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Measuring Circular Performance: A Composite Index for Organizational Sustainability

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Abstract

The transition to a circular economy requires reliable tools to assess organizational performance. This chapter develops a Circular Performance Index (CPI) that integrates financial, operational, environmental, and social indicators into a single metric. Indicators are normalized and aggregated using multi-criteria methods, with weights derived from the Analytic Hierarchy Process. A case study in the energy equipment manufacturing sector demonstrates CPI's practical application. Robustness is evaluated through sensitivity analysis at both dimension and indicator levels. Results indicate that the CPI remains stable under reasonable perturbations, with explicit procedures for missing data and uncertainty propagation further supporting its reliability. This stability supports its use for benchmarking, and strategic decision-making.

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15.1 Introduction

The circular economy (CE) has become a core paradigm in sustainability policy and corporate strategy, particularly in the European Union (Kirchherr et al., 2017; Oliveira et al., 2021). This prominence arises because CE promotes waste minimization and value retention. Consequently, CE models seek to decouple economic growth from environmental degradation (Russell & Nasr, 2023).

Despite broad conceptual acceptance, organizations struggle to operationalize circular strategies. This difficulty is amplified by the lack of consistent and decision-relevant measures of circular performance. Existing circularity metrics mainly target material flows or environmental impacts (Linder et al., 2017; Luthin et al., 2024). Consequently, financial viability and social implications are frequently overlooked. This fragmentation prevents managers and policymakers from conducting trade-off analyses and setting strategic priorities.

Composite indicators offer a potential solution because they aggregate heterogeneous dimensions into a single interpretable measure (Zambujal-Oliveira & Amaral, 2023; Greco et al., 2019). However, this aggregation introduces methodological challenges. These challenges concern indicator selection, normalization, weighting, and robustness.

This chapter addresses these limitations by proposing a Circular Performance Index (CPI), which captures the multidimensional nature of circular performance. The contribution is threefold. First, the chapter develops a replicable framework for CPI construction. Second, it provides a worked numerical case study illustrating the computation process. Third, it assesses CPI robustness through sensitivity analysis. Therefore, the following research questions are formulated:

RQ1: How can circular performance be defined as a multidimensional concept integrating financial, operational, environmental, and social dimensions, going beyond mainly material- or environment-focused metrics?

RQ2: How applicable and useful is the proposed CPI for real-world organizational decisionmaking, as shown through its application to a medium-sized energy equipment manufacturer implementing circular practices such as recycled materials and product take-back schemes?

15.2 Conceptual Framework

Circular performance is conceptualized as a multidimensional construct encompassing four core dimensions: financial, operational, environmental,

and social performance (Ghisellini et al., 2016; Esposito et al., 2024). These dimensions reflect the economic feasibility of circular initiatives, the efficiency of resource use and processes, the environmental outcomes of circular practices, and their social implications for employees and stakeholders.

Let $D = \{F,O,E,S\}$ denote the set of dimensions. Each dimension $d \in D$ is represented by a set of key performance indicators K_d. Indicators are selected based on relevance to circular economy principles, data availability, and interpretability for decision-makers. This structure allows both aggregated assessment and disaggregated analysis at the dimension and indicator levels.

15.3 Methodology

15.3.1 Indicator normalization

Given the heterogeneous nature of indicators, normalization is required to ensure comparability. All indicators are transformed to the unit interval [0,1] using min–max normalization. For benefit-type indicators, higher values indicate better performance and normalization is given by

$$z_{ij} = \frac{x_{ij} - \min\left(x_j\right)}{\max\left(x_j\right) - \min\left(x_j\right)}, \tag{1}$$

where x_{ij} denotes the observed value of indicator j for the organization under analysis. For cost-type indicators, where lower values are preferred, the transformation is reversed.

15.3.2 Weighting scheme and aggregation

Weights are assigned at two levels: within each dimension and across dimensions. In this study, weights are derived using the Analytic Hierarchy Process (AHP), based on expert judgment regarding the relative importance of dimensions and indicators (Bocken et al., 2016; Zambujal-Oliveira et al., 2025). Let w_{dj} denote the weight of indicator j within dimension d, and let W_d denote the weight of dimension d, with $\sum_d W_d = 1$. The sub-index for each dimension is computed as a weighted sum of normalized indicators:

$$CPI_d = \sum_{j \in K_d} w_{dj} z_{dj}. \tag{2}$$

The overall Circular Performance Index is then obtained by aggregating dimension sub-indices:

$$CPI = \sum_{d \in D} W_d \cdot CPI_d . \tag{3}$$

This aggregation and weighting scheme is consistent with recent composite index frameworks that integrate MCDA and entropy-based weighting to improve structural robustness (Boubaker et al., 2024; Del-Rosal-Salido et al., 2025).

15.3.2.1 Missing data treatment

Composite indicators are sensitive to incomplete datasets, particularly in sustainability assessments where circular procedures and social data may be inconsistently estimated or subject to measurement errors (Burgass et al., 2017; Mazziotta & Pareto, 2017). Missing values are managed according to the following guidelines for composite indicators (OECD, 2008):

1. **Case deletion**: Applied pairwise when missingness is negligible (< 5%) and does not introduce systematic bias.
2. **Single imputation**: Used for moderate missingness, employing mean or median imputation within comparable organizations' historical data.
3. **Multiple imputation**: Preferred for higher missingness (> 10%), generating multiple datasets (10–20 imputations) via predictive mean matching.

In the present case study, the dataset is nearly complete, with no relevant missing values. Nevertheless, these procedures ensure that the framework remains applicable to other real-world datasets.

15.3.2.2 Uncertainty propagation

Uncertainty stems from measurement errors (e.g., self-reported social metrics), expert-derived AHP weights, and data collection inconsistencies. Typically, following Couto et al. (2013) this uncertainty is quantified as follows:

- A Monte Carlo simulation is performed (10,000 iterations).
- Normalized indicator values are perturbed using uniform distributions based on uncertainty bounds (±10–20%).
- Sub-indicator weights are perturbed using beta distributions to preserve summation constraints.

Table 15.1 Key performance indicators. Benefit indicators are maximized and cost indicators are minimized.

Dimension	Indicator	Type	Value
Financial	Circular revenue share (%)	Benefit	32
Financial	ROI of circular projects (%)	Benefit	14
Operational	Material circularity rate (%)	Benefit	45
Operational	Energy intensity (MWh/unit)	Cost	0.82
Environmental	CO_2 reduction (%)	Benefit	28
Environmental	Waste to landfill (%)	Cost	12
Social	Training hours per employee	Benefit	24
Social	Accident rate	Cost	3.1

- The resulting distribution of CPI values yields probabilistic summaries: point estimate (median), 95% credible intervals, and probability density functions.

This uncertainty analysis complements the sensitivity tests by capturing joint effects and enabling probabilistic interpretation. When data quality is low, wider bounds are assigned, and results are reported with credibility intervals.

15.3.3 Case description

The CPI is applied to a medium-sized manufacturing firm in the energy-equipment sector. The firm has adopted circular practices, including recycled material use, product take-back schemes, and energy-efficiency investments. These initiatives generate financial and sustainability outcomes that can be assessed through the CPI. The analysis relies on data assumed to reflect publicly disclosed financial and sustainability information (Dey et al., 2022). Table 15.1 summarizes the observed performance indicators for the case study. Financial results indicate a moderate contribution of circular activities, with circular revenues accounting for 32% and a positive ROI of 14%. Operationally, the material circularity rate is substantial, although energy intensity remains non-negligible. Environmental indicators show meaningful CO_2 reductions, but residual waste to landfill persists. Social performance is generally favorable, supported by consistent training efforts and a relatively low accident rate.

The case study uses publicly available secondary data from official statistics and organizational reports. Data was selected for consistency and reliability. No personal or confidential data are involved. All information complies with applicable data protection regulations and the construction of the CPI is carried out in accordance with the methodological choices documented in this section.

Table 15.2 Sensitivity of the CPI to dimension weight variations

Scenario	CPI
Baseline	0.64
Environmental emphasis	0.66
Financial emphasis	0.63
Equal weights	0.62

15.4 Results

Indicators are first normalized and aggregated using equal weights within each dimension. This procedure yields sub-indices of $CPI_F = 0.64$, $CPI_O = 0.58$, $CPI_E = 0.71$, and $CPI_S = 0.55$. Dimension weights are then assigned, leading to an overall CPI of 0.64. Robustness is examined by perturbing dimension weights by ±20%, with proportional adjustments to the remaining weights. This sensitivity analysis considers environmental emphasis, financial emphasis, and equal weighting scenarios (Ahlroth et al., 2011; Bottero et al., 2024).

Results indicate limited variation in the CPI, suggesting robustness to reasonable changes in strategic priorities. A second analysis evaluates the influence of individual indicators. Each normalized indicator is independently perturbed by ±10%, holding all others constant. The maximum observed deviation in the CPI is ±0.03, indicating that no single indicator dominates the composite index.

15.4.1 Sensitivity analysis

The CPI's robustness is assessed through multiple layers. First, dimension weights are perturbed by ±20% (with proportional adjustment of remaining weights) to simulate shifts in strategic priorities. Second, each normalized indicator is independently perturbed by ±10%. Maximum deviation in the CPI remains below ±0.03, indicating no single input dominates the result.

To further address data limitations, a Monte Carlo-based uncertainty propagation was conducted. Assuming triangular distributions with ±15% bounds on all indicators and ±10% bounds on weights, 5,000 iterations yield a CPI distribution centered at 0.64 with a 95% interval of [0.59,0.69]. This limited spread confirms robustness under realistic uncertainties.

15.5 Discussion

The case study demonstrates the usefulness of the CPI as a decision-support tool. Strong environmental performance offsets weaker social outcomes,

thereby revealing cross dimensional trade-offs (Corvellec et al., 2022). Sensitivity analysis shows that results are not driven by specific modeling assumptions, which enhances analytical credibility. The CPI therefore reflects a balanced circular performance profile, with environmental initiatives as the main strength.

Limited sensitivity to dimension weight changes implies that strategic reorientation does not materially affect overall performance (Abdi & Labib, 2003; Bottero et al., 2024). This robustness grants managers flexibility to adapt priorities to regulatory or market conditions. Indicatorlevel analysis indicates that isolated interventions are insufficient. Consequently, coordinated actions across financial, operational, environmental, and social dimensions are more likely to sustain improvements in circular performance.

The CPI also has implications beyond internal managerial decision-making. By consolidating circular-economy performance into a transparent metric, CPI results can reduce information asymmetry between organizations and consumers, strengthening consumer trust. The public disclosure of CPI scores may enhance transparency regarding firms' environmental responsibility, supporting informed and fair consumption choices. Furthermore, comparability across organizations enables consumers to identify circular practices and reinforcing fairness in sustainable markets.

15.6 Conclusion

This chapter proposed a multidimensional Circular Performance Index and demonstrated its practical application through a numerical case study. Sensitivity analysis confirms the robustness of the index to weighting and indicator perturbations. The CPI provides a flexible and transparent framework for benchmarking circular performance across firms and sectors. This study contributes to the circular economy perspective by demonstrating that composite circularity metrics can serve not only organizational assessment purposes but also broader societal objectives.

When CPI results are communicated in an accessible manner, they can function as trust building signals that empower consumers and promote fair consumption practices aligned with circular-economy principles. In this sense, the CPI makes sustainability performance understandable for all stakeholders, including non-expert audiences.

15.6.1 Limitations and future research

This study has several limitations. The empirical validation of the proposed Circular Performance Index (CPI) is based on a single-case study of

a medium-sized firm in the energy equipment manufacturing sector, which limits the statistical generalizability of the results. The findings are therefore analytically generalizable, demonstrating the managerial relevance of the CPI rather than providing transferable benchmarks.

Differences in firm size, sectoral characteristics, and circular maturity may affect the relative importance of CPI dimensions, leading to different results in other contexts. Further validation through multiple-case and cross-sector studies is required to assess the framework's robustness and broader applicability.

While the single-case study limits statistical generalizability, the framework incorporates explicit strategies for missing data and input uncertainty (via Monte Carlo propagation), thereby mitigating bias from data, common in circular economy reporting.

Future research may extend the CPI framework toward product-level or consumer-facing indicators, enabling the translation of organizational circular performance into dashboards usable by consumers. Such extensions could integrate life-cycle-based product metrics or consumer relevant dimensions (e.g. recyclability).

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