Evaluating sufficiency practices for sustainable competitiveness using grey-AHP analysis

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Abstract. The concept of sufficiency has gained increased attention as companies seek sustainable pathways beyond efficiency and recycling within the Circular Economy (CE).This study explores the role of sufficiency practices in fostering sustainable competitiveness at the company level. Utilising the Grey Analytic Hierarchy Process (Grey-AHP), we assess and prioritise sufficiency practices that contribute to economic and market capability, resource capability, social ability and technological ability. A sample of 37 companies implementing CE principles was analysed to identify key sufficiency practices and their impact on competitiveness dimensions. The findings highlight that practices, such as reducing material use and extending product longevity offer significant competitive advantages. Furthermore, the application of multi-criteria decision-making enhances the decision-making process, offering companies a systematic approach to evaluate and prioritize sufficiency practices based on diverse sustainability dimensions.

Keywords: grey AHP, sufficiency, Circular Economy.

1 Introduction

The Circular Economy (CE) has been described as a transformative model that seeks to decouple economic growth from resource consumption and environmental degradation. One of the key implementation approaches within CE is sufficiency, which is predicated on reducing overall consumption and prioritising long-lasting, resource-efficient business practices. The concept of sufficiency, in this sense, is predicated on the notion that it is possible to achieve higher levels of well-being through a reduction in resource consumption, by prioritising needs over wants, reducing overproduction, and fostering sustainable lifestyles. In this way, sufficiency can be regarded as a fundamental change in both production and consumption patterns. For companies, this necessitates a shift from growth-driven models to strategies that emphasise resource moderation, purposeful production, and value-driven decision-making.

At the company level, sufficiency practices include the reduction of unnecessary production, the extension of product lifespans, the creation of a market for secondary products, the withdrawal of aggressive sales strategies, product planned obsolescence

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etc.. These practices align with broader sustainable development objectives by reducing material throughput and encouraging responsible consumption habits.

The literature identifies three key dimensions of sufficiency [1, 2]. Firstly, market sufficiency, which focuses on customers, product offerings, and fostering markets for second-hand goods. Secondly, production sufficiency pertains to the optimisation of production volumes and the enhancement of repair and maintenance support. Thirdly, social sufficiency relates to workforce well-being. Historically, most studies on sufficiency have been conceptual or based on systematic non-empirical reviews [3]. More recently, empirical work has begun to explore the demand side—focusing on how consumers take personal responsibility and how their values shift towards sufficiency [4]. However, there remains a notable scarcity of empirical research on the company side [5]. The focus of the previous studies on the companies is on the environmental benefits, while the impact on economic performance is marginalised [6]. To the best of our knowledge, no study has yet linked sufficiency with the competitiveness of companies, highlighting the need for further research into the competitive benefits for companies implementing such a strategy.

This study aims to address a research gap relating to the role of sufficiency in building the sustainable competitiveness of companies. This is crucial for three reasons. Firstly, the introduction of sufficiency into companies is subject to considerable barriers that necessitate economic incentivisation. It is, therefore, vital to emphasize the economic benefits of implementing sufficiency, as well as provide a clear definition of the specific areas in which these benefits are realized. Secondly, CE inherently requires sufficiency. It is a fundamental pillar of this transformation because it encourages companies to rethink their production and sales patterns by prioritising smart resource management. Thus, the objectives of the present study are as follows: 1. The identification and classification of sufficiency practices in companies; 2. The establishment of their impact upon the sustainable competitiveness; 3. The establishment of best sufficiency practices responsible for improving the company's competitiveness.

Firstly, a review of the literature was conducted to identify sufficiency practices. Secondly, the impact of these practices on sustainable competitiveness was established using the Grey Analytic Hierarchy Process (AHP) technique. Evaluating sufficiency practices necessitates Multi-Criteria Decision-Making (MCDM) methods, as such practices impact multiple dimensions of business performance. Given the inherent complexity in sufficiency-related decisions, MCDM techniques help to prioritise sufficiency practices based on expert judgment and quantitative data. By employing the Grey-AHP approach, this study introduces a systematic framework for prioritising sufficiency practices, addressing the challenge of vagueness and uncertainty in decision-making related to CE and corporate sustainability. Furthermore, while earlier studies have primarily focused on the environmental benefits, this research empirically investigates its impact on company competitiveness, thus offering a more comprehensive understanding of its economic implications.

The following section of the paper is organised as follows. Section 2 delineates the problem and the framework for the research. The results are then presented in the subsequent section 3.

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2 Research method

Since prioritizing organizational practices requires incorporating and evaluating multiple factors, the process is challenging due to inherent vagueness in the data and subjectivity. To address these limitations, the present study employes the Analytical Hierarchy Process (AHP) method in conjunction with Grey Relational Analysis (GRA). AHP serves as a structured approach to addressing multi-criteria decision-making problems by assigning relative priorities to criteria in relation to a predefined objective [7]. This method enables organizing complex problems into a hierarchical framework, integrating both qualitative and quantitative factors. According to [8], the fundamental steps of the AHP approach are as follows:

Step 1: Constructing the problem's hierarchical structure.

Step 2: Identifying weights of criteria and sub-criteria using pairwise comparisons.

Step 3: Determining alternative pairwise comparisons with regard to each criterion.

Step 4: Specifying each alternative overall score.

The initial step utilises the AHP method and comprises the following phases: (a) identification of essential practices and classification of practices within the competitiveness, (b) conducting pairwise comparisons of sustainable comp. dimensions. To identify the most relevant sufficiency practices, an extensive literature review was conducted, synthesising the findings to determine the most frequently cited sufficiency practices. Subsequently, experts were tasked with categorizing the identified practices under specific dimensions of sustainable competitiveness.

Before identifying the shortlisted influential practices, it is necessary to prioritise the categories of the competitiveness dimensions. The pair-wise comparisons were made for each of the criteria groups (i.e., the sustainable competitiveness dimensions). The classic 9-point scale was utilised for this evaluation. In order to make the result of AHP method basically reasonable, the consistency of judging matrix is tested. Thereinto, Consistency Ratio (CR) is an index that measures the consistency of the judging matrix by comparing its Consistency Index (CI) to a Random Index (RI).

In addition to AHP, this study incorporated Grey Relational Analysis (GRA), following the frameworks proposed by [9], [10]. In the Grey Analytic Hierarchy Process [11], values are still assigned on a scale from 9 to 1, corresponding to five grades: "very satisfactory" [9], "satisfactory" [7], "medium" [5], "unsatisfactory" [3], and "very unsatisfactory" [1]. When establishing the evaluation indicator system and determining the weights of the evaluation indicators, the values of l evaluation indicators can be assigned based on the evaluation indicator B_j. Subsequently, grey clusters are divided into grades as follows: (1) "very satisfactory" (e =1), grey number $\otimes_1 \in [0, 9, \infty)$, (2) "satisfactory" ($e$ =2), grey number $\otimes_1 \in [0, 7, 10)$, (3) "medium" (e=3), grey number $\otimes_1 \in [0, 5, 8)$, (4) "unsatisfactory" (e =4), grey number $\otimes_1 \in [0, 3, 6)$, (5) "very unsatisfactory" (e=5), grey number $\otimes_1 \in [0, 1, 3)$.

For a given evaluation indicator B, a candidate belonging to the lth grey evaluation cluster receives a grey assessment coefficient (X_{ije}). The total grey evaluation (X_{ij}) for indicator B is then the sum of assessments across all clusters. The grey evaluation weight (r_{ije}) of the eth evaluation grey cluster is determined as the ratio of its coefficient to the total evaluation (where e= 1, 2, 3, 4, 5). For indicator B, the grey evaluation

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weight vectors is $r_{ij} = r_{ij1}, r_{ij2}, r_{ij3}, r_{ij4}, r_{ij5}$.The grey evaluation weight matrix shows the relative importance of different criteria in the evaluation process.
The grey assessment weight vector for each grey classification is defined as: $B_i = W_i R_i$. By integrating the assessments of all grey classifications, the overall grey assessment weight vector is obtained: $B = W R$. Grey grades are determined based on the maximum principle. To minimize information loss and prevent distorted judgments, the vector B is considered as a single value, calculated as follows: $S = B C^T$, where C^T represents a vector containing the score values corresponding to the grey evaluation categories. A detailed description of the Grey-AHP method can be found in [8], [12].

The study examined 37 Polish organizations and international companies based in Poland. The companies were mainly from manufacturing (40%), trade (16%), service (10%). The selection criteria required that companies declare (in ESG reports) implementing circular economy principles. After obtaining formal approval, the survey was distributed to selected respondents, who were recognized as experts in sustainability or environmental management and responsible for their company's environ. performance.

3 Results

The identification of sufficiency practices was conducted based upon a literature review (Tab. 1). Their attribution to dimensions of sustainable competitiveness was carried out by experts. The dimensions of compeitiveness, we have adopted following [13], [14].

Table 1. Essential sufficiency practices impact upon sustainable competitiveness

Competitiv.	Sufficiency practices	Designation
Economic Capability EC	No sales incentives	E1
	Premium pricing products	E2
	Selling inconvenience for a better price	E3
	Limitation of deliveries	E4
	Reducing working time	E5
	Reduction of the material use	E6
Market Capability MC	Offering demand reduction services	M1
	Extending product longevity	M2
	Stirring consumers to sustainable choices	M3
	Offering of sharing products	M4
	Second-hand markets	M5
Technological Ability TA	Reducing the volume of production	T1
	Personalized production	T2
	Clustering production proces	T3
	Support for repair	T4
Social Ability SA	Reducing working time	S1
	Managers' commitment to Circular Economy	S2
	Increase in local community employment opportunities	S3
	Sufficiency-oriented project	S4
Resource Capability RC	Reduction of the material use	R1
	Effectiveness of reverse logistics systems	R2
	Use of environmentally friendly raw materials	R3
	Enacting limits to material growth	R4
	Offering local products	R5
	Design for the environment	R6

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The next step involved prioritization of the competitiveness dimensions category. Experts were requested to compare each pair based on 9-point scale [7] (Table 2).

Table 2. Pairwise comparison matrix (competitiveness dimensions)

	EC	MC	TA	SA	RC	AHP weights	Priority
EC	1	1,8	2,06	1,6	2,77	0,2946	1
MC	0,56	1	1,2	1,4	2,1	0,1715	3
TA	0,48	0,83	1	1,3	1,9	0,1429	4
SA	0,62	0,71	0,76	1	1,6	0,1845	2
RC	0,36	0,47	0,52	0,65	1	0,1064	5

The consistency ratio (CR) was found (for RI=1,12) to be 0,0419, which is less than the acceptable threshold of 0,1, indicating that the comparisons were consistent.

Similar steps were taken to prioritise the sufficiency practices within each competitiveness dimension, resulting in the determination of priority weights (Table 3). Normalised global weights were then calculated as the product of the local weight for each practice and the AHP weights of each corresponding competitiveness dimension. Among the practices, T1 (reducing the volume of production) appears to be the most prominent with a high local weight of 0,51 and E6 (reducing the use of materials) with a local weight of 0,45. Other practices with high global weights include E5 (reducing working time) and M2 (extending product life).

Table 3. Local and global weights of competitiveness dimensions and sufficiency

Dimension	Sufficiency practices	Weights for competitiveness dimension	Local weights of practices	Global weights of practices	Global ranking
EC	E1	0,2946	0,13	0,0383	16
	E2		0,09	0,0265	19
	E3		0,25	0,0737	7
	E4		0,11	0,0324	17
	E5		0,30	0,0884	5
	E6		0,45	0,1326	2
MC	M1	0,1715	0,22	0,0378	9
	M2		0,31	0,0532	4
	M3		0,18	0,0309	11
	M4		0,10	0,0172	18
	M5		0,24	0,0412	8
TA	T1	0,1429	0,51	0,0728	1
	T2		0,17	0,0243	12
	T3		0,08	0,0114	20
	T4		0,14	0,0200	15
SA	S1	0,1845	0,21	0,0387	10
	S2		0,18	0,0332	11

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	S3		0,16	0,0295	13
	S4		0,09	0,0166	19
RC	R1	0,1064	0,33	0,0351	3
	R2		0,24	0,0255	8
	R3		0,16	0,0170	13
	R4		0,15	0,0160	14
	R5		0,27	0,0287	6
	R6		0,18	0,0192	11

As discussed in the previous section, five gray grades, corresponding to e=1, 2, 3, 4, 5 were used to accommodate the five clusters. To the evaluating practice E1 (for data see Appendix 2), in this system the grey assessment coefficient belong to the e[th] grey type is: e=1, f_1(9)+ f_1(7)+ f_1(5)+ f_1(6)+…=1+ 0,77+0,55+0,66+…=23,44;
e=2 using f_2(x) =33,66; e=3 using f_3(x) = 23,66; e=4 using f_4(x) = 10; e=5 using f_5(x) =4,5. The total grey assessment coefficient is: X_{11} = 23,44+33,66+23,66+10+1=91,76.
Calculating the Gray Assessment Weight Vector and the Matrix is as follows:
e=1, r_{111}=23,44/91,76=0,25; e=2, r_{112}=33,66/91,76=0,36; e=3, r_{113} =0,25;& e=4, r_{114}=0,10; & e=5, r_{115}=0,01; so, by this way. Thus, the grey evaluation weight matrix R is approximately:

$$R=\begin{bmatrix} 0,25 & 0,36 & 0,25 & 0,10 & 0,01 \\ 0,32 & 0,50 & 0,16 & 0,00 & 0,00 \\ \dots & \dots & \dots & \dots & \dots \end{bmatrix}$$

The grey assessment weight vector for EC dimension is calculated as: B=(0,44; 0,46; 0,24; 0,14; 0,08). Finally, overall assessment score S is determined:
S=$B \ x \ C^T$=(0,44; 0,46; 0,24; 0,14; 0,08) x [9, 7, 5, 3, 1]=8,88 (Table 4).

Table 4. Summary of results of the G-AHP

Comp.	Suf. prac	Weight for comp	Weights of practices	Grey evaluated weighted matrix values					Total grey vector	Grey grad.
EC	E1	0,294	0,13	0,25	0,36	0,25	0,1	0,01	0,44; 0,46; 0,24; 0,14; 0,08	8,88
	E2		0,09	0,32	0,50	0,16	0	0		
	E3		0,25	0,21	0,36	0,31	0,11	0,09		
	E4		0,11	0,08	0,28	0,28	0,28	0,58		
	E5		0,30	0,13	0,31	0,31	0,23	0		
	E6		0,45	0,63	0,36	0	0	0		
MC	M1	0,171	0,22	0,15	0,43	0,26	0,17	0,08	0,25; 0,36; 0,25; 0,14; 0,04	6,48
	M2		0,31	0,21	0,25	0,15	0,09	0		
	M3		0,18	0,33	0,41	0,31	0,2	0,05		
	M4		0,10	0,28	0,37	0,29	0,14	0,03		
	M5		0,24	0,31	0,36	0,26	0,12	0,06		
TA	T1	0,142	0,51	0,53	0,43	0,35	0,18	0,09	0,35; 0,28; 0,21; 0,10; 0,05	6,31
	T2		0,17	0,24	0,19	0,15	0,09	0,05		
	T3		0,08	0,21	0,13	0,09	0,03	0		
	T4		0,14	0,18	0,15	0,06	0	0		

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SA	S1	0,184	0,21	0,19	0,35	0,29	0,13	0,06	0,11;	3,23
	S2		0,18	0,15	0,32	0,26	0,1	0,04	0,19;	
	S3		0,16	0,08	0,17	0,11	0,05	0	0,15;	
	S4		0,09	0,38	0,44	0,3	0	0	0,05; 0,01	
RC	R1	0,106	0,33	0,14	0,32	0,2	0,09	0,09	0,18;	4,49
	R2		0,24	0,15	0,19	0,12	0,06	0,08	0,27;	
	R3		0,16	0,18	0,14	0,14	0,07	0	0,15;	
	R4		0,15	0,12	0,1	0,1	0	0	0,06;	
	R5		0,27	0,09	0,21	0	0	0	0,05	
	R6		0,18	0,17	0,15	0,13	0,03	0,04		

The findings of the study demonstrate that, within the context of EC practices, the reduction of material use (E6) emerges as the most influential practice (local weight: 0,45, grey score: 8,88). This observation signifies that companies prioritise material efficiency with the objective of enhancing cost-effectiveness and optimising resource savings. The practice of reducing the volume of production (T1) (0,51, score: 6,31) also ranks highly, thus confirming that moderation of production is essential for competitiveness. Within MC, the top-ranking practice is the extension of product longevity (M1) (0,22, score: 6,48), which serves to reinforce the idea that durability is a key component of sufficiency. Resource Capability is the lowest-ranked competitiveness dimension (weight: 0,1064), suggesting that while businesses acknowledge resource sufficiency, economic and technological factors take precedence. Enacting limits to material growth (R2) and Use of environmentally friendly materials (R3) are lower in ranking, indicating that while CE models are valued, practical implementation challenges remain.

4 Conclusion

This paper proposes to evaluate sufficiency practices for sustainable competitiveness of companies based on grey clustering theory combined with AHP. We develop a grey hierarchy evaluation model, which verifies the elements of the evaluation matrix using grey numbers and explicit weight functions.

The results underline that reducing material consumption, extending product life and optimising production volumes are among the most effective practices for improving companies' sustainable competitiveness. In addition, market-driven approaches such as extending product longevity and offering demand reduction services are gaining in importance, but require further structural incentives.

By applying the Grey Analytic Hierarchy Process, this research validates the possibility of MCDM techniques in assessing sufficiency practices. Given that these practices influence multiple dimensions of business performance—including economic viability, resource efficiency, and social capabilities—MCDM methods enable a structured and data-driven evaluation of trade-offs. The use of Grey-AHP effectively addresses decision-making uncertainties by integrating expert judgment with prioritization. In particular, it allows for a more nuanced prioritization of sufficiency strategies, overcoming the limitations of small sample sizes and subjective biases. This approach

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provides valuable insights for managers and policy makers by offering a structured approach to prioritising sufficiency strategies that are consistent with long-term economic and environmental goals.

Future research should further refine MCDM applications to sufficiency strategy by incorporating dynamic models that adapt to market changes and evolving regulatory frameworks. In addition, expanding the sample size and industry scope could provide broader insights into the role of sufficiency in firms' competitive advantage.

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