i
C_N^+	normalized indicator whose increasing value has positive impact on the final rank of universities
C_N^-	normalized indicator whose increasing value has negative impact on the final rank 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
$\lambda_{\max}$	eigenvalue of the matrix

Indices

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

Acronyms

AHP	Analytic Hierarchy Process
ARWU	Academic Ranking of World Universities
CHEPRA	Consortium for Higher Education and Research Performance Assessment
CHE	Centre for Higher Education Development
EUR	Euro
GDP	Gross Domestic Product
ICT	Information and Communication Technology
OECD	Organization for Economic Co-operation and Development
QS	Quacquarelli Symonds
RFSU	Ranking Forum of Swiss Universities
SCI	Science Citation Index
SSCI	Social Sciences Citation Index
THES	Times Higher Education Supplement
TUR	Three dimensional University Ranking
UNESCO	United Nations Educational, Scientific and Cultural Organization
CEPES	European Centre for Higher Education

directed towards the prestige and power of the university. Marginson [5] argues that the THES ranking table does not express the quality of education, and only slightly touches the research dimension. The latter merely takes account of the number of citations per faculty member, which contributes 20% to the total ranking score.

An International Ranking Expert Group was established in 2004 in order to harmonize university rankings. In 2006, the group of experts published the Berlin principles on the ranking of higher education institutions from methodological and indicator perspectives. These principles are divided into four items [1]:

- *Purpose and goals of ranking* should be one of a number of diverse approaches to the assessment of higher education inputs, processes, and outputs; be clear about their purposes and their target groups.
- *Design and weighing of indicators* be transparent regarding the methodology used for creating the rankings, choose indicators according to their relevance and validity, make the weights assigned to different indicators (if used) prominent, and limit changes of them.
- *Collection and processing of data* use audited and verifiable data whenever it is possible, include data that are collected using proper procedures for scientific data collection, and apply measures of quality assurance to the ranking processes themselves.
- *Presentation of ranking results* provide consumers with a clear understanding of all the factors used to develop a ranking, offer them a choice of how rankings are displayed, ensure they are compiled in a way that eliminates or reduces errors in the original data, and be organized and published in a way that errors and faults can be corrected.

Enserink [4] argues that the principles are quite general in nature because they are the "most significant common denominators" of groups of rankers with diverse views.

From the indicator perspective, many international ranking tables emphasize the research dimension. The reason for this is invention, the element of competition and selection. Other reasons for emphasizing the research indicators are research oriented staff employment and promotion policies of funding universities. Educational indicators are reflecting social and cultural norms. Obstacles exist when measuring educational achievements, such as behaviour, values, or skills needed for future life, because countries differ in their cultural and educational traditions and perspectives.

Regarding the methodologies, data acquisition presents another problem of university rankings. Many ranking tables are based on subjective, qualitative data, received from universities themselves. Enserink [4] also argues that peer reviews, in which academic experts or graduate recruiters judge universities, are even more controversial. In the THES ranking table, 50% of the final score is based on subjective evaluations by peer reviewers. Researchers at the Leiden University carried out a correlation between rankings based on subjective evaluations, and citations counting – an accepted measure of scientific impact. The results showed that there was no correlation ($R^2 = 0.005$) between them [7]. This has fostered doubts about the credibility of the THES ranking table [4]. Doubts exist regarding the US News ranking table, too. The Institute of Educational Policy from Toronto documented evidence of cheating by universities listed in the US News [4]. Disagreement with the ranking methodologies makes universities hesitate to participate in the ranking.

Nowadays, universities are exhaustively compared from the educational and 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 universities are monitoring their environmental footprints. In our paper, a new ranking table is proposed, trying to improve the existing tables from methodological and indicator selection perspectives. Beside the research and educational indicators it introduces the environmental ones.

The indicators have been grouped, according to the sustainability model (Fig. 1). Sustainability refers to the holistic and interconnected phenomena of economic, environmental, and social aspects [8]. Sustainability oriented issues are always multidimensional and are organized within the economic, environmental and social dimensions. Strictly one-dimensional activity (e.g. environmental) hardly exists, since it is always related to economic and social effects. University's performance aspects (research, education, and environmental protection) are interconnected, multidimensional, too. They should all be evaluated when sustainability of University is under consideration. Research, development, investment and matriculation are aspects, which are closely linked with economic dimension of the development of universities. Thus, in order to organize the university performance into sustainability idea, the assumption has been made that these four aspects represent mainly the economic dimension of university's performance. Education and student services were assumed to relate mainly to social dimension, while resource usage, emissions, and waste represent environmental dimension of university's performance. In this way, all the three perspectives of sustainable development have been covered by the proposed three dimensional university ranking.

However, it is usually very difficult to draw a line between the three perspectives. For example, research could imply to economic, social and environmental interests. The same is true for the education. Expenses and patents are embraced under economic dimension, because they bring economic effects to the university, but they are not solely economic. Different proportions of them belong to the environmental dimension (innovations decreasing environmental burdens) and social dimension. Another example is environmentally responsible activity at the university, acting as an example of good practice with direct or indirect impact on education, individual and community behaviour, embracing social (educational) and economic (cost reduction) dimensions, too. It is also important to notice that not all research or education activities enhance sustainability.

The paper briefly introduces and analyses the indicators of existing, most popular and employed ranking tables (American, British, Asian, Canadian, Chinese, German, Spanish). From the methodological perspective it introduces a model, which allows the determination of a common index, enabling ranking and comparison between universities regarding their research, educational and environmental performances. The applicability of the proposed ranking was tested for 35 universities. Finally, correlations between various ranking tables, including the proposed one and their indicators were carried out.

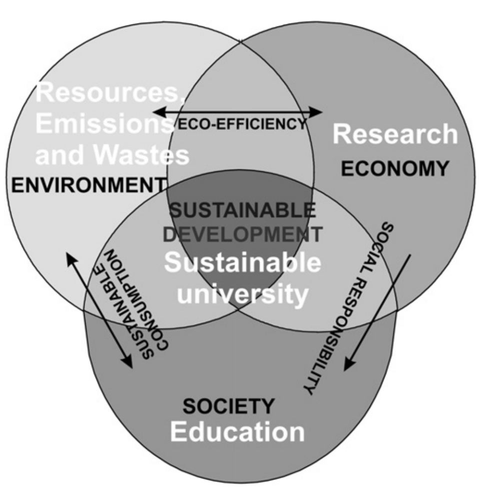

Fig. 1. A sustainability model.

2. Evaluation of ranking tables from the environmental perspective

The most influential of world ranking tables are the ARWU and THES ones [3,9]. Besides these two global ranking tables, other national ones exist (see above). Recently, ranking tables have been evaluated by some authors [9,10]. The analysis of well known ranking tables reveals some common indicators, Table 1. These indicators deal with reputation, mostly presented through scientific publications. Other common indicators are financial means of a university, and student selection. Specific indicators, typical for only one ranking table can also be found. Such indicators are for example rents, or commuting possibilities identified in the CHE (Centre for Higher Education Development) ranking table. The Webometrics ranking table differs from the others, 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 university 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 mostly not embraced. However, there have been some attempts to evaluate universities from the sustainability perspective. Shriberg [11] analyzed eleven methods for evaluating sustainable development at student campuses, which provided the basis for strategic planning, but do not permit comparison between campuses. In 2007 a Green Report Card has emerged [12] permitting a comparison of the US Colleges. Regarding the indicators, its weakness is to emphasize the environmentally oriented ones only, and some of them are based on qualitative definitions difficult to evaluate.

3. Conceptual model for ranking universities

In order to compile the ranking of universities from methodological perspective it is necessary to condense and merge varied information (indicators) into one index – an overall rank. During the index development process, complex information about systems is to be transformed into simpler information containing numerical fractions useful for stakeholders and decision-makers [13]. A quality university ranking table, which shows the development of universities from the research, educational and environmental perspectives to experts, stakeholders and decision-makers, shall have the following characteristics:

- Comprehensive comparison of universities
- Evaluation of development trends, compared to the vision, mission, goals and strategic plans
- Identification of "hot spots" and improvement options, and
- Communication with the public.

According to the European Commission [14] an index should be developed, using rigorous methodology, and having the following quality criteria:

Table 1
League tables from the research, educational and environmental perspectives.

Indicators	Ranking tables							
	Asia's best universities	Meclean's best universities	ARWU ranking	CHE ranking	THES ranking	Webometrics ranking	US News Best colleges	Green Report Card
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								✓

- giving added-value compared to simple indicators
- Including indicators and sub-indices, which are relevant for assessment
- Being based on high quality data,
- The method for weighing should be transparent, easy, and statistically valuable,
- Indices should be examined using sensitivity analysis.

Such a quality ranking table, based on indices, permitting evaluation of universities also from the environmental perspective, and fulfilling the criteria of the European Commission has not been developed, yet. In practice, indicators and indices are a result of compromise between scientific accuracy, concise information, and usage for strategic decision making [15].

The methodology presented in Fig. 2 has been followed, in order to develop the new ranking table. Indicators have been selected covering various aspects of university performance, based on the principle of objectivity and quantitative expression. Indicators have been ordered in groups, based on various aspects, and judged according to their positive or negative impacts on the particular group (sub-index). Indicators have also been normalized in order to obtain the final ranking (index). The analytic hierarchy process (AHP) has been employed for determining the weights of indicators [16].

3.1. Hierarchy levels

The proposed ranking uses a comprehensive model, based on the research, educational, and environmental performances of universities. The overall objective of the study is to rank universities according to the criteria mentioned above and to construct a three dimensional index, resulting in a final rank (A), thus enabling a simple comparison of universities. The final rank is an integrated function of a university's activities. The intermediate, sub-indices level is composed of research (B_1), educational (B_2) and environmental (B_3) dimensions, while the lowest level consists of individual indicators (C_i), Fig. 3. The selection of indicators is based on objectivity, using some quantitative representations of other ranking tables and some new ones, while adding environmental indicators.

3.1.1. Research dimension

In the *research dimension* patents (C_1), expressed as number per staff, provide for transfer of knowledge and innovations into industry, showing the economic relevance regarding university research and development. The data have been obtained from Esp@cenet, an online service for searching patents [17].

The second indicator, research expenditure (C_2) is expressed as investment per student in EUR/a. It identifies a particular mainstream of higher education research, and provides for investment made in each student [18]. These data have been obtained from the Internet (Google search engine, and web pages of universities).

The indicator **highly cited researchers** (HiCi, C_3) is expressed as a fraction of the top score citations in percent, provided from ARWU university ranking [19]. This indicator identifies and appreciates researchers whose collective publications have received the highest number of citations over the last two decades. It is an indicator of scientific contribution, presented by Thomson Scientific and covering 21 fields; providing that an individual is among the 250 most cited researchers in each field according to his/her published articles within a specific time-period [20]. The data have been obtained from the ARWU 2007 ranking table.

The **Hirsch index** (C_4) quantifies both the actual scientific productivity and the apparent scientific impact of a scientist. The index is based on a set of a scientist's most cited papers and the number of citations that he/she has received in other people's publications. The index can also be applied to the productivity and impact of a group of scientists, such as a department, university, or country [21]. The data have been obtained from the Web of Science [22], where the h-index has been counted and normalized by the number of academic staff in each university.

The **SCI** index (C_5) has been extracted from the ARWU [19]. It embraces the total number of articles indexed in Science Citation Index-expanded (SCI) and Social Science Citation Index (SSCI) in 2006. Only article type publications are considered.

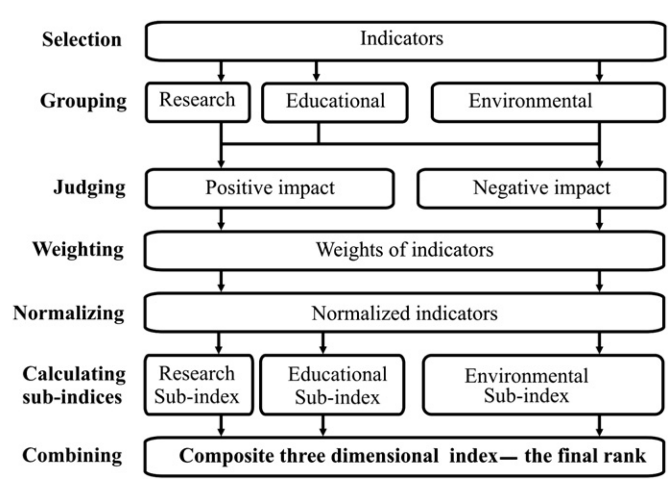

Fig. 2. A methodology for determining the final ranks of universities.

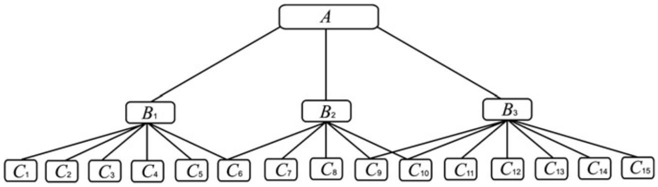

Fig. 3. Hierarchical structure of the composite index for university ranking.

Annual expenses for computers and/or library per student (C_6) provide information about the investment into data-bases, availability of literature and comfort of researchers and students. The data for this indicator have been searched for via Internet using the Google search engine.

3.1.2. Educational dimension

The **student to academic staff ratio** (C_7) is an indicator of the share of teaching resources available for students in tertiary education. It provides an overall indication of the effort made by universities to ensure that their students receive more personal provision [23]. The data for this indicator were obtained from the Internet, Quacquarelli Symonds (QS) Top Universities [24], Wikipedia, and web pages of universities.

Graduation rate (C_8) is an indicator determined by the fraction of students in a university reaching their educational goal. For example, for a four-year programme, the graduation rate includes students who have graduated over the six years since the programme's inception [25]. The data for this indicator were obtained from the Internet using Google search engine.

Presence on the web (C_9) is taken from data published by Webometrics [26].

Foreign student's rate (mobility) (C_{10}) shows the tendency of a university to internationalize. It highlights the attractiveness of the programmes and the university itself to students from abroad [18], and support to their own students to spend some time in other universities worldwide. The data were obtained via the Internet.

3.1.3. Environmental dimension

The activities of a university within the environmental dimension have been considered by:

- The number of **voluntary environmental agreements** or **commitments** (C_{11}), to carry out 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}),
- **Sustainability 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 the web pages of universities.

3.2. Weighing

Weighing of the data can have a significant impact on the resulting numerical value of the index [27,28]. It is also very difficult to determine with sufficient accuracy the importance of the proposed indicators [29]. In determining the weight of each indicator, the AHP has been employed to calculate its contributions to the various sub-indices. It is an intuitive method for formulating and analyzing decisions which has been applied to numerous practical problems over the last few decades [30,31]. This method was developed by Saaty [16]; it decomposes the decisional process into a hierarchy of criteria, sub-criteria, and alternatives, using a set of weights that reflect the relative importance of alternatives [32].

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

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

In the step of weighing, the indicators of a particular level 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 [31]. Saaty [33] suggested the use of a 9-point scale to transform verbal judgments into numerical quantities. It has been agreed [16,33] that the priorities of criteria can be estimated by finding the principal eigenvector of the matrix, λ_{max}. Once the judgmental matrix is obtained by comparing criteria with respect to the goal, the consistency of the judgments is determined by the consistency ratio R_c, [31]:

$$R_C = \frac{I_C}{R_I} \tag{1}$$

where R_I values of randomly generated matrices (Table 2) have been provided by Saaty [16,33]. I_C is a consistency index, calculated from Eq. (2):

$$I_C = \frac{\lambda_{max} - N}{N - 1} \tag{2}$$

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

Pair-wise comparisons of indicators (e.g. importance of patents in comparison with research expenses) have been carried out, in order to determine the importance (weights) of each indicator. 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 1–9. The experts were chosen as individuals with an in-depth knowledge of the research, education and environmental sustainability. Each expert entered his/her judgments in, and made a distinction. They compared all the 15 indicators proposed. The relative weights of indicators in each group were estimated following the AHP model. Building on the procedure, the first order judgment matrix was set up. The calculation results are presented in Table 3, showing that the results have a satisfactory consistency ($R_c = 0.008$). The contribution of the third level to the second one is based on the same principle (Table 4).

Once the individual priorities of the indicators 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:

Table 3
Contribution by sub-indices (B) to the final index (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
Indicators according to their positive or negative impact on university ranking.

Indicators group	Indicators with positive impact	Indicators with negative impact
Research	C_1, C_2, C_3, C_4, C_5, C_6	
Educational	C_8, C_{10}	C_7, C_9[a]
Environmental	C_{11}, C_{12}, C_{13}, C_{14}, C_{15}	

[a] Presence on the web is not a negative indicator by itself, but Webometrics ranking calculates the final rank in the way, where lower final value of the university presents the best one.

$$w(C_{ij})_A = \sum_{ij}^{N}\left[w(C_{ij})_{B_j} w(B_j)_A\right] \tag{3}$$

$w(C_i)_{B_j}$ is the local priority (weight) of C_i with respect to B_j, and $w(C_{ij})_A$ the local priority (weight) of indicator 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 [28]. A suitable normalization procedure was used (Eqs. (4) and (5)):

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

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

$C^{+}_{N,ij}$ is the normalized indicator i of the type "more is better", for indicator group j, and $C^{-}_{N,ij}$ is the normalized indicator i, of the type "less is better", for indicator group j. One of the advantages of the proposed indicator normalization is the clear compatibility of different indicators [13].

3.4. Aggregation

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

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

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

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

In order to rank universities, the final rank A has to be developed embracing 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

Thirty five universities from the ARWU 2007 and THES 2007 ranking tables, listed up to the 30th position of each one were considered, in order to evaluate and compare their performance from the three perspectives (research, educational, and environmental), and to test the three dimensional index developed, the final result being a TUR ranking table. The input data used were obtained in 2007 from various ranking tables (e.g. ARWU, Webometrics), Web of Science, and Esp@cenet, or extracted from the Internet (e.g. graduation rate) to guarantee data accessibility and objectivity. Allowing for the fact that universities do not post data on the internet every year, the latest available data was taken into consideration during the research.

It is important to notice that CO_2 emissions, water consumption, and other environmental data have not been considered due to their prevailing inaccessibility, so far. The index (A), and thereby university ranking is problematic if data are unavailable for some of the individual indicators. OECD [34] argues that data unavailability is a common weakness regarding all sustainability efforts at present, regardless of the scale of publicity.

Indicators were classified according to their positive or negative influence, Table 4. For example, increasing number of highly cited researchers has a positive impact on the research performance of

Table 5
The order of hierarchy of C (indicators) to hierarchy B (sub-indices) and A (final index).

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

a university (indicator is of the type "more is better"), whilst increasing student to staff ratio has a negative influence on the educational process (indicator is of the type "less is better").

The results of the pair-wise comparisons and the importance of indicators are presented in Table 5. Based on opinions of the 16 experts, the more important are research indicators are patents, expenditure for research, library and information–communication technology (ICT), followed by highly cited researchers and their number of publications in SCI and SSCI.

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 6), the normalized value of each indicator was multiplied by its corresponding weight, as given in Table 5.

4.1. Assessment and university ranking

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 7). Some universities have been randomly chosen in order to present them on the graph, based on the "triangle method" [35], giving a visual evaluation of universities. A triangular diagram is produced when connecting the three dimensions of the universities together (Fig. 4). Each angle delivers important information regarding research, educational or environmental dimensions about the university, showing their advantages and disadvantages. Universities can be characterized by the prevailing type of their quality characteristics:

- R (research universities), where the angle R is upward

Table 6
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 7
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[a]	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[a]	0.230	Hong Kong Univ
33[a]	0.212	Univ Coll London
34[a]	0.204	Kyoto Univ
35[a]	0.095	King's Coll London

[a] Not all the data were available.

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

The average for each of the three dimensions can be calculated, respectively. Thus, a deviation of an individual university from the average practice can be observed. The overall comparison of the universities from excellent to very good and good is presented in Fig. 4, too. For example, 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 top 35 average, while King's College, London is an EN-peak university with all the three characteristics below the 35-average. The results reveal a university's place in comparison with other universities, indicate opportunities of universities, and their room for improvement. In other words, it shows where 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.

4.2. Correlations between ranking tables and indicators

A correlation between randomly-chosen indicators, as well as between ranking tables, was carried out, in order to obtain their mutual relationship. The results of the correlation between ARWU and TUR, and THES and TUR are presented in Table 8. The results show that medium correlation exists between ARWU and TUR ranking tables while, the correlation between THES and TUR could be denoted as 'low'. A medium correlation with the ARWU ranking

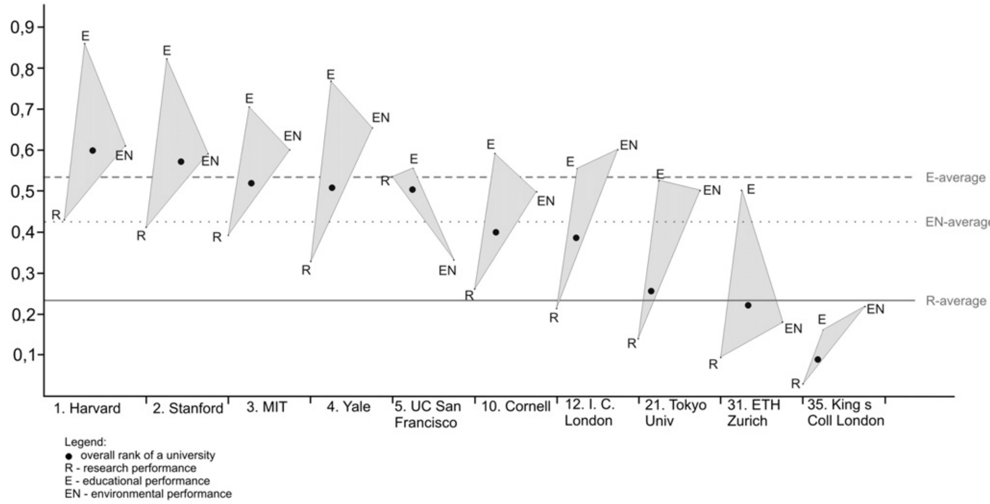

Fig. 4. Triangular diagram: comprehensive comparison of randomly-selected universities.

table is a consequence of emphasizing research dimensions in both ranking tables. The insufficient correlation with THES is the result of the subjectively-obtained data in THES, which have only indirect emphasis on research and educational indicators.

A correlation can also be determined between indicators of the various ranking tables, e.g. between Hirsch indices and highly cited researchers, research expenditure and Hirsch indices (Table 9). Table 9 shows a high correlation between highly cited researchers and Hirsch indices, and between Hirsch indices and number of researchers awarded with Nobel Prizes or Fields Medals. These results are in line with studies at the Thomson Scientific [20] carried out for the last 30 years, confirming a strong correlation between citations and Nobel Prize winners. These evaluations counted citations to detect individuals with a high potential of becoming Nobel Prize winners in the current year, or in forthcoming years. Based on this method, the researchers at the Thomson Scientific have successfully predicted 27 Nobel Prize winners since the year 1989 [20].

In our study, a medium correlation between Hirsch 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 a difference between knowledge creation mechanism and knowledge transfer to the industrial environment. Surprisingly, there is insignificant correlation between a low student to staff ratio and the graduation rate. Other correlations could also be investigated.

5. Discussions and conclusion

The purpose of this new ranking method is to provide simplified information about the qualities of universities with respect to the three missions of universities (research, educational and environmental). Our study showed that the TUR gives a lot of information, not only about the quality and characteristics of universities, but also in analyzing their development. It enables quick detection of potential weaknesses or strengths of a particular university, and its opportunities 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 the pair-wise comparison of indicators.

The first limitation of this methodology is in the number of indicators considered; they shall be objective and accessible, obtained from published sources and web pages of universities. The environmental indicators, such as CO_2 and other air emissions, source reduction, waste management, land use, and consumption to name a few are not represented in the study, because universities, especially in Europe do rarely publish them. Therefore, a need exists for standardizing environmental indicators to allow for evaluation of the third dimension mentioned above by stimulating universities to introduce, register and publish the information. These indicators should be reported in annual reports of universities. This would foster data acquisition, and a data-base could be designed. The data used in this study were obtained via the Internet, what was very time consuming. The environmental indicators included in the study might not fully address the environmental performance of universities. Many schools have committees, reports, offices but they do not necessarily change the behaviour at the campus. International community (e.g. European Commission together with European University Association, National Accreditation or Quality Control Agencies), should standardize environmental performance at universities, and also keep verifying the authenticity of reported data.

The second limitation of the ranking table can be the determination of the indicator weights, which are mostly based on personal opinions of experts. Better results could be obtained if the study included more experts from different fields, and other

Table 8
The correlation between ranking tables.

Ranking tables	Correlation coefficient
ARWU and TUR	0.6711
THES and TUR	0.3418

Table 9
Selected correlations between various indicators.

Indicators compared	Correlation coefficient
HiCi and Hirsch indices	0.7131
Hirsch indices, and Nobel Prizes and Fields Medals	0.7059
Hirsch indices and research expenses	0.6020
Hirsch indices and presence on the web	0.5873
Patents and HiCi	0.2985
Student/Staff Ratio, and graduation rate	0.0650

stakeholders, using the AHP process to check the consistency of the answers.

In our ranking table, higher positions belong to American universities (similar to ARWU and THES), which are listed in the first thirteen places. This is not surprising, as the US allocate around 5.52% of its GDP to higher education, research and development, while Europe contributes only 2.89% of its GDP for the purpose [36,37,38]. This could be a consequence of the American Higher Education system, which differs from the European one, and represents a success story of the twentieth century, forming the basis for the American economy [39]. American universities mainly differ from the European ones with regard to the financial investment. They are financed from both the public and private sector, including fees contributed by students, donations from industries, and many foundations. They also have high fraction of foreign students [40]. The higher education sector in the US is also very market oriented. High quality education is costly and requires high financial input. Due to excellent research and education, the competition for students and professors is very high [41]. Also, from the environmental-sustainability perspective, American universities are in forefront and were the first to start approaches characterized by environmental management schemes, and constant curriculum adaptations [42].

The proposed ranking was created in order to examine universities with regard to all the three important dimensions: research, educational, and environmental. Our findings suggest that ranking of universities does not only provide valuable information about their characteristics, but allows to better understand their development, too. The ranking results provide opportunities for determining "hot spots", and foster their improvement.

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

The CHERPA (the Consortium for Higher Education and Research Performance Assessment) network has won an open call for tender by the European Commission to develop and test an alternative methodology for global ranking of universities [43]. During the next two years, the network will conceptualize and test the feasibility of a multidimensional global ranking based on the CHE ranking methodology, and they are expected (hoped for) to develop multidimensional ranking, including environmental indicators.

Acknowledgments

The authors would like to thank Katja Kocuvan and Saša Hočurščak for their efforts in searching the Internet data, and to anonymous reviewers for their valuable comments and suggestions.

References

[1] Berlin Principles Berlin Principles. Available online: http://www.cepes.ro/hed/meetings/berlin06/Berlin%20Principles.pdf; 2006 [6 November 2006].
[2] UNESCO CEPES, European Centre for Higher Education. Higher education ranking systems and methodologies: how they work, what they do. Available online: http://www.cepes.ro/hed/policy/ranking.htm [13 January 2006].
[3] Jesenšek M. Why the rankings are important? Katedra (Maribor) 2006;1(4):6–7 [in Slovene].
[4] Enserink M. Who ranks the university rankers? Science 2007;317:1026–8.
[5] Marginson S. Global university rankings: implications in general and for Australia. Journal of Higher Education Policy and Management 2007;29(2):131–42.
[6] RFSU – The Ranking Forum of Swiss Universities. Ranking methodology: how are universities ranked? Available online: http://www.universityrankings.ch/en; 2008 [3 March 2008].
[7] Van Raan AFJ. 2005. Challenges in ranking of Universities. Invited paper for the First International Conference on World Class Universities, Shanghai Jaio Tong University, Shanghai, June 16–18, 2005.
[8] Lozano R. Envisioning sustainability three-dimensionally. Working paper series no. 39. Centre for Business Relationships, Accountability, Sustainability and Society (BRASS). Available online: http://works.bepress.com/rodrigo_lozano/5; 2007 [15 May 2009].
[9] Dill DD, Soo M. Academic quality, league tables, and public policy: a cross-national analysis of university ranking systems. Higher Education 2005;49:495–533.
[10] Usher A, Savino M. World of difference: a global survey of university league tables. Toronto, Canada: Educational Policy Institute; 2006.
[11] Shriberg M. Towards sustainable management: the University of Michigan housing division's approach. Journal of Cleaner Production 2002;10:41–5.
[12] Green Report Card. Available online: http://www.greenreportcard.org; 2009 [15 June 2009].
[13] Krajnc D, Glavič P. How to compare companies on relevant dimensions of sustainability. Ecological Economics 2005;55(4):551–63.
[14] European Commission. Commission to the European Communities. Structural indicators – Communication from the Commission, Brussels, 16. 10. 2002. Available online: http://europa.eu.int/eur-lex/en/com/cnc/2002/com2002_0551en01.pdf; 2002 [6 June 2006].
[15] Opschoor JB, Reijnders L. Towards sustainable development indicators. In: Verbruggen H, Kuik O, editors. Search of indicators for sustainable development. Dordrecht: Kluwer Academic Press; 1991. pp. 7–29.
[16] Saaty TL. Analytical hierarchy process: planning, priority setting, resource allocation. New York: McGraw-Hill; 1980.
[17] Esp@cenet. Available online: http://si.espacenet.com/search97cgi/s97_cgi.exe?Action=FormGen&Template=si/SI/home.hts; 2008 [27 September 2008].
[18] OECD. Educational database. Available online: http://www.oecd.org/education/database; 2007 [21 August, 2007].
[19] ARWU. Academic ranking of World Universities (2007). Available online: http://www.arwu.org/rank/2007/ranking2007.htm; 2007 [10 September 2007].
[20] Thompson Scientific. Highly cited researchers. Available online: http://scientific.thomsonreuters.com/isi/; 2008 [4 March 2008].
[21] Hirsch JE. An index to quantify an individual's scientific research output. Proceedings of the National Academy of Sciences 2005;102(46):16569–72.
[22] ISI Web of Science. Available online: http://apps.isiknowledge.com/WOS_GeneralSearch_input.do?product=WOS&search_mode=GeneralSearch&SID=Q1IKAHnMkfk4eo4n4no&preferencesSaved=&highlighted_tab=WOS; 2007 [10 September, 2007].
[23] Eurydice. Student–staff ratio. Available online: http://www.eurydice.org/portal/page/portal/Eurydice/PubPage?pubid=088EN&fragment=62&page=1; 2007 [17 December 2007].
[24] QS Top Universities. Available online: http://www.topuniversities.com/; 2008 [3 March 2008].
[25] Online Education Database. Available online: http://oedb.org/rankings/graduation-rate; 2007 [21 August 2007].
[26] Webometrics. Available online: http://www.webometrics.info/; 2008 [27 February 2008].
[27] Parris T, Kates R. Characterizing and measuring sustainable development. Annual Review of Environmental Resources 2003;28(13):559–86.
[28] Mayer AL. Strengths and weaknesses of common sustainability indices for multidimensional systems. Environment International 2008;34(2):277–91.
[29] Afgan NH, Carvalho MG. Sustainability assessment of hydrogen energy systems. International Journal of Hydrogen Energy 2004;29:1327–42.
[30] Shim JP. Bibliographical research on the analytic hierarchy process (AHP). Socio-Economic Planning Science 1989;23:161–7.
[31] Ramanathan R. A note on the use of the analytic hierarchy process for environmental impact assessment. Journal of Environmental Management 2001;63(1):27–35.
[32] Berrittella M, Certa A, Enea M, Zito P. An analytic hierarchy process for the evaluation of transport policies to reduce climate change impacts. Available online: FEEM Fondazione Eni Enrico Mattei Research Paper Series http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm 2007 [25 January 2008].
[33] Saaty TL. Fundamentals of the analytic hierarchy process. Pittsburgh: RWS Publications; 2000.
[34] OECD — Organization for Economic Co-operation and Development. An Update of the OECD Composite Leading Indicators. Short-term Economic Statistics Division, Statistics Directorate/OECD.
[35] Xiang-mei L, Min Mand Chuan-feng T. The functional assessment of agricultural ecosystems in Hubei Province, China. Ecological Modelling 2005;187:352–60.
[36] OECD. Statistics portal. Available online: http://www.oecd.org/statsportal/0,3352,en_2825_293564_1_1_1_1_1,00.html; 2008 [1 October 2008].
[37] OECD. Education at a glance. Available online: http://www.oecd.org/document/30/0,3343,en_2649_39263238_39251550_1_1_1_1,00.html; 2007 [23 June 2007].

[38] Report on Development. Institute of macroeconomic analysis and development. Available online: http://www.umar.gov.si/en/zapisi/?no_cache=1; 2007 [3 June 2008] [in Slovene].
[39] Hunt JB. How does it measure up for the 21st century?. Availabe online: http://www.highereducation.org/reports/hunt_tierney/hunt.shtml; 2007 [12 April 2008].
[40] Altbach PG. Higher education crosses borders. Change 2004;36(2):18–25.
[41] Glavič P. Remarks on National Programme of Higher Education. Available online: abra.fkkt.uni-lj.si/fn01leban/resolucija/7.doc; 2006a [16 January 2007] [in Slovene].
[42] Glavič P. Sustainability engineering education. Clean Technologies and Environmental Policy 2006b;8:24–30.
[43] International Observatory on Academic Rankings and Excellence. Available online: http://www.ireg-observatory.org/; 2009 [20 June 2009].