USE OF DOUBLE WEIGHTING TO COMPENSATE FOR DATA VARIATION IN A MULTICRITERIA SUSTAINABILITY EVALUATION

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1. Introduction

Assigning weights to the different indicators is one of the important steps in a multicriteria sustainability evaluation. Weights represent the indicator importance preferences of the decision makers when comparing alternatives in terms of their sustainability score; however, because of the plurality of preferences, no single set of weights is truly appropriate. Moreover, assigning weights directly without regard to the internal data variation and correlations of the indicators could result in double counting, magnifying of the effect of indicator(s) due to overlap in the data. If weights should reflect the importance of indicators, such a phenomenon should be avoided [1] as this could introduce bias to the analysis, affecting the sustainability score of the alternatives and the subsequent stakeholder decisions. In this paper, to be sensitive to the data structure, a double weighting (DW) scheme is proposed for the multicriteria sustainability evaluation by combining the weight representing the desired indicator importance and the other weight to account for the contribution of an indicator to the data variation.

2. The concept of double weighting

Aggregating indicators with a high degree of correlation, even if, i.e., equal weighting is used, results in data overlap [1]. Essentially, therefore, correction factors for data overlap need to be applied when aggregating indicators. In this vein, a double weighting scheme, such as proposed in Eq. 1, is of practical value. In Eq. 1, w_i represents the normalized weight of an indicator over n indicators (i = 1, 2, …, n), which is a combination of w_{ai}, representing the importance and w_{bi} – the 'weight' accounting for data overlap. Additionally, $\sum w_i = 1$.

$$w_i = \frac{w_{ai} w_{bi}}{\sum_{i=1}^{n} w_{ai} w_{bi}} \quad \text{Eq. 1}$$

2.1. Importance Weighting (w_{ai})

Weights representing the relative importance of indicators are often applied to better reflect policy priorities [1]. There are a number of ways weights can be assigned, e.g., by participatory approaches such as budget allocation process and the analytic hierarchy process (see e.g., [1] for other weighting techniques). Weighting in terms of the relative importance of indicators, however, is still heavily debated partly due to the multiplicity of weighting techniques and the due to the disagreements between stakeholders on priority preferences.

2.2. Weights for data overlap (w_{bi})

Weights accounting data overlap are generally obtained by statistical models, e.g., principal component analysis (PCA) and factor analysis (FA), among others. Accordingly, the weights from PCA and FA intervene to correct for overlapping information between correlated indicators [1]. For this reason, this paper focused on using PCA as an example to obtain w_{bi}. PCA groups together individual indicators which are collinear and with the highest association to a principal component [1]. The method from [1] to obtain w_{bi} from PCA is adopted.

3. Demonstration Study

The consequence of using DWs is illustrated by using the multicriteria sustainability evaluation of concrete materials as an example. The sustainability scores of 6 concrete mixes of similar compressive strength (Section 3.1) were compared based on 10 indicators (Section 3.2). Additionally, two cases relevant to data structure were explored: Case 1, to represent a condition wherein all indicators uniformly contribute to the data variation and, Case 2, to represent the condition wherein indicators contribute to the data variation unequally.

3.1. Concrete Mix Data

Table 1 contains the mix proportion of the 6 mixes with the coefficient of variation of fc' equal to 7.06%.

Table 1 Mix proportions

Mix	Proportion (kg/m^3)						fc'
	W	C	FA	S	NA	RA	(MPa)
S1	171	342	0	746	1015	0	43.5
S2	135	225	225	659	1067	0	46.9
S3	135	225	225	659	533	478	47.5
S4	135	225	225	659	0	957	41.3
S5	135	180	180	721	1095	0	40.4
S6	165	275	275	590	0	856	39.7

3.2 Indicators

The indicators used for evaluating the sustainability scores are listed in Table 2. Two orderings of indicators were used to simulate the differences in preference based on the perspectives of academics (Acad) and material engineers (Mat) taken [2]. The weights w_{ai} based on these orderings were then obtained by randomly sampling 1000 sets of weight to reduce bias in assigning numerical values. For the calculation of the indicator's individual value, the reader is referred to [3].

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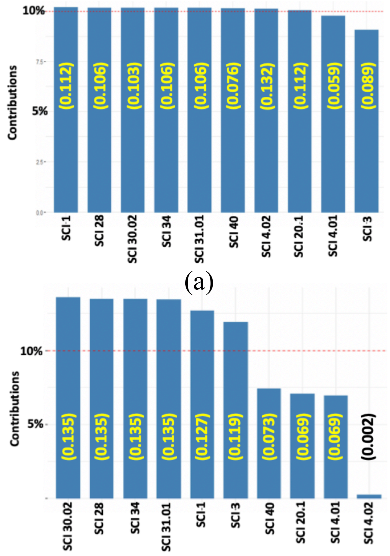

Figure 1 Contribution of indicators to the total variance (a) Cases 1 - uniform and (b) Case 2 - unequal.

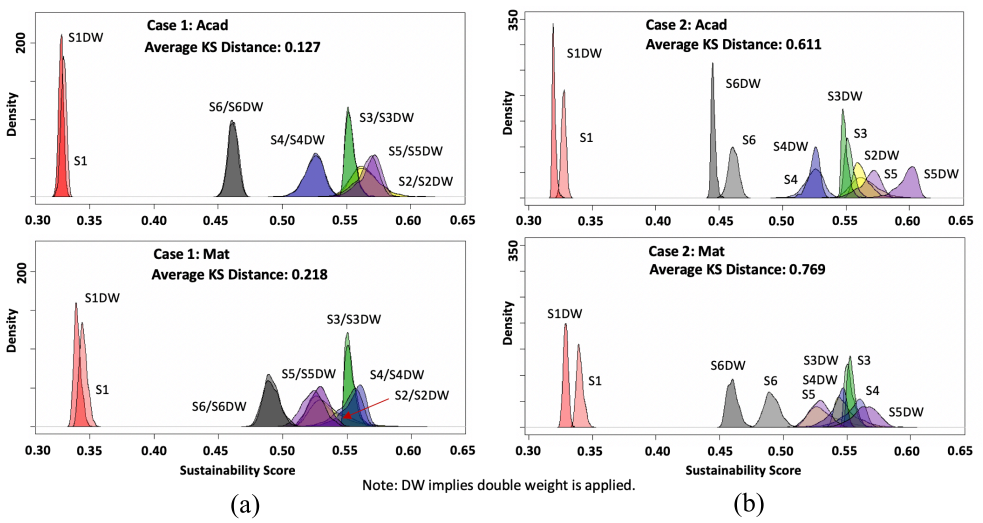

Figure 2 distribution of sustainability scores for (a) Cases 1 and (b) Case 2.

Table 2 Indicators

Indicator		Order	
Symbol	Name	Acad	Mat
SCI 1	Primary energy consumption	7	4
SCI 3	Water consumption	9	6
SCI 4.01	Pre-consumer recycled & waste material	8	5
SCI 4.02	Post-consumer recycled & waster material	6	3
SCI 20.1	Air Permeability	1	1
SCI 28	Global warming potential	3	8
SCI 30.02	Acidification potential – aquatic	4	9
SCI 31.01	Eutrophication potential – terrestrial	2	7
SCI 34	Human toxicity potential	5	10
SCI 40	Production cost	10	2

3. Results and Discussion

3.1 PCA weights for Cases 1 and 2

Figure 1 shows the difference between Case 1 and 2, which were developed using 3 and 1 principal components from PCA, respectively. In Figure 1a, all indicators almost uniformly contribute to the total variance, while in Figure 1b the indicators contribution are unequal. The indicator weights, w_{bi}, from PCA also are reflected enclosed in parenthesis in both cases. It is clear from Figure 1 that the PCA weights change as the data structure changes. Further, indicators contributing most to the total variance are awarded higher weights than those that are not. This is particularly evident in Case 2 (Figure 1b).

3.2 Effect of Double Weighting

DWs were obtained by multiplying the randomly sampled 1000 sets of weights based on importance by the PCA weights and normalized as in Eq. 1. DWs were then applied to the indicators that were aggregated linearly as the sustainability scores.

Applying DWs for Case 1 (Figure 2a) barely affect the distribution of the sustainability scores for both Acads and Mat. This is supported by the small average Kolmogorov-Smirnov (KS) distance in both Acad and Mat (Figure 2a). In other words, when the indicators uniformly contribute to the total variance, there is no immediate need to compensate for the data structure. The sustainability scores of the mixes, in this case, is governed only by the importance order.

When DWs are applied to Case 2 (Figure 2b), significant changes in the shape and spread on the distribution of the sustainability scores are observed. For some mixes in Case 2, the distribution shift substantially, i.e., S6 to S6DW in Figure 2b for Acad and Mat. This is further supported by a higher average KS distance in both Acad and Mat in Figure 2b than in Case 1. For Case 2, therefore, the sustainability scores are jointly governed by the effect of both importance and the application of PCA weights to compensate for data overlap.

4. Conclusions

The use of double weighting to compensate for the data structure in a multicriteria evaluation is beneficial for situations when high correlations between indicators cause data overlap, affecting the resulting sustainability score. It has been shown, however, that the effect of double weighting is prevalent only when the indicators have uneven contributions to the total variance. Therefore, in such cases, applying double weighting for sustainability evaluation should be considered.

References

[1] OECD, "Handbook on Constructing Composite Indicators – Methodology and user guide," European Commission – JRC, 2008.

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