Multicriteria decision methods applied to the selection and hierarchy of campus sustainability indicators of a Higher Education Institution

L D M Sanchez¹, M F L Almeida¹, R F Calili¹, D R Louzada¹

¹Postgraduate Programme in Metrology, Pontifícia Universidade Católica do Rio de Janeiro, PUC-Rio, Rio de Janeiro, 22451-900, Brazil.

E-mail: fatima.ludovico@puc-rio.br

Abstract. Higher Education Institutions (HEIs) have a preponderant role in promoting sustainability and must themselves be models for society. From this perspective, sustainability initiatives by HEIs have significantly gained importance in the last two decades, as well as the application of several tools and guidelines that focus on campus sustainability. However, one of the most frequent problems faced by the HEIs is the measurement and evaluation of efforts and results associated with their Sustainability Agendas. Therefore, this article aims to propose a multicriteria approach for selecting and hierarchizing campus sustainability indicators of an HEI (PUC-Rio, Brazil), focusing on one of the thematic axes of its Environmental Agenda. Two multicriteria methods (AHP and AHP-PROMETHEE) were applied in this institutional context, and seven evaluation criteria were considered. The results of both methods were also compared to give more robustness to the selection and hierarchization of the environmental indicators associated with the chosen thematic axis (water). The main contribution of the research to the field of environment measurement and also to HEIs that wish to achieve higher levels of sustainability is a multicriteria methodological approach aiming to improve the current practices for selecting and hierarchizing indicators that could better measure and communicate their sustainability performance.

1. Introduction
The humanity’s most significant global challenges such as environmental preservation and fight against hunger and poverty require educational and innovative solutions that are shaped by changes in habits, values, and attitudes. From this perspective, the Higher Education Institutions (HEIs) are privileged organs of knowledge diffusion through their core activities, forming and guiding a large part of the people who will hold key positions in society. Therefore, HEIs have a preponderant role in promoting sustainability and must themselves be models for society. From this perspective, sustainability initiatives by HEIs have significantly gained importance in the last two decades, as well as the application of several tools and guidelines that focus on campus sustainability. They take into account the impacts of the HEI’s most relevant activities - education, research, community outreach; campus operation and management [1].

The evaluation of sustainability in HEIs has been carried out with the support of several tools based on specific indicators, defined on the basis of consistent conceptual frameworks, such as the Global Reporting Initiative [2], The College Sustainability Report Card (2017 edition), and UI GreenMetric
World University Ranking (2017 edition) [1]. These tools and their indicators have been adapted from models designed for other types of organizations, such as the Global Reporting Initiative, whose structure of indicators was adapted by Lozano-Ros for HEIs in 2003 [3]. In many cases, monitoring and evaluation frameworks and tools have been developed for HEIs, such as the Campus Sustainability Assessment Framework proposed by Cole [4], The College Sustainability Report Card, and UI Green Metric World University Ranking 2017 [1].

Following this global trend, the Pontifical Catholic University of Rio de Janeiro (PUC-Rio) created its own Environmental Agenda in 2008. The Agenda is a result of a collective effort and a reflection process of an interdisciplinary group composed by teachers and students, from different centers and departments, coordinated by PUC-Rio Interdisciplinary Nucleus for Environment (NIMA). The PUC-Rio Environmental Agenda was structured around seven thematic axes: (i) biodiversity; (ii) water; (iii) energy; (iv) atmosphere; (v) materials; (vi) waste; and (vii) environmental education [5].

The PUC-Rio Environmental Agenda has been considered as a symbolic expression of the University’s systemic effort of looking for sustainable alternatives, in short, medium, and long terms. However, measuring and evaluating the results of the Agenda in each thematic axis has been admittedly a difficult task for its Coordination, particularly the choice of relevant indicators and metrics associated to each thematic action plan. As an attempt to meet this challenge, this paper aims to apply two multiple-criteria decision-making (MCDM) methods to select and hierarchize indicators for monitoring and evaluating the efforts and results of the action plan concerning one of the thematic axes of the Agenda – ‘Water’.

The results of both methods were compared to give more robustness to the selection and hierarchy of the environmental indicators associated with the chosen thematic axis (water). The main contribution of the research is a multicriteria methodological approach for monitoring and evaluating the efforts and results of all thematic axes of the PUC-Rio Environmental Agenda. Moreover, we believe that this methodological approach can be replicated in others HEIs aiming to select and hierarchy their campus sustainability indicators.

2. Theoretical background
In recent years, it was highlighted the use of indicators to assess campus sustainability in HEIs [1]. The criteria for selecting and hierarchizing alternative indicators can be: (i) eliminatory; and (ii) classificatory (to classify and hierarchize indicators in a final ranking).

The literature review showed that the MCDM methods are used in several areas of knowledge to resolve decision problems. In the field of sustainability assessment, they are largely employed in function of their flexibility, multidimensionality, and possibility of facilitating dialogue between decision-makers and experts involved. Nevertheless, we did not identify works about the application of MCDM methods to establish campus sustainability indicators for monitoring and evaluating HEIs’ Sustainability Agendas. Based on this evidence and with an attempt to bridge existing HEIs’ sustainability assessment frameworks with a multicriteria methodological approach, this article is focused on the application of two MCDM methods for selecting and hierarchizing campus sustainability indicators of an HEI. They are the Analytical Hierarchy Process – AHP and a hybrid method, namely AHP-PROMETHEE.

The method AHP was created by Thomas L. Saaty and allows to measure the qualitative and the quantitative aspects of a decision problem since the judgments are based on the evaluator's preference. To resolve a problem with support of this method, the decision-maker must perform a decomposition of the problem in the following steps [7]: (i) to define the problem and the objective of the application; (ii) to establish the hierarchical structure (objective, criteria; alternatives); (iii) to make pairwise comparisons of criteria and alternatives by subjective judgments, using the fundamental scale proposed by Saaty [7]; (iv) verify if the Consistency Ratio (RC) of the judgments is less than 10% [8].

The application of PROMETHEE encompasses the following steps [8]: (i) to elaborate the matrix of performance evaluation of the alternatives in the light of each criterion; (ii) to establish a preference function for each criterion; (iii) to calculate the degree of outranking; and finally (iv) to calculate the
positive and the negative flow. Nowadays, there are several versions of this method. Among them, the PROMETHEE I establishes a relation of partial outranking and the PROMETHEE II establishes a complete order following a decreasing flow [8]. For this work, we selected two MCDM methods – AHP [7] and a hybrid AHP-PROMETHEE [9].

3. Methodology

The research methodology comprised: (i) a systematic search performed on articles that were published between January 1997 and December 2017 about the central research themes and content analysis to select the most relevant works; (ii) selection and application of two MCDM methods – AHP and AHP-PROMETHEE, combined with the logical framework tool and the quantitative matrix for classifying and selecting indicators; (iii) proposition of indicators and metrics to monitor and evaluate efforts and results of the PUC-Rio Environmental Agenda, focusing in one of its thematic axes (‘Water’).

4. Application of MCDM methods for selecting and hierarchizing indicators for the PUC-Rio Environmental Agenda

Due to space limitations, we focused the application of MCDM methods on the thematic axis ‘Water’ of the PUC-Rio Environmental Agenda.

The indicators for monitoring and evaluating efforts and results related to this thematic axis are here considered as alternative indicators (A1 to A7): (i) total consumption of water by source (A1); (ii) water resources significantly affected by water consumption (A2); (iii) amount of water recycled and reused (A3); (iv) total water discharge by quality and destination (A4); (v) identification, dimension, a statute of protection and value for biodiversity of water resources and their respective habitats, significantly affected by water discharges and surface runoff (A5); (vi) amount of water from precipitation, considering possible climatic events resulting from climatic changes (A6); (vii) research on water resources management and effluent quality, as well as a search of technological solutions to the reuse of water resources in the Campus, to abstraction, to storage and use of water from precipitation (A7).

4.1. Criteria for classification of indicators

The choice of criteria to evaluate the alternative indicators was based on [6] and also on the Recommendation 2003/2253/EC.

The final list of criteria includes: (i) representativeness (C1) shows whether the indicator represents the directives of the Agenda; (ii) continuity (C2) establishes that indicators should be defined on the basis of similar criteria and in period or units of time comparable; (iii) traceability (C3) shows whether indicators can be traceable; (iv) temporality (C4) indicates the ability of the indicator to be regularly updated to take corrective measures if necessary; (v) comparability (C5) shows the capacity of the indicator to allow comparisons and must point out the changes in environmental performance over a given period; (vi) clarity and simplicity (C6) establishes that the indicator should be understandable and clear; (vii) equilibrium (C7) is concerned with the ability of the indicator to differentiate areas with good and poor performance with greater proximity.

4.2. Application of MCDM methods

The proposed methodological approach encompasses two stages. In the first stage, the AHP is used to calculate the weights of the criteria in which the hierarchical analytical structure was built. Secondly, the pairwise comparison of criteria is done using the fundamental scale proposed by Saaty [7]. Then, the matrices are normalized, and finally, the RC is calculated to accept or not the judgments. In the second stage, the final ranking of alternative indicators is achieved by pairwise comparison of alternative indicators; calculation of the consistency ratio, and matrix normalization.

On the other hand, the PROMETHEE method is also used to generate a ranking, being the first step the performance matrix of the alternative indicators in relation to each criterion. After the function
TYPE I (Usual Criteria) is chosen for all criteria, in which each criterion is identified as a benefit, the objective is to get the maximum possible value. Then, the degree of outranking is calculated. Finally, the flows and the final weights of alternative indicators can be calculated by PROMETHEE II, according to [8].

5. Results
The results of the application of both methods were compared to provide greater robustness in the choice of alternative indicators associated with thematic axis ‘Water’ of the Environmental Agenda of PUC-Rio (Table 1).

| MCDM method         | Indicators associated with thematic axis ‘Water’ of the Environmental Agenda of PUC-Rio |
|---------------------|----------------------------------------------------------------------------------------|
|                     | A1 | A2 | A3 | A4 | A5 | A6 | A7 |
| AHP                 | 2  | 1  | 3  | 4  | 5  | 6  | 7  |
| AHP-PROMETHEE       | 2  | 1  | 4  | 5  | 6  | 3  | 7  |

6. Final remarks
This work presented an application of AHP [7] and AHP-PROMETHEE [9] methods to classify and select alternative indicators for monitoring and evaluating efforts and results of the PUC-Rio Environmental Agenda.

From the results shown in Table 1, we could not distinguish which method is the best to classify the alternative indicators (A1 to A7). However, the application of both methods showed that the AHP is simple but very demanding because the decision-maker has to judge all alternatives according to his (her) preferences avoiding any inconsistency. On the other hand, the AHP method contributes to the robustness of the application of the hybrid AHP-PROMETHEE method by eliminating the subjectivity in determining criteria weights. For further research, we suggest combining the hybrid AHP-PROMETHEE with Fuzzy Logic to overcome the uncertainty, ambiguity, and complexity inherent to the selection of environmental indicators for HEIs. Finally, we believe that this methodological approach can be replicated in others HEIs aiming to select and hierarchy their campus sustainability indicators.

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