

FROM INDUSTRIAL CIRCULARITY TO WELL-BEING: ASSESSING THE SOCIAL EFFICIENCY OF THE CIRCULAR ECONOMY IN THE EU

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Abstract

This study investigates how effectively European Union Member States transform circular economy (CE) practices into social well-being, addressing a critical but underexplored dimension of circular transition research. While existing CE assessments primarily emphasize material flows, recycling performance, and resource productivity, far less is known about how circularity contributes to consumer-relevant and inclusive social outcomes.

Using an output-oriented Data Envelopment Analysis (DEA) framework under variable returns to scale, the study evaluates the social efficiency of CE across 27 EU countries, drawing on indicators of circular material use, material intensity, international recycling flows, self-perceived health, social inclusion, and real income. The results reveal substantial heterogeneity in social efficiency, showing that higher levels of circular activity do not automatically translate into stronger well-being outcomes for consumers.

Countries such as Denmark, Finland, Estonia, Ireland, Luxembourg, and Spain achieve full efficiency, indicating effective alignment between circularity practices, welfare structures, and socially inclusive outcomes. Conversely, several countries operate under decreasing returns to scale, suggesting that CE initiatives may dilute social effects and generate uneven distributional outcomes when implemented beyond their optimal capacity. Overall, the findings highlight the importance of policy coherence, institutional capability, and consumer-oriented governance in ensuring that circular economy strategies deliver inclusive and socially sustainable benefits.

Key words: *Industrial circularity, social well-being, sustainable integration, consumer relevance, efficiency*

Introduction

The transition toward a Circular Economy (CE) has become a central pillar of the European Union’s sustainability agenda, particularly following the adoption of the 2021 EU Climate Law and the European Green Deal, which commit Member States to achieving climate neutrality by 2050 and to decoupling economic growth from resource use (European Parliament and Council, 2021; European Commission, 2019). These commitments have been operationalized through successive Circular Economy Action Plans (CEAP), which aim not

only to improve resource efficiency and reduce waste but also to foster more resilient, equitable, and sustainable socio-economic systems (European Commission, 2020, 2022; Chioatto and Sospiro, 2023). As CE policies expand beyond waste management toward systemic transformations in production, consumption, and innovation, a growing question emerges: to what extent do industrial circularity efforts translate into improved social well-being?

In this context, the circular economy is increasingly understood not only as a production-side transformation but also as a consumer-facing transition, where issues of consumer protection, fairness, access, and inclusion become central. CE policies shape how consumers interact with goods and services by influencing affordability, product durability, access to repair and reuse, and exposure to environmental and economic risks. Consequently, the social outcomes of circularity are closely linked to how effectively CE practices are embedded within consumer-oriented governance frameworks, determining whether circular transitions enhance well-being broadly or generate uneven social effects.

In line with EU consumer and social policy frameworks, this study adopts a broad interpretation of consumer-relevant well-being. Rather than focusing narrowly on market transactions, consumer well-being is understood as encompassing key preconditions for effective consumer protection and empowerment in circular transitions, including economic security, access to essential services, and the capacity of households to benefit from durable, repairable, and affordable products. In this sense, health and social inclusion are treated as proxy indicators of consumer empowerment and welfare within circular economy systems.

Recent EU policy developments further reinforce the importance of this consumer-oriented perspective. In particular, Directive (EU) 2024/1799 on common rules promoting the repair of goods explicitly frames repair not only as an environmental strategy but as a core consumer right, linking circular economy performance with affordability, access to after-sales services, and legal enforceability. This policy shift highlights the growing recognition that circular economy transitions must deliver tangible consumer benefits, rather than remaining confined to upstream industrial or environmental performance.

Although the CE has traditionally been conceptualized through the 3R framework—reduce, reuse, recycle—recent scholarship argues for a broader understanding that incorporates redesign, remanufacturing, and recovery (Liu et al., 2021), or even more extensive R-strategies such as refuse, rethink, and repurpose within the 9R hierarchy (Kirchherr et al., 2017). These expanding conceptual boundaries reflect the recognition that circularity is not solely a technical or industrial process but also a societal transition involving behavioural change, institutional capacity, and shifts in value creation. Accordingly, CE is increasingly viewed through three interconnected dimensions—environmental, economic, and social—each contributing differently to sustainability transitions (Remeikienė et al., 2025). While the environmental and economic benefits of CE, such as reduced material consumption and improved resource productivity, are well documented (Mazur-Wierzbicka, 2021; Mohammed et al., 2021), the social implications of circularity remain less clearly understood, particularly from the perspective of consumers and distributional outcomes.

Emerging evidence suggests that circular systems may contribute to human well-being by improving living environments, reducing exposure to pollution, promoting repair and sharing cultures, supporting green employment, and fostering more inclusive consumption models (Moreau et al., 2017; Schröder et al., 2020). User-centred circular design, such as flexible and healthy interior systems, has been shown to enhance subjective well-being and health outcomes (Geldermans et al., 2019). Similarly, social life-cycle assessment frameworks demonstrate how circular products can influence social impacts across value chains (Tsalis et

al., 2022). Despite these insights, existing CE performance assessments overwhelmingly prioritise material flows, recycling rates, waste generation, and resource productivity, leaving open the question of how effectively countries convert circularity efforts into consumer-relevant social value, including fairness, inclusion, and protection.

This gap is particularly important because the circular economy is increasingly positioned not only as an environmental policy but also as a lever for promoting social resilience, equity, and quality of life at the consumer level. Without explicit attention to distributional effects, consumer protection mechanisms, and fairness considerations, CE strategies risk generating uneven social outcomes—benefiting certain groups while placing disproportionate costs or constraints on others. Nevertheless, empirical evidence on how efficiently countries transform industrial circularity into inclusive and consumer-relevant social well-being remains limited. There is still insufficient understanding of which countries achieve such transformations more effectively, what structural and governance factors shape these outcomes, and how CE policies interact with broader welfare and consumer protection systems.

Against this backdrop, this study contributes to the emerging research frontier by examining the social efficiency of the CE across EU-27 Member States. Moving beyond assessments focused solely on environmental and economic performance, the analysis evaluates the extent to which circular economy inputs are translated into improvements in subjective health, social inclusion, and living standards. By framing social efficiency as the capacity of circular economy practices to generate socially meaningful and consumer-relevant outcomes, the study aligns with calls in the literature to position the circular economy as a driver of inclusive social transformation rather than merely a tool for resource optimization. At the same time, it offers policy-relevant insights into how circular economy governance can be better aligned with consumer protection, fairness, and sustainable consumption objectives within the European Union.

Literature Review

Existing studies on the Circular Economy (CE) predominantly rely on indicator-based assessment frameworks, multi-criteria decision analysis (MCDA) methods, and composite indices to evaluate circularity performance, with a strong emphasis on environmental pressures, waste flows, and resource efficiency. These approaches have enabled researchers to capture multi-dimensional aspects of circularity, yet they typically prioritise measurable material outcomes over broader societal impacts. A significant line of research employs MCDA techniques to compare CE outcomes across countries, reflecting a growing interest in benchmarking progress and identifying structural drivers of performance differences. For instance, Štreimikienė et al. (2025) apply a CRITIC-weighted TOPSIS model to assess CE performance in the Baltic States and identify material productivity, waste-management efficiency, and secondary material use as key determinants of circularity. Similarly, Rađenović and Rajić (2024) use TOPSIS to rank EU member states based on circular material use, revealing higher performance among countries with stronger recycling infrastructures and mature regulatory frameworks. Grybaitė and Burinskienė (2024), employing the SAW method, further show that high-performing CE countries typically benefit from greater institutional capacity and long-term policy commitment. Collectively, these MCDA-based studies demonstrate the analytical value of multi-indicator assessments but remain largely centred on material flows and environmental criteria.

Beyond MCDA-based contributions, several empirical analyses offer a broader perspective on cross-country CE disparities. Nazarko et al. (2021) combine Data Envelopment Analysis with factor and cluster analysis to evaluate CE performance across 27 EU member states. Their findings show that numerous CE indicators cluster into five meta-groups—general waste recycling, special waste recycling, waste generation, circular material use, and CE-related jobs and investments—illustrating the high degree of inter-indicator correlation. Their results also indicate that CE leadership is domain-specific rather than universal, with different countries excelling in different recycling or material use indicators. Importantly, the study finds a strong link between GDP per capita and CE advancement, suggesting that economic capacity significantly shapes the feasibility of circular transitions. Complementing this view, Ūsas et al. (2022) develop an indicator system that captures circularity inputs, trade flows, and recycling processes, and identify Germany, Sweden, and the Netherlands as the most advanced CE performers. Their results highlight structural constraints faced by water-locked or newer EU member states and emphasise the critical role of monitoring systems and recycling infrastructure. In a similar vein, Fura et al. (2019), using multidimensional comparative analysis, show that the Benelux countries—Luxembourg, Belgium, and the Netherlands—are consistently among the most advanced in CE development, whereas countries such as Malta, Cyprus, Estonia, and Greece lag behind. Together, these contributions reinforce the conclusion that CE performance across the EU is highly heterogeneous and shaped by a combination of economic, infrastructural, institutional, and regulatory factors.

Broader European assessments further confirm the heterogeneity of CE performance across the EU. Radenović et al. (2023) shows that waste-management efficiency varies substantially across countries due to uneven infrastructure investment, differences in regulatory enforcement, and varying levels of administrative capacity. D’Adamo et al. (2024) complement these findings by showing that national circularity trajectories are strongly shaped by innovation capacity, technological modernization, and recycling-oriented industrial structures. Remeikienė et al. (2025) similarly document significant variation in resource productivity, circular material use, and waste generation, highlighting structural, institutional, and policy-related determinants as critical explanatory factors. Contributions linking CE to economic outcomes reinforce this pattern. Potkány et al. (2025) show that countries with stronger CE indicators tend to achieve higher levels of competitiveness, productivity, and value-added creation, while Milanović et al. (2022), using a DEA-based composite index, find that waste-management efficiency plays a substantial role in determining national CE performance. Yet, despite these contributions, the dominant focus of this literature remains on production systems, waste flows, and resource efficiency, reinforcing the prevalence of environmental and economic indicators in CE measurement.

Methodological reflections in the literature further emphasize the fragmented nature of CE measurement. dos Santos et al. (2022) highlight persistent inconsistencies in indicator selection, normalization procedures, and weighting schemes across MCDA-based CE studies, arguing that such inconsistencies hinder the comparability and robustness of CE performance evaluations. They also emphasize that social indicators continue to be markedly underrepresented in CE assessments, despite increasing acknowledgment that circularity has implications extending beyond material efficiency. This observation is echoed in broader critiques of CE research: Moreau et al. (2017) argue that circularity cannot be fully understood without accounting for social and institutional dynamics, such as behavioural norms, governance systems, labour conditions, and inequality structures. Schröder et al. (2020) similarly contend that CE strategies need to be aligned with human development goals,

suggesting that circular initiatives should be designed not only to improve resource efficiency but also to promote equity, social welfare, and human capabilities.

Recent years have witnessed growing interest in the social implications of circular practices. Nikonorova et al. (2020) emphasize the importance of incorporating social well-being indicators into CE assessments, while Bianchini et al. (2022) propose a structured framework for evaluating social sustainability within CE contexts, illustrating how social criteria can complement environmental indicators in assessing circular transitions. Tsalis et al. (2022) move this discussion forward by developing a social life-cycle assessment framework adapted to circular products, thereby demonstrating methodological pathways for quantifying social impacts across entire product chains. Additional insights come from Geldermans et al. (2019), who explore how circular interior design configurations, particularly flexible infill systems, can influence human health and well-being by shaping indoor comfort, adaptability, and user experience. Such findings illustrate that circularity can affect outcomes at the operational and everyday life level, beyond macro-level performance metrics.

Other recent contributions broaden the social dimension of CE. Skare et al. (2024) examine how research and development activities within a CE framework may contribute to reducing inequality and enhancing societal well-being across the EU, positioning CE as a potential tool for promoting social cohesion. Sharma and Bangur (2025) highlight the public health benefits associated with circular practices, suggesting that reduced pollution, safer material cycles, and improved environmental quality may collectively strengthen population health. At the consumer level, Petreca et al. (2025) show that circular textile systems influence psychological and experiential aspects of well-being, pointing to the importance of understanding CE impacts not only at macro scales but also within individual consumption experiences. Methodological developments have also supported the integration of social metrics into CE research: Ahmadi et al. (2017) demonstrate that complex social criteria can be systematically weighted using the Best–Worst Method (BWM), offering a structured approach for incorporating social dimensions into CE evaluations. Finally, Calisto et al. (2024) argues that transitioning toward a circular society requires explicit attention to justice, inclusivity, and broader socio-economic transformation, as resource efficiency alone is insufficient to achieve socially sustainable outcomes.

Taken together, these studies reveal a consistent pattern: CE assessments remain largely dominated by indicators related to material flows, waste-management efficiency, and resource productivity, while the social implications of circular practices—including well-being, inclusion, equity, and health—receive comparatively limited empirical attention. Although recent studies have begun to explore inequality reduction, human development, public health improvements, consumer well-being, and broader social sustainability within CE contexts, these contributions remain fragmented and only loosely connected to mainstream CE performance frameworks. Systematic analyses that integrate CE indicators with measurable social well-being outcomes are still scarce, leaving an important gap in understanding how effectively countries translate circularity efforts into social value. The present study seeks to contribute to this emerging discussion by proposing a framework that evaluates CE performance alongside social well-being indicators across EU member states, offering a broader and more holistic perspective on the societal dimension of circular economy practices.

Research Method

This study evaluates the ability of EU 27 member states to transform circular-economy–related resource flows into social well-being outcomes. For this purpose, a non-parametric

Data Envelopment Analysis (DEA) framework is employed. DEA is particularly suitable for this research because it enables the assessment of relative efficiency across multiple decision-making units (DMUs) when several inputs and outputs coexist without requiring a predefined functional form (Charnes et al., 1978).

Given that countries differ considerably in economic size, industrial composition and demographic structure, the analysis uses both Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) models to capture overall technical efficiency and pure technical efficiency (TE), respectively. Scale efficiency (SE) is then derived as the ratio of CRS to VRS scores, allowing identification of whether inefficiency stems from suboptimal scale or managerial/technical factors. An output-oriented specification is adopted in the analysis. This choice reflects the conceptual focus of the study: the objective is not to reduce circular economy inputs, but rather to assess how effectively these inputs are transformed into desirable social outcomes such as social inclusion, subjective health, and economic well-being.

The output-oriented DEA models used in this study follow the standard formulations introduced by Charnes, Cooper, and Rhodes (1978) for the constant returns to scale (CRS) model and by Banker, Charnes, and Cooper (1984) for the variable returns to scale (VRS) model. The CRS (CCR) model captures overall technical efficiency, whereas the VRS (BCC) model isolates pure technical efficiency while allowing for variable returns to scale. Scale efficiency is subsequently derived following Banker et al. (1984).

For each DMU, the output-oriented VRS model is formulated in equation 1 (Banker et al., 1984):

$$\begin{aligned}
 & \max_{\phi, \lambda_j} \quad \phi \\
 & \text{s.t.} \quad \sum_{j=1}^n \lambda_j x_{ij} \leq x_{io}, \quad i = 1, \dots, m, \\
 & \quad \sum_{j=1}^n \lambda_j y_{rj} \geq \phi y_{ro}, \quad r = 1, \dots, s, \\
 & \quad \sum_{j=1}^n \lambda_j = 1, \\
 & \quad \lambda_j \geq 0, \quad j = 1, \dots, n.
 \end{aligned} \tag{1}$$

The VRS technical efficiency score is computed as in equation 2:

$$\text{VRS_TE}_o = \frac{1}{\phi_o^*}. \tag{2}$$

A DMU is VRS-efficient when $\phi^* = 1$.

The CRS model is derived by removing the convexity constraint $\sum_{j=1}^n \lambda_j = 1$ (Charnes et al., 1978):

$$\begin{aligned} \max_{\phi, \lambda_j} \quad & \phi \\ \text{s.t.} \quad & \sum_{j=1}^n \lambda_j x_{ij} \leq x_{io}, \\ & \sum_{j=1}^n \lambda_j y_{rj} \geq \phi y_{ro}, \\ & \lambda_j \geq 0. \end{aligned} \tag{3}$$

The resulting efficiency score is denoted as CRS_TE.

Scale efficiency is computed as in equation 4 :

$$SE_o = \frac{CRS_TE_o}{VRS_TE_o}. \tag{4}$$

Returns to scale (RTS) are determined by standard DEA procedures:

- CRS when $CRS_TE = VRS_TE$,
- IRS when the sum of optimal $\lambda_j < 1$,
- DRS when the sum of optimal $\lambda_j > 1$.

These indicators allow the study to differentiate between inefficiencies arising from policy, structural factors, and scale mismatches.

Furthermore, to deepen the interpretation of the DEA results and to identify underlying structural patterns among EU member states, a K-means cluster analysis (k=3) was conducted using the three efficiency indicators (CRS-TE, VRS-TE, and SE). The purpose of this procedure is to group countries that exhibit similar efficiency characteristics, allowing for a clearer understanding of performance heterogeneity across the region. The clustered heatmap was subsequently organized according to these K-means groupings and further sorted within each cluster by CRS scores. This integrated approach improves interpretability by visually linking efficiency intensity with the structural similarity of countries, thereby providing a more nuanced assessment of cross-country efficiency dynamics.

Selection of Inputs and Outputs

In this study, to ensure cross-country standardization and comparability, all variables were obtained from Eurostat, and the analysis uses data from the year 2023. The selected indicators capture three fundamental dimensions of the analysis: (i) industrial circularity, (ii) material efficiency, and (iii) socioeconomic well-being. Table 1 summarizes the input and output variables used in the Data Envelopment Analysis (DEA). Three indicators representing material circularity and resource processing constitute the input set, while three indicators reflecting socioeconomic well-being form the output set, enabling an assessment of how effectively EU member countries convert circular economy practices into social outcomes.

Table 1. Input and Output Variables Used in the DEA Model

Type	Code	Variable Name	Description / Definition	Expected Direction
Input	X1	Circular Material Use Rate (%)	Share of material inputs coming from recycled materials in the economy. Indicates the level of circularity and secondary material integration.	Higher values indicate better circularity (desirable input).
Input	X2	Domestic Processed Output per Capita (tonnes)	Total material processed domestically per person, reflecting the economy's material intensity. Higher values imply greater environmental pressure.	Lower values are preferred; treated as an undesirable input (transformed as $1/X2$ in the model).
Input	X3	Exports of Waste for Recovery/Recycling (tonnes per capita)	Amount of waste exported for recycling, capturing the country's circular economy infrastructure and international circularity performance.	Higher values indicate better circular economy performance (desirable input).
Output	Y1	Social Inclusion (100- Severe material deprivation rate by degree of urbanization %)	Percentage of population not experiencing severe material deprivation. Reflects social well-being and living standards for consumers	Higher values indicate higher social well-being.
Output	Y2	Self-Perceived Health (Very Good/Good, %)	Share of the population aged 16+ reporting very good or good health. Captures subjective well-being and quality of life.	Higher values indicate better health outcomes.
Output	Y3	Real GDP per Capita (EUR)	Income-based measure of economic welfare and living standards, adjusted for price levels.	Higher values indicate stronger economic well-being.

Circular Material Use Rate (X1) and Exports of Waste for Recycling (X3) are treated as desirable inputs, whereas Domestic Processed Output per capita (X2) is considered an undesirable input due to its association with higher material throughput and resource intensity. To ensure model consistency, X2 is transformed using its inverse value ($1/X2$), allowing lower material output to be reflected as higher input efficiency. Together, these three indicators capture key dimensions of industrial circularity and material flow efficiency, representing different stages of the circular economy cycle—resource recirculation, material processing intensity, and cross-border recovery activities. Collectively, they reflect the structural capacity of countries to operate within a circular production system.

The output variables—Social Inclusion (Y1), Self-Perceived Health (Y2), and Real GDP per capita (Y3)—represent complementary aspects of social and economic well-being. The social dimension is mainly addressed at an aggregate level, with attention to distributional effects and the specific impacts on consumers. These indicators enable an assessment of how effectively circular economy inputs are translated into societal benefits. By combining resource-oriented inputs with human-centered outputs, the model allows for a holistic evaluation of the social efficiency of circular economy performance, in line with current sustainability and well-being frameworks.

Table 2. Descriptive Statistics of Input and Output Variables

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
X1	Circular Material Use Rate (%)	27	10.28	7.11	1.30	30.60
X2	Domestic Processed Output per Capita (tonnes)	27	0.115	0.0335	0.0608	0.1798
X3	Exports of Waste for Recovery/Recycling (tonnes per capita)	27	0.384	0.269	0.080	1.020
Y1	Social Inclusion (% not severely deprived)	27	94.31	3.38	83.70	99.00
Y2	Self-Perceived Health (% good/very good)	27	67.47	8.09	48.90	80.10
Y3	Real GDP per Capita (EUR)	27	31,898.89	20,783.14	9,140	93,670

Table 2 shows notable cross-country variation in both inputs and outputs. Circular Material Use (X1) ranges widely from 1.3% to 30.6% (mean 10.28%), indicating uneven adoption of secondary materials. Waste exports for recovery (X3) also vary substantially (0.08–1.02 tonnes per capita). The undesirable input, Domestic Processed Output (X2), shows a narrower range (0.06–0.18 tonnes).

On the output side, Social Inclusion (Y1) is generally high but still spans from 83.7% to 99%. Self-perceived health (Y2) shows greater dispersion (48.9%–80.1%), while GDP per capita (Y3) exhibits the widest gap—from €9,140 to €93,670. These variations highlight strong heterogeneity among EU countries and support the use of an efficient framework to assess how effectively circular inputs are transformed into social well-being.

Table 3. Variables Correlation Matrix

Variables	X1	X2	X3	Y1	Y2	Y3
X1 – Circular Material Use Rate	1.0000					
X2 – Domestic Processed Output (1/X2)	-0.1247	1.0000				
X3 – Waste Exports for Recovery	0.3264	-0.3742	1.0000			
Y1 – Social Inclusion	0.1110	-0.4283	0.3769	1.0000		
Y2 – Self-Perceived Health	0.2096	0.0789	-0.2677	-0.2923	1.0000	
Y3 – GDP per Capita	0.1645	-0.5158	0.1155	0.3695	0.4090	1.0000

The correlation matrix in Table 3 indicates that the relationships among the variables are generally weak to moderate in magnitude. Most coefficients fall well below 0.40, suggesting that the input and output variables capture distinct dimensions of circularity and well-being. The only moderately strong associations are the negative relationship between X2 (Domestic Processed Output) and Y3 (GDP per capita), and the positive relationship between Y2 (Self-Perceived Health) and Y3, both of which align with expected economic and social patterns. Overall, the low-to-moderate correlations confirm that no variables are excessively related, and the dataset does not exhibit multicollinearity concerns. This indicates that the variables are suitable for inclusion in the DEA model and contribute unique information to the efficiency analysis.

Results

The DEA results presented in Table 4 reveal substantial heterogeneity in the ability of EU member states to convert circular-economy-related inputs into socioeconomic outcomes. Under the output-oriented VRS specification, twelve countries—Denmark, Estonia, Finland, Greece, Ireland, Italy, Luxembourg, Malta, Poland, Portugal, Romania, and Spain—achieve a pure technical efficiency score of 1, indicating that they operate on the efficient frontier once scale effects are removed. These countries demonstrate the strongest capability to translate

circular inputs such as circular material use, domestic processed output, and recycling-related flows into higher levels of social inclusion, better self-perceived health, and higher income levels.

When the CRS assumption is imposed, the same set of countries remains fully efficient, suggesting that they are not only technically efficient but also operate at an optimal scale. This dual efficiency indicates a highly effective transformation mechanism between industrial circularity and consumer-level well-being in these economies.

In contrast, several countries exhibit notable gaps between CRS and VRS efficiency levels. For example, Austria, Slovenia, Slovak Republic, Latvia, and France show relatively high VRS efficiency (0.93–0.99) while maintaining substantially lower CRS scores (0.52–0.69). This divergence implies that these countries possess adequate technological capabilities but experience scale inefficiencies, which prevent them from operating on the global frontier. Their inefficiency is therefore driven not by poor input–output conversion but by suboptimal production scale.

The scale efficiency estimates confirm this pattern: the lowest values are observed in Slovenia (0.53), Latvia (0.58), Slovak Republic (0.62), Austria (0.69), and France (0.72). These results indicate that these countries could improve overall efficiency by adjusting the scale at which circular-economy activities are implemented.

The Returns to Scale (RTS) classification provides additional insight into the nature of scale deviations. Most inefficient countries operate under Decreasing Returns to Scale (DRS), meaning that their current scale is larger than optimal and that downsizing or restructuring resource-use patterns would yield efficiency gains. In contrast, only Belgium and Malta operate under Increasing Returns to Scale (IRS), implying that an expansion of circular-economy capacity—through greater recycling infrastructure, increased circular material flows, or larger CE markets—would enhance their efficiency. Countries classified as CRS (including Denmark, Finland, Estonia, Luxembourg and Spain) already operate at the optimal scale.

Overall, the results indicate that while a group of EU economies demonstrates efficient transmission of circular-economy capabilities into social well-being, many others face structural scale constraints. The findings highlight the importance of considering both technological efficiency and scale effects when assessing the social efficiency of circular-economy performance.

Table 4. DEA Efficiency Scores for EU Member States (CRS, VRS and Scale Efficiency)

Country	CRS_TE	VRS_TE	Scale Efficiency	RTS
Austria	0.6427	0.9381	0.6851	DRS
Belgium	0.6444	0.9563	0.6739	IRS
Bulgaria	0.6718	0.9073	0.7405	DRS
Croatia	0.6884	0.9967	0.6907	DRS
Cyprus	0.8691	0.9963	0.8723	DRS
Czechia	0.6648	0.9737	0.6828	DRS
Denmark	1.0000	1.0000	1.0000	CRS
Estonia	1.0000	1.0000	1.0000	CRS
Finland	1.0000	1.0000	1.0000	CRS
France	0.6845	0.9551	0.7166	DRS
Germany	0.7373	0.9582	0.7695	DRS
Greece	1.0000	1.0000	1.0000	CRS
Hungary	0.6132	0.9643	0.6359	DRS
Ireland	1.0000	1.0000	1.0000	CRS
Italy	1.0000	1.0000	1.0000	CRS

Latvia	0.5754	0.9872	0.5829	DRS
Lithuania	0.6617	0.9892	0.6689	DRS
Luxembourg	1.0000	1.0000	1.0000	CRS
Malta	0.9034	1.0000	0.9034	IRS
Netherlands	0.6588	0.9616	0.6851	DRS
Poland	0.9635	1.0000	0.9635	DRS
Portugal	0.9870	1.0000	0.9870	DRS
Romania	1.0000	1.0000	1.0000	CRS
Slovak Republic	0.5749	0.9245	0.6219	DRS
Slovenia	0.5264	0.9969	0.5281	DRS
Spain	1.0000	1.0000	1.0000	CRS
Sweden	0.6792	0.9869	0.6882	DRS

CRS: Constant Returns to Scale → optimal scale

DRS: Decreasing Returns to Scale → scale too large (downsizing efficiency)

IRS: Increasing Returns to Scale → scale too small (scaling up efficiency)

In this study, the reference set frequency was identified to determine which efficient units shape the frontier and serve as benchmarks for underperforming countries as well. This measure highlights the most influential performers and provides insight into which countries' circularity–well-being transformation patterns offer the strongest policy-learning potential.

The reference set frequency (Figure1) provides critical insights into which EU Member States serve as efficiency benchmarks in transforming circular economy inputs into social well-being outcomes. The results indicate that Luxembourg and Ireland each appear 14 times, and Poland appears 10 times, in the reference sets of inefficient countries, making them the most influential benchmark countries in the model. This pattern suggests that these countries form the core of the DEA efficient frontier and represent the most effective models of converting circularity indicators into improved well-being.

A second group of benchmark countries, Italy and Romania, exhibit moderate peer frequency, being referenced only a few times. Several countries, including Spain, Portugal, Malta, Greece, Finland, Estonia and Denmark appear only once in the reference sets. While technically efficient, their limited benchmarking role suggests that their efficiency patterns are either context-specific or less transferable to other countries with different structural profiles.

Figure 1. Reference Set Frequency (Peer Frequency)

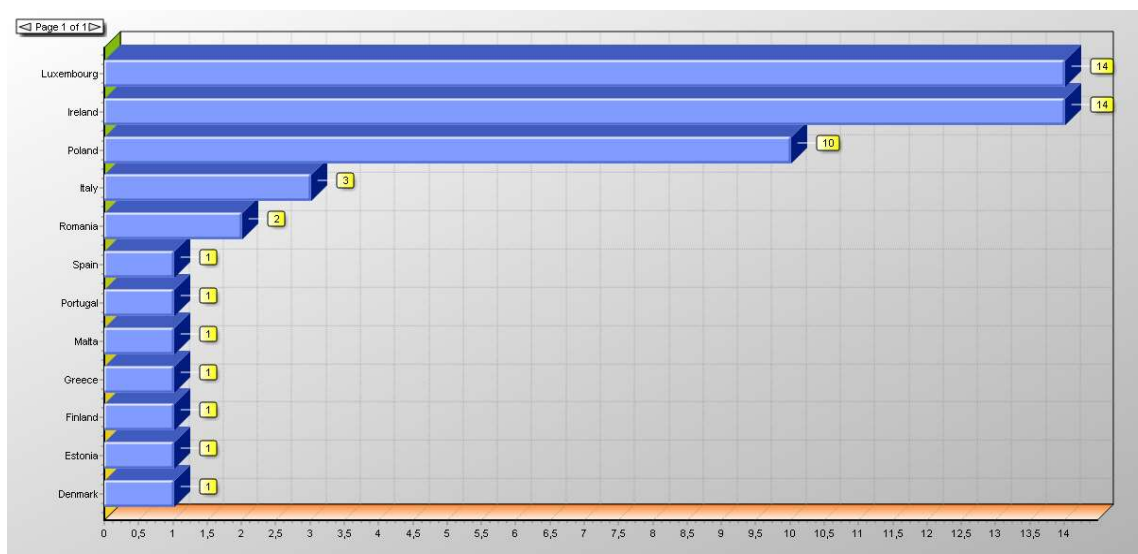
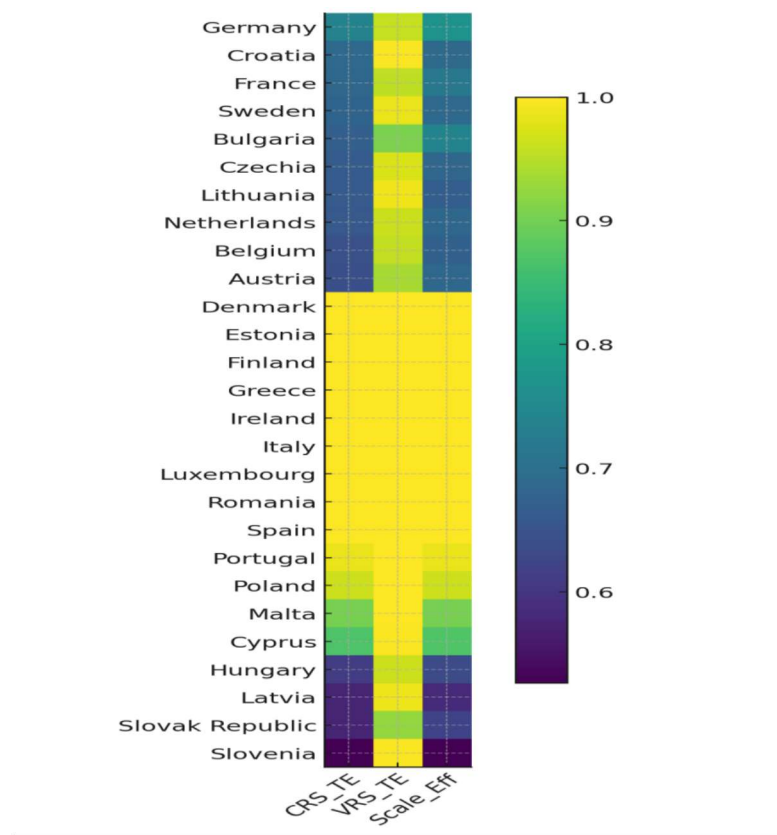


Figure 2. Clustered Heatmap of DEA Efficiency Scores

In Figure 2, the heatmap presents clear cross-country differences in the ability of EU members to convert circular economy inputs into social well-being outcomes. A K-means cluster analysis ($k = 3$), based on CRS, VRS and scale efficiency scores, was used to structure the visual ordering of countries. Countries were grouped according to similarity in efficiency profiles, and the heatmap was sorted first by cluster membership and then by CRS efficiency within each cluster. This approach allows the visualization to reflect both efficiency intensity and the underlying structural grouping.

The resulting clusters reveal three distinct performance patterns. Denmark, Finland, Ireland, Luxembourg and Spain constitute the high-performing group, exhibiting strong results across all efficiency measures. Austria, Belgium, France, Germany and the Netherlands form a medium-efficiency cluster, where high VRS scores but lower CRS and scale efficiency suggest suboptimal scale in circular economy implementation. A third cluster—including Latvia, Hungary, Slovenia and the Slovak Republic—shows the lowest efficiency levels, indicating structural and scale-related constraints in transforming circular economy practices into social outcomes.

Discussion

The results of this study reveal that the relationship between Circular Economy (CE) performance and social well-being across EU Member States is far from uniform. While CE policies have traditionally been justified through environmental and economic gains, the

findings demonstrate substantial cross-country variation in the capacity to convert circularity inputs into improved living standards, subjective health, and social inclusion. This confirms a growing consensus in the literature that the CE cannot be assessed solely as a technical system of material loops, but must instead be understood as a broader socio-economic transformation process that directly affects consumers and social outcomes (Moreau et al., 2017; Schröder et al., 2020).

One of the central insights of the efficiency analysis is that high levels of circular economy activity do not automatically translate into higher social well-being or consumer-relevant benefits. Countries such as Germany and the Netherlands—characterized by advanced recycling infrastructures, high circular material use rates, and long-standing CE policies—exhibit notable inefficiencies in transforming circularity inputs into social outcomes. Despite their strong industrial and technological capacity, these countries do not achieve proportional improvements in indicators such as subjective health or social inclusion. This suggests a disconnect between technical circularity performance and the lived social experience of circular transitions, including how benefits and costs are distributed across consumers. In contrast, countries such as Ireland and Luxembourg, which may not lead in material recycling volumes to the same extent, demonstrate substantially higher efficiency in translating circular economy efforts into well-being improvements. These patterns challenge the conventional assumption that environmentally advanced economies are automatically leaders in socially inclusive circular transitions. Instead, the findings support arguments by Bianchini et al. (2022) and Nikonorova et al. (2020), who emphasize that the social benefits of circularity depend critically on how CE practices are embedded within welfare systems, labour markets, consumer cultures, and behavioral norms.

The study further underscores the importance of policy scale and targeting in shaping the social and consumer-level outcomes of CE initiatives. Countries operating under decreasing returns to scale appear to implement CE measures at levels that exceed their effective capacity to generate proportional social benefits. From a consumer perspective, such scale inefficiencies may translate into higher costs, limited access to circular products or services, and uneven distribution of benefits, particularly for vulnerable or lower-income groups. Broad, undifferentiated CE strategies may therefore dilute social returns when they are not sufficiently aligned with sectoral priorities, local socioeconomic conditions, and consumer protection mechanisms. These findings resonate with concerns raised in methodological and policy-oriented reviews (e.g., dos Santos et al., 2022) regarding fragmentation in CE implementation and the mismatch between policy ambition and institutional capacity.

From a consumer-protection perspective, these scale inefficiencies carry important distributional implications. Countries operating under decreasing returns to scale may face higher compliance costs, limited access to repair and reuse services, or uneven availability of circular products and services, potentially placing disproportionate burdens on lower-income and vulnerable consumer groups. Such dynamics suggest that beyond technical efficiency, circular economy governance must explicitly address affordability, accessibility, and fairness in order to ensure inclusive consumer welfare outcomes and to prevent circular transitions from reinforcing existing social inequalities.

The scale inefficiencies observed across several EU Member States suggest that the societal impact of the circular economy depends not only on technical or infrastructural capacity, but also on the appropriate calibration of governance frameworks. When circular economy activities are deployed beyond their optimal scale—across wide geographical areas or heterogeneous sectors—their contribution to social well-being and consumer fairness becomes less effective. For example, the broad industrial structures and high material-use

intensity of Austria and France appear to reduce the marginal social returns of CE investments, while in smaller economies such as Slovenia and the Slovak Republic, the dispersion of CE initiatives across multiple sectors leads to similar inefficiencies. These patterns indicate that more targeted, locally grounded, and sector-prioritised policy designs—combined with consumer-oriented regulatory instruments—may enhance both resource-use efficiency and socially inclusive outcomes.

A further implication of the results is that economic development alone is insufficient to guarantee socially effective and fair circular transitions. Several high-income Member States, despite their advanced CE infrastructures and technological capabilities, display limited efficiency in converting circular inputs into well-being outcomes that are meaningful for consumers. This finding aligns with the observation by Calisto Friant et al. (2024) that resource efficiency gains do not automatically translate into social justice, inclusivity, or improved quality of life. To realize the full societal potential of the circular economy, the social dimension must be explicitly integrated into CE strategies through governance mechanisms that prioritize consumer protection, address distributional effects, and ensure equitable access to the benefits of circular production and consumption systems.

Conclusions

This study assessed the efficiency with which EU Member States transform circular economy (CE) inputs into social well-being outcomes using a Data Envelopment Analysis framework. The results demonstrate that CE efforts are not uniformly converted into social benefits across the European Union. Countries such as Denmark, Finland, Ireland, Luxembourg, Estonia, and Spain achieve full efficiency, indicating that their circular economy infrastructures are effectively aligned with improvements in subjective health, social inclusion, and living standards.

In contrast, several countries—most notably Germany, the Netherlands, Austria, and France—exhibit significant inefficiencies, suggesting that strong industrial or environmental CE performance does not automatically generate proportional social gains. These findings reinforce the growing view that the social value of the circular economy depends not merely on technical or material performance, but on how circular practices are embedded within broader behavioral, institutional, welfare, and consumer-related structures. In this sense, circular transitions that are not adequately aligned with consumer access, affordability, and protection may deliver limited improvements in lived social outcomes.

Scale effects play a particularly important role in shaping these results. Countries operating under decreasing returns to scale often implement CE policies at a scope or intensity that exceeds their capacity to translate such efforts into social benefits. When circular initiatives are dispersed across too many sectors or wide geographical areas without sufficient coordination, resources become diluted and the social returns of circularity diminish. From a consumer perspective, such scale mismatches may also result in uneven distribution of benefits and costs, potentially placing disproportionate burdens on certain consumer groups rather than enhancing inclusive well-being. These patterns suggest that more targeted, context-specific, and locally grounded CE strategies—focused on priority sectors, vulnerable groups, or specific regions—can generate higher social returns by aligning implementation scale with institutional capacity and consumer needs.

The study also yields clear policy implications. Strengthening the social benefits of circular transformation requires closer alignment between circular economy policies and consumer protection frameworks, social programmes, behavioral incentives, and community-

level initiatives. Ultimately, the extent to which circularity contributes to societal well-being depends not on the scale of activities alone, but on the efficiency, coherence, and strategic design of governance frameworks that connect circular practices to fairness, consumer inclusion, and broader social outcomes. Without such alignment, circular economy transitions risk achieving environmental objectives while falling short of their social and consumer-oriented potential.

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