

A Fuzzy Multiplicative Performance Indicator to Measure Circular Economy Efficiency

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Abstract

In a world where the linear economy has already proven its limits. Sustainable development through circular economy becomes a necessity more than a choice. To verify the adequacy between a sustainable development objective and the related management of operations, a variety of performance indicators exist in the literature and an overall is required to ease comparisons. Here we use an extended fuzzy weighted product to avoid overvaluation of an indicator over the others. To handle qualitative aspects, fuzzy logic is used to shorten the gap between humans' perception and machine language. These qualitative features require various evaluators to reduce bias. Thus, a coherence measure is adapted.

Keywords- Circular economy (CE), Multi-criteria decision making (MCDM), Fuzzy consensus, Fuzzy weighted product.

1. Introduction

Human impacts on earth have become so obvious since the Industrial Revolution that some scientists are talking about a new geological era called Anthropocene (Ellis, 2018). Facing the climate urgency, humanity is forced to implement sustainable practices. However, the economic models used are based on consumption in a linear pattern; which consists of producing consumer goods from raw materials that will be discarded at the end of their life cycle; this model of thought including the entire supply chain and the related operations management, has to be replaced by a circular economy scheme. Unfortunately, the multiplicity of definitions leads us to irreconcilable practices. Section 2 will be devoted to clarify definitions.

To make sure that the management of operations aligns with a sustainable perspective. Adequate measures need to be used. A review of 1,803 measurement scales from 230 published articles was proposed in (Roth et al., 2008). However, what to measure? And how measuring it? According to (EASAC, 2016) more than 300 Performance Indicators (PI) of circular economy exist. Furthermore, trying to measure the overall performance, the economic aspect is carving the lion's share, which calls into question the whole process. Here, it is proposed in Section 3, a multiplicative aggregation to avoid the dominance of one aspect over the others.

These performance indicators can be classified into two broad categories, objective and subjective. While the former reflects a measure taken. The latter depends heavily on the appreciation of the people implementing them. It is for this reason that the process includes several persons, in order to minimize the bias of judgments. Section 4 includes an adapted consensus-building process.

The expression of these judgments is clearly more suitable using linguistic variables than with numbers. Fuzzy logic, in addition to facilitating the understanding of human language, can incorporate both qualitative and quantitative data.

In the sequel. A consensual approach based on fuzzy logic to measure the overall performance of CE is proposed. Thus, in section 2, we review some close definitions and approaches in addition to our perspective to CE. Section 3 contains the extended fuzzy weighted multiplication and the required fuzzy logic background. Section 4 presents the adapted consensus measure. Section 5 portrays an illustrative example, while Section 6 concludes this paper.

2. Definitions

Circular Economy (CE) receives unprecedented growing attention. However, with more than 114 definitions (Kirchherr et al., 2017) and a plethora of sound alike words; even for initiated persons; such as sustainability (Fuller, 2010), sustainable development (Giddings et al., 2002), bio and green economy (Ferreira Gregorio et al., 2018). Clarification is needed.

Wanting to be exhaustive, authors tend to develop long definitions, which are hardly memorized. Here, a simple one is retained where the details explained in others will result “one, where the resources coming into the economy are not allowed to become waste or lose their value” (Benton et al., 2017). It can be inferred from this definition that:

- In contrast to authors who believe that, the CE does not require closed loop (Howard et al., 2019). The abolition of waste, requires its reuse and thus to close the loop.
- Furthermore, the prohibition of degradation between each reuse, invokes not only cycling, but also upcycling. Obliging stakeholders to match the technical and the biological cycles (Jørgensen and Pedersen, 2018). A circularity metric taking into consideration upcycling was introduced in (Figge et al., 2018).

This distinction between upcycling and recycling challenges several things. Let us consider soft drinks sold in plastic bottles as an example. The latter; plastic bottles; are only recyclable in "downcycling". Despite all the promises made, it seems that we are always far from the count, and especially late. Advertisements advocating a lighter weight compared to the glass bottle, prompted the consumer to adopt what manufacturers want. Note that glass bottles are reusable and require manufacturers to manage the return chain of empty bottles. This calls into question our will, citizens of the world, to change our habits. As well as the willingness of the media and the competent authorities to regulate the messages conveyed. The mission is all the more difficult in the presence of climate-septic governments.

Further discussion clarifying the distinction between Green Economy, Bio Economy and CE could be found in (D’Amato et al., 2017, 2019; Ferreira Gregorio et al., 2018). And between Green Supply Chain Management, Sustainable Supply Chain Management, Environmental Supply Chain Management and Closed Loop Supply Chains (Farooque et al., 2019).

What to measure is all the more debatable. A series of national (Geng et al., 2012, 2013) regional (Avdiushchenko and Zajac, 2019; Smol et al., 2017; Tantau et al., 2018) and industry based measures (Molina-Sánchez et al., 2018) were proposed. It is true that national or regional policy and related indicators could be seen as a step in the right way. However, are they enough when

Supply Chains are involving several countries and regions? To avoid any emissions due to transportation and logistics, it seems that the only true CE can only be local.

In order to achieve the CE, two approaches exist in the literature. The Rs approach and the ReSOLVE approach. While ReSOLVE contains (Regenerate, Share, Optimize, Loop, Virtualize and Exchange) (Lopes de Sousa Jabbour et al., 2019). Various Rs frameworks exist in the literature, varying from 3Rs (Xuan et al., 2011), 4Rs (Hu et al., 2011), 6Rs (Sihvonen and Ritola, 2015) and even 9Rs (Potting et al., 2017). The last includes (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover).

3. Performance Indicators

In the 3Rs approach used in Geng et al. (2012), the authors maintained that the Chinese CE indicators overvalued reuse and recycle over reduce. Thus, how to formulate an overall performance indicator while avoiding the predominance of one aspect over the rest?

Mathematically speaking, the Weighted Average Mean (WAM) is frequently used due its simplicity. However, its compensatory nature is not desirable in this context. This is all the more alarming when strong economic results mask poor ecological performance. The Weighted Product Mean (WPM) on the other side imposes a simultaneous considerations of all entry elements. However, if one of them is dysfunctional, it does not mean that the whole system is dysfunctional systematically. In order to include all aspects, while avoiding the aforementioned problems, we will adapt the formula proposed in El Alaoui and Ben-Azza (2017b):

$$PI_O = \frac{\prod_{i=1}^n (PI_i + w_i)^{1/n} - \prod_{i=1}^n w_i^{1/n}}{\prod_{i=1}^n (1 + w_i)^{1/n} - \prod_{i=1}^n w_i^{1/n}} \quad (1)$$

where w_i represents the weight of the i^{th} PI: PI_i . The weights are inversely proportional to PI's importance. n the number of PIs. And PI_O the overall performance.

PIs could be divided into two main categories, quantitative ones and qualitative ones (El Alaoui and Ben-Azza, 2017a). With regard to quantitative indicators, the difficulty lies mainly in the normalization step. Since it requires merging values with different units. In the following, the data is considered to be normalized in the unity interval [0, 1].

Qualitative indicators are more difficult to capture. Fuzzy logic (Zadeh, 1965), seems to be the perfect tool to handle such situations, since it permits capturing human judgements and handling both quantitative and qualitative data. For computational reasons, the frequently used notation is based on trapezoidal Fuzzy Numbers FNs denoted by 4-tuple $\tilde{A}(a^1, a^2, a^3, a^4)$ (El Alaoui, 2018). If $a^2 = a^3$ then the trapezoidal FN becomes a triangular FN. If $a^1 = a^2 = a^3 = a^4$ then we have a classical crisp number. Thus, crisp numbers are considered as a special case.

4. Consensus

The qualitative assessments depend mainly on the evaluator. Thus, the process involves several Decision Makers (DM) in order to reduce bias. Since full and unanimous consensus is rarely achieved, a fuzzy soft measure would be more appropriate (Herrera-Viedma et al., 2014). However, first what is the consensus? It has various meaning and utilization (Briggs, 2013) varying from philosophy and mathematics (Lehrer and Wagner, 1981) to design (Day and Parnell, 2003) and CE

(Prieto-Sandoval et al., 2018), or even as a measure of sustainability (Bender and Simonovic, 1997), making consensus on consensus barely achievable (Cook et al., 2016). In the fuzzy context, it is usually linked to similarity measures (López-Ortega and Castro-Espinoza, 2019). It should be noted that by consensus, it is suggested here, the aggregation of several opinions into the one that may fit all participants (El Alaoui et al., 2019a). In that sense, we will use the improved version of Lee’s algorithm (Lee, 2002) proposed in El Alaoui et al. (2019b) aiming to minimize weighted incoherencies:

$$\min \sum_{k=1}^K w_k^t * (c - S(\tilde{R}_k, \tilde{R})), \quad (2)$$

where w_k are the decisions weights, verifying $w_k \geq 0$ and $\sum_{k=1}^K w_k = 1$. $t \in \mathbb{N}^* \setminus \{1\}$, $c \in [1, +\infty[$, \tilde{R}_k expressed opinions, \tilde{R} the consensus to be achieved, K the number of DMs involved and $S(\tilde{R}_k, \tilde{R})$ the similarity than can computed by:

$$S(\tilde{R}_k, \tilde{R}) = 1 - \frac{1}{4} \left(\sum_{q=1}^4 (|r_k^q - r^q|)^p \right)^{\frac{1}{p}} \quad (3)$$

5. Illustrative Example

This example proposed (Zhao et al., 2017), combining quantitative and qualitative criteria. 4 DMs are to evaluate 6 alternatives in accordance to 9 subjective indicators. In addition, the DMs have to estimate all 26 indicators weights. To ease comparison, we adopt the same linguistic variables for weights and alternatives assessments (Table 1).

Table 1. Linguistic variables for weights and alternatives assessments

Linguistic variable	Fuzzy number	Linguistic variable	Fuzzy number
Very Poor (VP)	(0, 0, 0.2)	Very Low (VL)	(0, 0, 0.3)
Poor (P)	(0, 0.2, 0.4)	Low (L)	(0, 0.3, 0.5)
Fair (F)	(0.3, 0.5, 0.7)	Medium (M)	(0.2, 0.5, 0.8)
Good (G)	(0.6, 0.8, 1)	High (H)	(0.5, 0.7, 1)
Very Good (VG)	(0.8, 1, 1)	Very High (VH)	(0.7, 1, 1)

The evaluations of indicators weights by the 4 DMs in addition to their nature (quantitative/qualitative) (Max/min) and the consensual assessments are given in Table 2.

To avoid further discussions due to normalization, we use the normalized measures presented in Zhao et al. (2017) (Table 3).

Table 4 contains the individual assessments according to each subjective indicator

While the weights of the performance indicators to be minimized will remain as is, the others will be reversed to be adapted to the formula used (Eq. 1).

The Table 5 resumes the consensual evaluations (Eq. 2-3) for the 6 alternatives in accordance to the subjective indicators, in addition to the overall evaluations (Eq. 1)

Table 2. Indicators individual evaluations, nature and collective assessments

Indicator	Quantitative/qualitative	Max/min	DM1	DM2	DM3	DM4	Aggregated assessment
I1	Quantitative	max	High	High	Medium	Medium	(0.35, 0.6, 0.9)
I2	Quantitative	max	High	Medium	High	High	(0.430, 0.653, 0.953)
I3	Quantitative	max	Medium	Medium	High	Medium	(0.270, 0.547, 0.847)
I4	Quantitative	max	Low	Low	Low	V Low	(0, 0.229, 0.452)
I5	qualitative	max	Medium	High	Medium	Medium	(0.270, 0.547, 0.847)
I6	Quantitative	Min	High	High	High	Medium	(0.430, 0.653, 0.953)
I7	Quantitative	Min	Medium	High	High	Medium	(0.35, 0.6, 0.9)
I8	Quantitative	max	High	High	High	High	(0.5, 0.7, 1)
I9	Quantitative	max	Medium	Medium	High	High	(0.35, 0.6, 0.9)
I10	Quantitative	max	High	High	High	High	(0.5, 0.7, 1)
I11	qualitative	max	Medium	Medium	High	High	(0.35, 0.6, 0.9)
I12	Quantitative	Min	High	High	High	Medium	(0.430, 0.653, 0.953)
I13	Quantitative	Min	High	Medium	High	Medium	(0.35, 0.6, 0.9)
I14	Quantitative	Min	High	High	High	Medium	(0.430, 0.653, 0.953)
I15	Quantitative	max	High	High	High	High	(0.5, 0.7, 1)
I16	Quantitative	max	High	High	High	High	(0.5, 0.7, 1)
I17	Quantitative	max	High	High	High	High	(0.5, 0.7, 1)
I18	qualitative	max	High	High	High	High	(0.5, 0.7, 1)
I19	qualitative	max	Medium	Medium	High	Medium	(0.270, 0.547, 0.847)
I20	qualitative	max	Medium	High	High	Medium	(0.35, 0.6, 0.9)
I21	Quantitative	max	Medium	Medium	High	High	(0.35, 0.6, 0.9)
I22	qualitative	max	Medium	Medium	High	High	(0.35, 0.6, 0.9)
I23	qualitative	max	Medium	High	Medium	Medium	(0.270, 0.547, 0.847)
I24	qualitative	max	Medium	High	Medium	Medium	(0.270, 0.547, 0.847)
I25	qualitative	max	Medium	High	High	Medium	(0.35, 0.6, 0.9)
I26	Quantitative	max	Medium	Medium	Medium	High	(0.270, 0.547, 0.847)

Table 3. Normalized quantitative assessments

Indicator	A1	A2	A3	A4	A5	A6
I1	0.15949	0.07407	0.24958	0.24394	0.21496	0.05797
I2	0.21742	0.21212	0.19697	0.17424	0.18939	0.00985
I3	0.20549	0.24631	0.19704	0.21675	0.09923	0.03519
I4	0.18479	0.15529	0.13976	0.28061	0.14162	0.09793
I6	0.12228	0.20380	0.12738	0.24456	0.14912	0.15285
I7	0.14980	0.17174	0.33371	0.15898	0.15131	0.03446
I8	0.18292	0.16781	0.18909	0.17984	0.13647	0.14387
I9	0.16393	0.11241	0.07728	0.19672	0.09836	0.35129
I10	0.17978	0.17127	0.18945	0.16180	0.13145	0.16625
I12	0.19064	0.19064	0.11255	0.31139	0.12292	0.07186
I13	0.17669	0.22087	0.29449	0.17669	0.12621	0.00505
I14	0.17707	0.27826	0.14428	0.16232	0.19478	0.04328
I15	0.17584	0.17407	0.17762	0.17052	0.16874	0.13321
I16	0.17331	0.17331	0.16464	0.16811	0.15598	0.16464
I17	0.17422	0.16899	0.17422	0.17247	0.17073	0.13937
I21	0.19280	0.18123	0.17138	0.12725	0.14996	0.17738
I26	0.36611	0.34728	0.06485	0.12343	0.07950	0.01883

Table 4. Individual assessments in accordance to the subjective indicators

DMs	Alternative	I5	I11	I18	I19	I20	I22	I23	I24	I25
DM1	A1	Good	Good	Good	Good	Good	Good	Good	Good	Good
	A2	Fair	Good	Fair	Good	Good	Good	Good	Fair	Good
	A3	Good	Fair	VG	Fair	Fair	Good	Fair	Fair	Fair
	A4	VG	Fair	Good	Fair	Fair	Good	Fair	Fair	Good
	A5	Good	Good	Poor	Poor	Good	Fair	Fair	Fair	Fair
	A6	Fair	Poor	Fair	Fair	VP	Fair	Fair	Fair	Poor
DM2	A1	VG	Good	Good	Good	Good	Good	Good	Good	Good
	A2	Good	Fair	Fair	Fair	VG	Good	Fair	Fair	Fair
	A3	Good	Fair	Good	Good	Fair	Fair	Good	Fair	Fair
	A4	VG	Fair	Fair	Good	Fair	Fair	Fair	Fair	Good
	A5	Good	Good	VP	Poor	Fair	Poor	Fair	Fair	Fair
	A6	Fair	Poor	Poor	Fair	Poor	Poor	Poor	Poor	Fair
DM3	A1	Good	Good	Good	VG	Good	Good	Good	Good	Good
	A2	Good	Good	Fair	Fair	Good	Fair	Fair	Fair	Good
	A3	Good	Fair	Good	Fair	Poor	Fair	Fair	Fair	Fair
	A4	VG	Fair	Fair	Good	Good	Good	Good	Fair	Fair
	A5	Good	Good	VP	Fair	Good	Good	Good	Fair	Fair
	A6	Fair	Poor	Poor	Poor	Poor	Poor	Fair	Fair	Poor
DM4	A1	Good	Fair	Good	Good	Good	Good	Good	Good	VG
	A2	Good	Fair	Fair	Fair	Good	Fair	Fair	Fair	Good
	A3	Good	Fair	Good	Good	Fair	Fair	Fair	Fair	Fair
	A4	Good	Fair	Fair	Good	Fair	Good	Fair	Fair	Fair
	A5	Good	Good	VP	Poor	Fair	Fair	Fair	Fair	Fair
	A6	Fair	Fair	Poor	Poor	Poor	Poor	Fair	Fair	Fair

Three main approach exist to rank FN, the most accurate in this situation is by using a ranking function mapping the FN to the real line. While several ranking functions exist in the literature (El Alaoui et al., 2018; Wu and Mendel, 2009), we adopt the one used in Zhao et al. (2017) for triangular FN $\tilde{A}(a^1, a^2, a^3)$ to ease comparison: $\mathcal{R}(\tilde{A}) = (a^1 + 4 * a^2 + a^3)/6$.

It is true that the final ranking (Table 5) remains the same as in Zhao et al. (2017). However, the gap between the final scores changes mainly due to several reasons:

The opinions aggregation in Zhao et al. (2017) consist of a simple WAM, while the coherence measure proposed tends to be closer to the consensus.

In Zhao et al. (2017) the authors proceed to early defuzzification, which results on information loss. While in the proposed it is realized till the end for the final ranking. This is possible, thanks to the aggregation formula used that permits simultaneous handling of both fuzzy and crisp data, in addition, to avoid aspiration by extrema values.

Table 5. Consensual subjective evaluations, overall fuzzy, defuzzified evaluations, and final rank

Indicators	A1	A2	A3	A4	A5	A6
I5	(0.648, 0.848, 1)	(0.533, 0.733, 0.933)	(0.6, 0.8, 1)	(0.752, 0.952, 1)	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)
I11	(0.533, 0.73, 0.93)	(0.45, 0.65, 0.85)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.6, 0.8, 1)	(0.067, 0.267, 0.467)
I18	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0.648, 0.848, 1)	(0.367, 0.567, 0.767)	(0, 0.048, 0.248)	(0.067, 0.267, 0.467)
I19	(0.648, 0.848, 1)	(0.367, 0.567, 0.767)	(0.45, 0.65, 0.85)	(0.533, 0.733, 0.933)	(0.067, 0.267, 0.467)	(0.15, 0.35, 0.55)
I20	(0.6, 0.8, 1)	(0.648, 0.848, 1)	(0.233, 0.433, 0.633)	(0.367, 0.567, 0.767)	(0.45, 0.65, 0.85)	(0, 0.152, 0.352)
I22	(0.6, 0.8, 1)	(0.45, 0.65, 0.85)	(0.367, 0.567, 0.767)	(0.533, 0.73, 0.93)	(0.15, 0.35, 0.55)	(0.067, 0.267, 0.467)
I23	(0.6, 0.8, 1)	(0.367, 0.567, 0.767)	(0.367, 0.567, 0.767)	(0.367, 0.567, 0.767)	(0.367, 0.567, 0.767)	(0.233, 0.433, 0.633)
I24	(0.6, 0.8, 1)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.233, 0.433, 0.633)
I25	(0.648, 0.848, 1)	(0.533, 0.733, 0.933)	(0.3, 0.5, 0.7)	(0.45, 0.65, 0.85)	(0.3, 0.5, 0.7)	(0.15, 0.35, 0.55)
Overall evaluation	(0.196, 0.476, 1)	(0.183, 0.461, 0.981)	(0.179, 0.454, 0.972)	(0.183, 0.461, 0.980)	(0.083, 0.434, 0.974)	(0.143, 0.411, 0.915)
Defuzzified evaluation	0.5369	0.5216	0.5147	0.5214	0.4743	0.4704
Rank	1	2	4	3	5	6

6. Conclusion

This paper presents a fuzzy mathematical methodology to build an overall PI for CE. While fuzzy logic is used as a powerful tool that permits handling quantitative and qualitative quantities. The last, qualitative aspects need numerous decision-makers to reduce bias. Hence, a fuzzy coherence measure was adapted.

CE as a tool to reach sustainability requires simultaneous consideration for different aspects. To do so, an extended fuzzy weighted multiplication was proposed to avoid the overvaluation and drawbacks of classical operators. The merits of the proposed method were proven in an illustrative example.

Conflict of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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