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JRC Statistical Audit of the Competitive Sustainability Index 2022

Saisana, Michaela

Caperna, Giulio

Moura, Carlos

Neves, Ana Rita

Papadimitriou, Eleni

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Contact information
European Commission
Joint Research Centre
Directorate for Competences
Monitoring, Indicators and Impact Evaluation Unit
Competence Centre on Composite Indicators and Scoreboards
Email: jrc-coin@ec.europa.eu

Competence Centre on Composite Indicators and Scoreboards
https://ec.europa.eu/knowledge4policy/composite-indicators
Visualisation tools: https://composite-indicators.jrc.ec.europa.eu/

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Abstract

'Competitive sustainability' is to be understood as the ability of an economy, companies and industrial ecosystems to excel relative to international competitors in their transition to sustainable economy – with climate neutrality at its core – through investment in the necessary innovation. The competitive sustainability concept is a term first used by the European Commission in its 2020 Annual Sustainable Growth Strategy. In November 2021 the Competitiveness Council called for new performance indicators to measure the success of its industrial policy. The Cambridge Institute for Sustainability Leadership, following a working paper on the rationale for competitive sustainability[1], operationalised the concept by developing the Competitive Sustainability Index to provide EU Member States with a tool to measure and benchmark competitive sustainability as determining element of a country' ability to be competitive and to grow in a sustainable way.

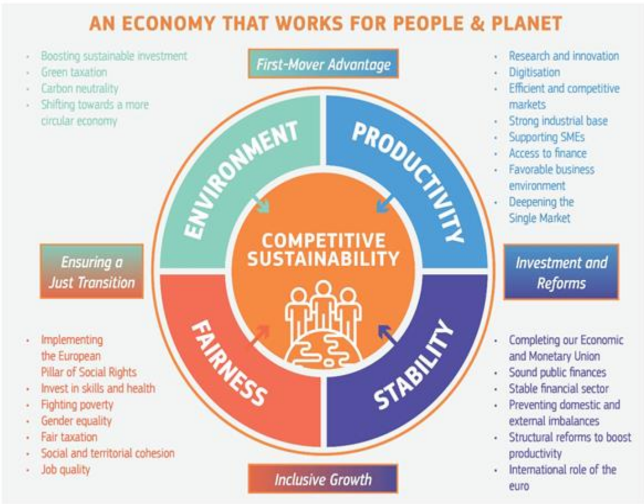
This first edition of the Competitive Sustainability Index builds on four dimensions: Economy/Productivity, Society/Fairness, Governance/Stability, and Green/Environment. The conceptual framework is populated with 84 indicators, further aggregated into 31 components, 10 sub-dimensions, 4 dimensions, and finally into an overall index. This statistical audit, conducted by the European Commission's Joint Research Centre (JRC), aims at maximising the reliability and transparency of the Competitive Sustainability Index framework. This statistical quality check should enable policy analysts and researchers alike to draw more relevant and meaningful advice to improve or fully unleash the competitive sustainability potential of the EU Member States.

[1] University of Cambridge Institute for Sustainability Leadership (CISL). (2020). Developing the EU's 'competitive sustainability' for a resilient recovery and dynamic growth. Cambridge, UK: the Cambridge Institute for Sustainability Leadership. https://www.cisl.cam.ac.uk/resources/low-carbon-transformation-publications/developing-the-eus-competitive-sustainability-for-a-resilient-recovery-and-dynamic-growth

1 Introduction

‘Competitive sustainability’ is to be understood as the ability of an economy, companies and industrial ecosystems to excel relative to international competitors in their transition to sustainable economy – with climate neutrality at its core – through investment in the necessary innovation. The competitive sustainability concept is a term first used by the European Commission in its 2020 Annual Sustainable Growth Strategy (Figure 1) and it is captured by four dimensions: Productivity, Fairness, Stability and Environment. In November 2021 the Competitiveness Council called for new performance indicators to measure the success of its industrial policy.

Figure 1. Commission’s concept for Competitive Sustainability in the 2020 Annual Sustainable Growth Strategy



Source: 2020 Annual Sustainable Growth Strategy

The Cambridge Institute for Sustainability Leadership, following a working paper on the rationale for competitive sustainability, operationalised the concept by developing the Competitive Sustainability Index to provide EU Member States with a tool to measure and benchmark competitive sustainability as determining element of a country’s ability to be competitive and to grow in a sustainable way.

The Joint Research Centre (JRC) has been invited to audit this first edition of the Competitive Sustainability Index. The present JRC assessment of the 2022 edition of the Competitive Sustainability Index focuses on two main issues: (1) the statistical coherence of the indicator framework and (2) the impact of key modelling assumptions on the Competitive Sustainability Index scores and ranks. The JRC analysis complements the reported country rankings for the overall Competitive Sustainability Index, and for the four dimensions of competitive sustainability, with confidence intervals in order to better appreciate the robustness of these ranks to the computation methodology (in particular, the missing data estimation, weights, and aggregation formula). Furthermore, the JRC analysis includes an assessment of the added value of the Competitive Sustainability Index and a comparison with other global measures of attractiveness, competitiveness, and innovation.

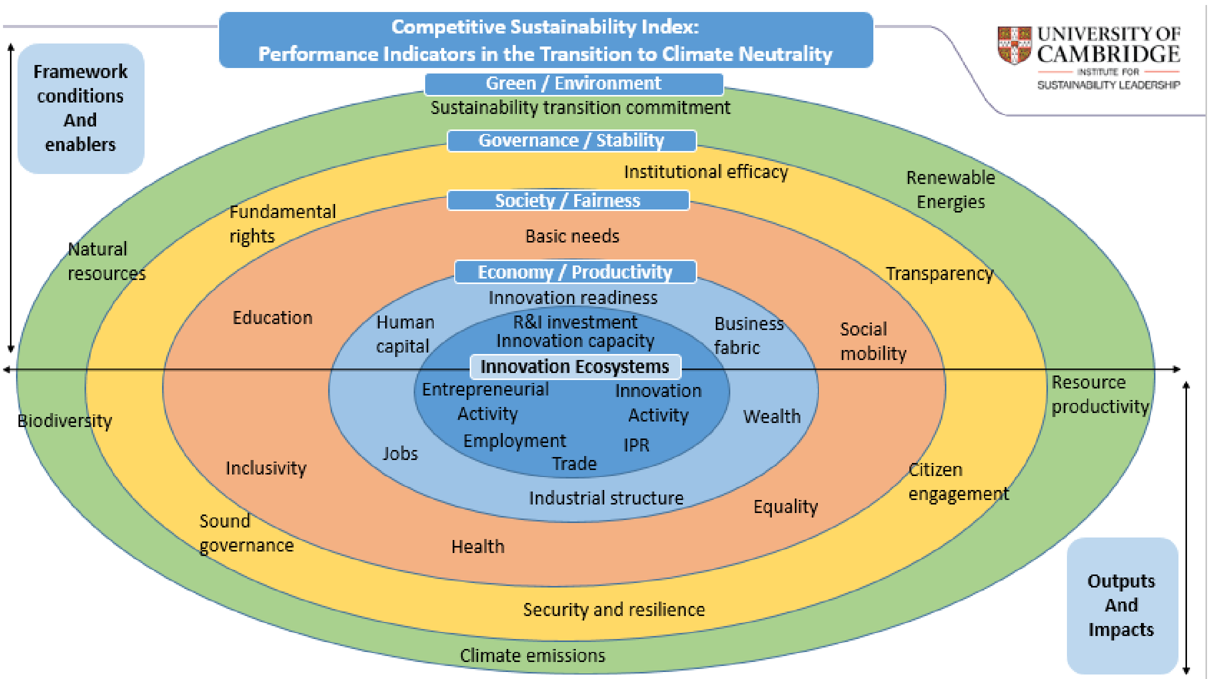
Given that the present statistical analysis of the Competitive Sustainability Index will mostly, though not exclusively, be based on correlations, the correspondence of the Competitive Sustainability Indicator Framework to a real-world phenomenon needs to be critically addressed because correlations need not necessarily represent the real influence of the individual indicators on the phenomenon being measured. In this respect, the Competitive Sustainability Index has been developed following an iterative process that went back and forth between the theoretical understanding of competitiveness and sustainability on the one hand, and empirical observations on the other. The Competitive Sustainability Index needs thus to continuously be nurtured by a dynamic iterative dialogue between the principles of statistical soundness and conceptual relevance.

The JRC's statistical assessment aims at maximising the reliability and transparency of the Competitive Sustainability Index framework. The statistical quality checks and findings herein should enable policy analysts and researchers alike to draw more relevant and meaningful insights to improve or fully unleash the competitive sustainability potential of the EU Member States.

2 Conceptual framework and statistical coherence

This first edition of the Competitive Sustainability Index benchmarks EU Member States' performance on four dimensions of competitive sustainability: Economy/Productivity, Society/Fairness, Governance/Stability, and Green/Environment. The conceptual framework is populated with 84 indicators, further aggregated into 31 components, 10 sub-dimensions, 4 dimensions, and finally into an overall index (Figure 2).

Figure 2. Competitive Sustainability Index framework

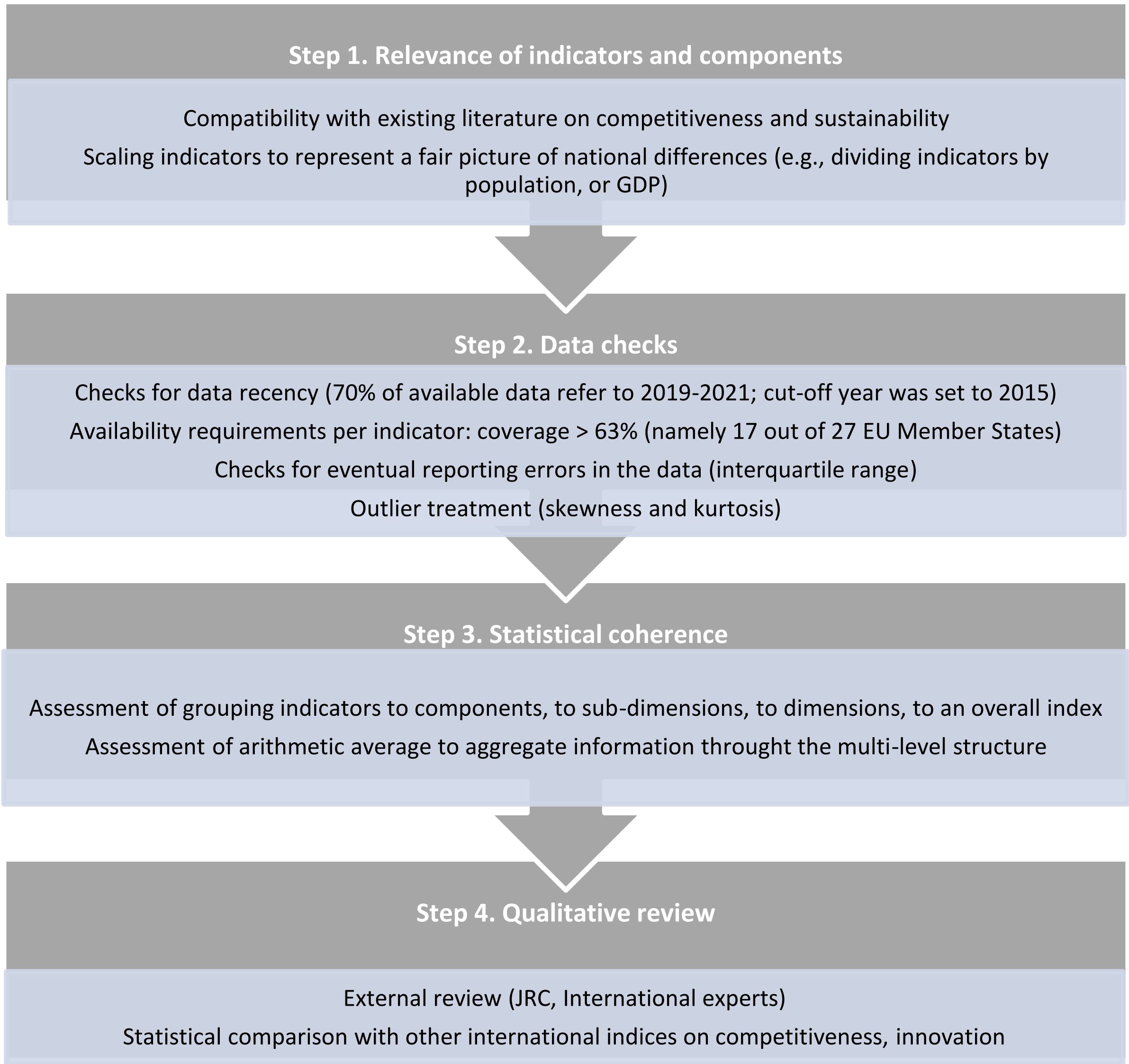


Source: Cambridge Institute for Sustainability Leadership

Both the concepts and indicators underlying the Competitive Sustainability Index benefitted from expert workshops organised by the developers in September and December 2021, whereby the JRC was invited to attend. Following an invitation by the index developers, the JRC also undertook an initial assessment of the Competitive Sustainability data set in July–September 2022. The revised indicator framework provided by the development team to the JRC largely incorporated the issues identified and discussed in earlier versions of the framework, with particular attention to the exclusion or substitution of indicators that were proven not to add to the coherence of the framework or to be not influential on the final values of the index.

Following the iterative process during which the indicator framework was fine-tuned, the JRC assessment of the statistical coherence in this final version of the Competitive Sustainability framework followed four steps (Figure 3).

Figure 3. Conceptual and statistical coherence in the Competitive Sustainability Index Framework



Source: European Commission's Joint Research Centre, 2022.

Step 1: Relevance

Almost 430 indicators were initially screened by the index developers for their relevance to the four dimensions of competitive sustainability on the basis of literature review and expert consultation in 2021-2022. After screening for data coverage and timeliness, and subsequently testing for statistical coherence, 84 indicators were selected. To represent a fair picture of country differences, indicators were scaled either at the source or by the developing team as appropriate and where needed.

Step 2: Data checks

The most recently released data within the period 2015–2021 were used for each EU Member State to reflect the latest updates issued by Eurostat and other leading international statistical bodies from which the database is derived.

Indicators were included if data availability was at least 63% (namely 17 out of the 27 EU Member States). As a result, the Competitive Sustainability dataset data set has 94.7% data coverage across the 27 EU Member States and 84 indicators. The impact of missing values on the competitive sustainability results is further discussed in Section 2.

Potentially problematic indicators that could bias the overall results were identified by the development team, as per the JRC guidelines, on the basis of two measures related to the shape of the indicators' distribution: skewness and kurtosis. Values were treated if the indicators had absolute skewness greater than 2 and absolute value of kurtosis greater than 3.5 (or only kurtosis greater than 10). The indicators affected by outliers were treated through winsorisation, i.e. extreme values were replaced by the closest neighbour. Values were replaced iteratively, until the skewness and kurtosis of the indicator met the above criteria. This data treatment, which is common in a composite indicator context, is undertaken with a view to avoid that few very high or very low values result in polarised indicators and scores, and introduce distortion in the correlation coefficients that are subsequently used for the analysis of the statistical coherence in the competitive sustainability framework.

Step 3: Statistical Coherence

The reliability of the Competitive Sustainability Index depends, inter alia, on the degree of coherence between the conceptual framework – 84 indicators grouped into 31 components, 10 sub-dimensions, 4 dimensions and finally into an index – and the statistical relations of the data. The more the statistical structure of the selected dataset is compatible with the conceptual framework for measuring Competitive Sustainability, the higher will be the reliability of the Index ranks and of the dimensions ranks. The statistical coherence of the indicator framework was assessed by analysing whether the 84 indicators and 31 components explain a sufficient amount of variation in the aggregate scores (either in the dimensions or the overall index) by means of correlation, cross-correlation, and principal component analysis.

Given that the analysis of statistical coherence of the Competitive Sustainability Index is based on correlations, the correspondence of the index to a real-world phenomenon needs to be critically addressed by experts in the field because 'correlations need not necessarily represent the real influence of the individual indicators on the phenomenon being measured'[2]. The point made here is that the validity of the indicator framework underpinning the Competitive Sustainability Index relies on the combination of both statistical soundness and conceptual relevance. In this respect, the Competitive Sustainability framework has been developed following an iterative process that went back

[2] See (OECD-JRC, 2008).

and forth between the theoretical understandings of competitive sustainability on the one hand, and data observations on the other.

Principal component analysis was used to assess the extent to which the conceptual framework underpinning the Competitive Sustainability Index is compatible with the data statistical properties. Results suggest that the expectation of a single statistical dimension (i.e., no more than one principal component with eigenvalue greater than 1.0) is confirmed for 24 of the 31 components, for 8 of the 10 sub-dimensions, for all 4 dimensions, and for the overall index. The presence of more than one "statistical dimensions" suggests that some of the information content of some indicators and components in the Competitive Sustainability framework does not arrive at the higher aggregation levels. This finding is discussed in more detail later in this section.

A more detailed analysis of the correlation structure within and across the four dimensions of Competitive Sustainability confirms the expectation that the 31 components are generally more correlated to their own dimension than to any other (see Table 1). This result suggests that the allocation of the 31 components to a specific dimension of a country's competitive sustainability is consistent both from conceptual and statistical perspectives. Furthermore, most associations between components and the respective dimension are statistically significant, and most correlation coefficients within a dimension are close to or greater than 0.70, which suggests that at least half of the variance in the dimension scores can be explained by the underlying components.

The four dimensions of Competitive Sustainability share a single statistical dimension. The Competitive Sustainability Index captures 75% of the total variance in the four dimensions, and the four correlation coefficients (between the index and each dimension) are sufficiently high, 0.90 or greater for the first three dimensions, and 0.68 for the Green/Environment dimension. This result supports the aggregation of the four dimensions into one number and suggests that all four dimensions of a country's competitive sustainability can explain more than half of the variation of the Index scores, and vice versa. The reliability of the Competitive Sustainability Index, measured by the Cronbach-alpha value, is very good at 0.84—well above the 0.7 threshold for a reliable aggregate of the four dimensions[3].

[3] See Nunnally (1978).

Table 1. Statistical coherence in the Competitive Sustainability framework: correlations between components with the dimensions and with the overall index

Dimensions	Sub-dimensions	Components	Economy / Productivity	Society / Fairness	Governance / Stability	Green / Environment	Competitive Sustainability Index
Economy / Productivity	Framework conditions	1.1.1 Innovation readiness	0.78	0.81	0.90	0.58	0.90
		1.1.2 Human capital	0.61	0.76	0.74	0.59	0.79
		1.1.3 Business fabric	0.55	0.37	0.55	0.51	0.55
	Innovation enablers	1.2.1 Business R&I investment	0.83	0.55	0.58	0.51	0.70
		1.2.2 Innovation capacity	0.81	0.53	0.54		0.59
	Outputs	1.3.1 Intellectual Property Rights (IPR)	0.70	0.43	0.55	0.40	0.60
		1.3.2 Innovation Activity	0.67	0.53	0.41		0.53
		1.3.3 Entrepreneurial Activity	-0.36	-0.33			-0.31
		1.3.4 Trade	0.53		0.32	0.38	0.40
		1.3.5 Employment	0.71	0.47	0.43		0.50
	Impacts	1.4.1 Wealth	0.58	0.41	0.44	0.40	0.52
		1.4.2 Industrial structure	0.47			0.34	0.38
		1.4.3 Jobs	0.62	0.59	0.60		0.57
Society / Fairness	Framework conditions	2.1.1 Education	0.67	0.75	0.81	0.41	0.78
		2.1.2 Basic needs	0.50	0.79	0.57		0.64
		2.1.3 Social mobility	0.65	0.81	0.73		0.72
	Impacts	2.2.1 Inclusivity	0.52	0.81	0.60		0.65
		2.2.2 Equality	0.63	0.69	0.62	0.42	0.69
		2.2.3 Health	0.58	0.74	0.53	0.42	0.66
Governance / Stability	Framework conditions	3.1.1 Fundamental rights	0.81	0.86	0.96	0.58	0.95
		3.1.2 Transparency	0.82	0.80	0.93	0.67	0.94
		3.1.3 Institutional efficacy	0.77	0.78	0.92	0.64	0.91
	Impacts	3.2.1 Sound governance	0.49	0.55	0.71		0.59
		3.2.2 Citizen engagement	0.77	0.75	0.90	0.57	0.88
		3.2.3 Security and Resilience to External Shocks	0.51	0.45	0.65	0.40	0.59
Green / Environment	Framework conditions	4.1.1 Renewable Energies	0.30		0.32	0.65	0.36
		4.1.2 Sustainability transition commitment	0.50	0.67	0.60	0.60	0.68
		4.1.3 Natural resources	0.35		0.31	0.49	0.34
	Impacts	4.2.1 Resource productivity				0.60	0.19
		4.2.2 Climate Emissions	0.48	0.63	0.55	0.63	0.65
		4.2.3 Biodiversity		-0.40		-0.04	-0.22
		Dimensions of Competitive Sustainability					
			Economy / Productivity	**Society / Fairness**	**Governance / Stability**	**Green / Environment**	**Competitive Sustainability Index**
		Economy / Productivity	1.00	0.77	0.83	0.50	0.90
		Society / Fairness	0.77	1.00	0.84	0.41	0.90
		Governance / Stability	0.83	0.84	1.00	0.60	0.96
		Green / Environment	0.50	0.41	0.60	1.00	0.68

Notes: Numbers represent the Pearson correlations coefficients between the Competitive Sustainability Index (and its four dimensions) with the underlying 31 components for the latest year available (2015-2021) for the 27 EU Member States. Shaded areas show the conceptual grouping of the components into dimensions. Values greater than 0.7 (in the shaded areas) are desirable because they imply that the competitive sustainability dimension (or index) captures at least 50% (≈ 0.7×0.7) of the variation in the underlying components. Values between 0.3 and 0.7 are acceptable. Instead, values lower than 0.3 are not presented because they are considered to be negligible.

Source: European Commission's Joint Research Centre, 2022.

Thus far, the statistical coherence tests corroborate the multi-level structure in the Competitive Sustainability Index framework. At the same time, a critical review of the results in Table 1 evidences issues that are worth of further reflection by the index developers, either because they indicate avenues for refining the indicator framework in next releases of the index or because they point interesting avenues for policy analysis.

First, eight of the 31 components are found to have a transversal impact across three dimensions in the Competitive Sustainability framework. Innovation readiness (1.1.1), which is part of the Framework conditions for Economy/Productivity (with correlation 0.78), it is also found to have strong statistical association to Society/Fairness (correlation 0.81) and to Governance/Stability (correlation 0.90). Similarly, Human capital (1.1.2), which is also part of the Framework conditions for Economy/Productivity (correlation 0.61), is also found to have a good correlation to Society/Fairness and to Governance/Stability (correlation about 0.75). The other six components in the framework with such a transversal impact across three dimensions of competitive sustainability are: Education (2.1.1), Social Mobility (2.1.3), Fundamental rights (3.1.1), Transparency (3.1.2), Institutional efficacy (3.1.3), and finally Citizen engagement (3.2.2). The transversal impact of these eight components of competitive sustainability may be worth of further reflection and analysis by the index developers, as it may offer additional insights on EU Member States competitive sustainability attributes. In fact, given this transversal impact across three dimensions, these eight components – Innovation readiness, Human capital, Education, Social Mobility, Fundamental rights, Transparency, Institutional efficacy, and Citizen engagement – are also found to be the best predictors for a country's competitive sustainability in the European Union.[4]

Second, there are three components of competitive sustainability that do not significantly correlate either with the respective dimension, or with the overall index. These are Entrepreneurial activity (1.3.2) that is part of the Outputs of Economy/Productivity, and Resource productivity (4.2.1) and Biodiversity (4.2.3) that are both part of the Impacts of Green/Environment. Although conceptually enriching the Competitive Sustainability framework, these three components (and some of their underlying indicators) are found not to co-vary with the overall index. This means that EU Member States may achieve high Competitive Sustainability scores despite of poor performance in Entrepreneurial activity, Resource productivity, and Biodiversity. On one hand, the poor correlation between Entrepreneurial activity and the Competitive Sustainability Index may be attributed to the calculation of the indicators underlying Entrepreneurial activity. The JRC recommendation to the developing team is to consider whether a different formulation or different data sources for these indicators may be more appropriate. On the other hand, the poor correlation between Resource productivity and Biodiversity (and also Renewable energies, and Natural resources) with the overall Competitive Sustainability Index is more worrisome, yet not surprising. This finding is in line with relevant scientific literature and a recent article in Nature Communications [5], and it points towards a masking - rather than a synergistic effect - of competitiveness on environmental protection, and the more worrisome finding that up until 2021 there has not been sufficient integration of environmental priorities into EU Member States' growth and competitiveness plans.

Overall, the statistical coherence tests corroborate the multi-level structure in the Competitive Sustainability Index framework, whereby the desired unidimensionality is confirmed for 24 of the 31 components, 8 of the 10 sud-dimensions, all four dimensions and for the overall index. Furthermore, most components in the Competitive Sustainability framework are found to be influential, having statistically significant correlations with the dimensions, and their influence arrives up to the overall index. This is a desirable outcome as it suggests that the information content in most of the underlying indicators and components is maintained at all levels of aggregation in the Competitive Sustainability framework.

[4] The correlation coefficients between these components with the Competitive Sustainability Index range from about 0.78 (in the case of Education or Human capital) to about 0.95 (in the case of Fundamental rights or Transparency).

[5] Zeng et al., 2020

Step 4: Qualitative Review

The Competitive Sustainability Index results for the EU Member States were also evaluated by an ad-hoc Advisory Panel and by international experts invited by the Cambridge Institute for Sustainability Leadership to verify that they are, to a great extent, consistent with current evidence, existing research and prevailing theory.

To complement this qualitative evaluation, the Competitive Sustainability Index results are compared herein vis-à-vis other similar international indices. The expectation is that the Competitive Sustainability Index correlates strongly to other international indices on competitiveness and innovation. Table 2 compares the Competitive Sustainability Index for the EU Member States with the most recent versions of four relevant international indices—the World Intellectual Property Organization (WIPO)'s 2022 Global Innovation Index; the European House Ambrosetti's 2022 Global Attractiveness Index; the International Institute for Management Development (IMD)'s 2022 World Competitiveness Index; and INSEAD's Global Talent Competitiveness Index—using the most recent rankings for the EU Member States extracted from these projects' websites. The rank correlation between the Competitive Sustainability Index and all four international indices is substantially high (correlation ranges 0.81-0.94), which suggests that the Competitive Sustainability Index framework is consistent with the frameworks on global innovation, global attractiveness, and global competitiveness. At the same time, looking at the shifts in rankings, 30%, 59%, 19% and 19% of the EU Member States that feature in the other four international indices differ in ranking by 4 or more positions when comparing the Competitive Sustainability Index with the four selected international indices. This indicates that the Competitive Sustainability Index offers additional insights into EU Member States competitive sustainability compared to the 2022 Global Innovation Index, the 2022 Global Attractiveness Index, the 2022 World Competitiveness Index, and the 2022 Global Talent Competitiveness Index.

Table 2. Statistical consistency between the Competitive Sustainability Index and relevant international indices

Rank differences with respect to the Competitive Sustainability Index (CSI)	Global Innovation Index 2022 (Cornell, INSEAD, WIPO)	Global Attractiveness Index 2022 (The European House Ambrosetti)	World Competitiveness Index 2022 (IMD)	Global Talent Competitiveness Index 2022
6 or more positions	15%	26%	12%	7%
4 or 5 positions	15%	33%	8%	11%
4 or more positions *	**30%**	**59%**	**19%**	**19%**
3 positions	22%	7%	12%	11%
1 or 2 positions	33%	19%	50%	52%
0 positions	15%	15%	19%	19%
Total	100%	100%	100%	100%
Spearman rank correlation coefficient with the CSI	0.86	0.81	0.92	0.94
Common countries with the CSI	27	27	26	27

Notes: The comparison between the Competitive Sustainability Index and the other international indices was based on the common set of countries (27 EU Member States, except for the World Competitive Index where Malta is not included).
(*) This row is the sum of the two rows above.

Source: European Commission's Joint Research Centre, 2022.

Notwithstanding these statistical tests and the positive outcomes regarding the statistical soundness and conceptual relevance of the Competitive Sustainability Index, it is important to mention that the index and its indicator framework has to remain open to future improvements as better data, more comprehensive surveys and assessments, and new relevant research studies and data become available.

3 Impact of modelling assumptions in the Competitive Sustainability Index

Assessing the effect of varying the modelling assumptions in the Competitive Sustainability Index inside plausible ranges is an important part of the statistical audit. The rationale for the choices made by the developing team is manifold. For instance, literature review and expert opinion on competitive sustainability, coupled with statistical analysis, is behind the selection of the 84 indicators and the multi-level structure of the index; common practice and easy of interpretation suggests the use of a min-max normalization approach in the [0–100] range for the indicators; statistical analysis guides the choice on the treatment of outliers; and simplicity seems to advocate for not estimating missing data, assigning equal weights at all levels and adopting an arithmetic average formula.

Despite the well-substantiated rationale for the choices made during the Competitive Sustainability Index development, there is an unavoidable subjectivity (or uncertainty), which is accounted for in the robustness assessment carried out by the JRC. More precisely, the uncertainly analysis is conducted herein in order to allow for the joint analysis of the impact of the modelling choices on the index results, resulting in error estimates and confidence intervals calculated for the 27 EU Member States included in the Competitive Sustainability Index.

As suggested in the relevant literature on composite indicators[6], the robustness assessment of the Competitive Sustainability Index was based on Monte Carlo simulation and multi-modelling approaches, applied to 'error-free' data where eventual errors and typos have already been corrected in a preliminary stage. In particular, the three key modelling issues considered in the assessment of the index were the treatment of missing data, the aggregation formula and weights at the sub-dimension and at dimension level.

Missing data. The Competitive Sustainability Index developers, for transparency and replicability and following common practice on composite indicator development, opted not to estimate missing data. Technically, the 'no imputation' choice is equivalent to replacing an indicator's missing value for a given country with the respective component score. Hence, the available data (indicators) in the incomplete component of competitive sustainability may dominate the results, sometimes biasing the ranks up or down. Furthermore, the 'no imputation' choice might encourage countries not to report low data values. To test the impact of the 'no imputation' choice, the JRC estimated missing values in the Competitive Sustainability dataset using the Expectation Maximization (EM) algorithm that was applied in the entire set of 84 indicators.[7]

Aggregation. Regarding the aggregation formula, decision-theory practitioners challenge the use of simple arithmetic averages because of their fully compensatory nature, in which a comparative high advantage on a few indicators can compensate a comparative disadvantage on many indicators.[8] To assess the impact of this compensability issue, the strong perfect substitutability assumption inherent in the arithmetic average was relaxed in this analysis; instead the geometric average within each of the four dimensions and across them was considered as an alternative. Nevertheless, the arithmetic average has

[6] Saisana et al., 2005; Saisana et al., 2011 ; Vértesy 2016; Vértesy and Deiss, 2016

[7] The Expectation-Maximization (EM) algorithm (Little and Rubin, 2002; Schneider, 2001) is an iterative procedure that finds the maximum likelihood estimates of the parameter vector by repeating two steps. Step 1: The expectation E-step: Given a set of parameter estimates, such as a mean vector and covariance matrix for a multivariate normal distribution, the E-step calculates the conditional expectation of the complete-data log likelihood given the observed data and the parameter estimates. Step 2: The maximization M-step: Given a complete-data log likelihood, the M-step finds the parameter estimates to maximize the complete-data log likelihood from the E-step. The two steps are iterated until the iterations converge.

[8] Munda, 2008.

been maintained at the indicator level and component levels, where full compensability may be justifiable. The geometric average is a partially compensatory approach that rewards countries with balanced profiles, and motivates other countries to improve in the Competitive Sustainability sub-dimensions and dimensions in which they perform poorly, and not just in any Competitive Sustainability dimension.[9]

Weights. While the term multi-modelling refers to testing alternative assumptions—that is, an alternative aggregation method, and missing data estimation method—the Monte Carlo simulation explored the issue of weighting and comprised 1,000 runs, each corresponding to a different set of weights for the 10 sub-dimensions and 4 dimensions, randomly sampled from uniform continuous distributions centred in the reference values (equal weighting within and across dimensions). The choice of the range for the weights' variation was driven by two opposite needs: to ensure a wide enough interval to have meaningful robustness checks, and to respect the rationale of the Competitive Sustainability Index that places equal importance on all sub-dimensions and dimensions. Given these considerations, limit values of uncertainty intervals for the sub-dimension and dimension weights are presented in Table 3. In all simulations, sampled weights are then rescaled so that they always sum to 1.

Table 3. Uncertainty parameters in the Competitive Sustainability Index: missing values, weights, aggregation

		Reference	Alternative
I. Uncertainty in the treatment of missing values		No estimation of missing data	Expectation Maximization (EM)
II. Uncertainty in the aggregation formula at pillar level		Arithmetic average	Geometric average
IIIa. Uncertainty in the weights (within a dimension)			
Dimension	*Sub-dimension*	*Reference value for the weight*	*Distribution assigned for robustness analysis*
	Framework conditions	0.25	U[0.15, 0.35]
	Innovation enablers	0.25	U[0.15, 0.35]
	Outputs	0.25	U[0.15, 0.35]
Economy/Productivity	Impacts	0.25	U[0.15, 0.35]
	Framework conditions	0.50	U[0.40, 0.60]
Society/Fairness	Impacts	0.50	U[0.40, 0.60]
	Framework conditions	0.50	U[0.40, 0.60]
Governance/Stability	Impacts	0.50	U[0.40, 0.60]
	Framework conditions	0.50	U[0.40, 0.60]
Green/Environment	Impacts	0.50	U[0.40, 0.60]
IIIb. Uncertainty in the weights (when calculating the index)			
		Reference value for the weight	*Distribution assigned for robustness analysis*
Economy/Productivity		0.25	U[0.15, 0.35]
Society/Fairness		0.25	U[0.15, 0.35]
Governance/Stability		0.25	U[0.15, 0.35]
Green/Environment		0.25	U[0.15, 0.35]

Source: European Commission's Joint Research Centre (2022)

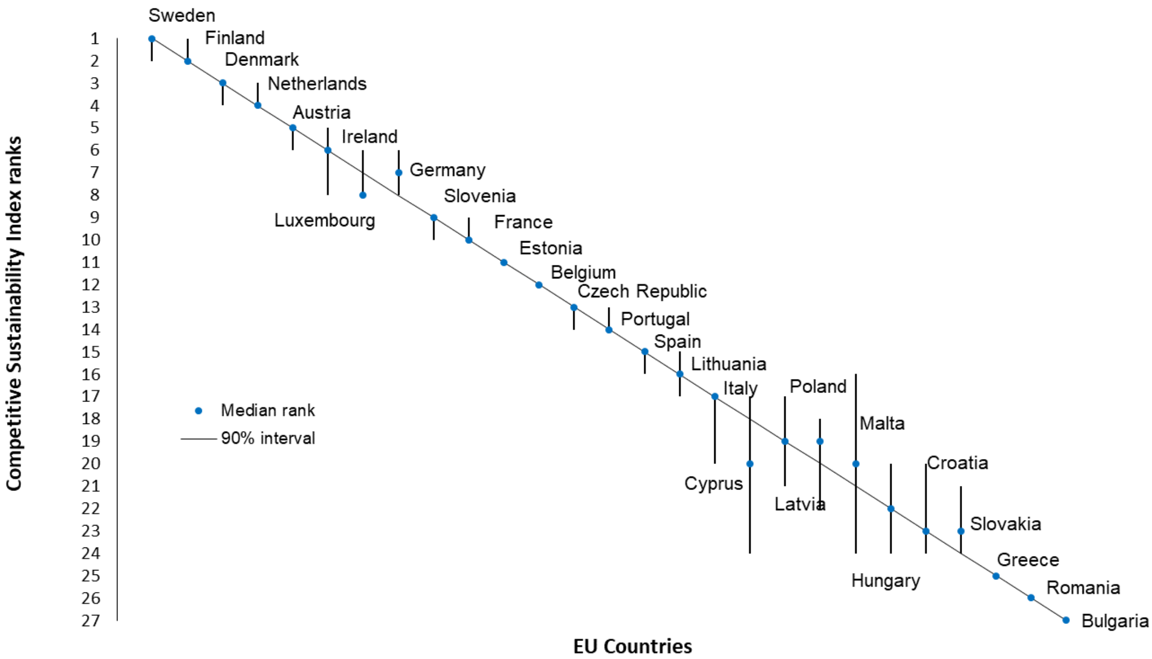
[9] In the geometric average, pillars are multiplied as opposed to summed in the arithmetic average. Pillar weights appear as exponents in the multiplication. A constant of 0.001 was added to the pillar scores to avoid zero values that would have led to zero geometric averages.

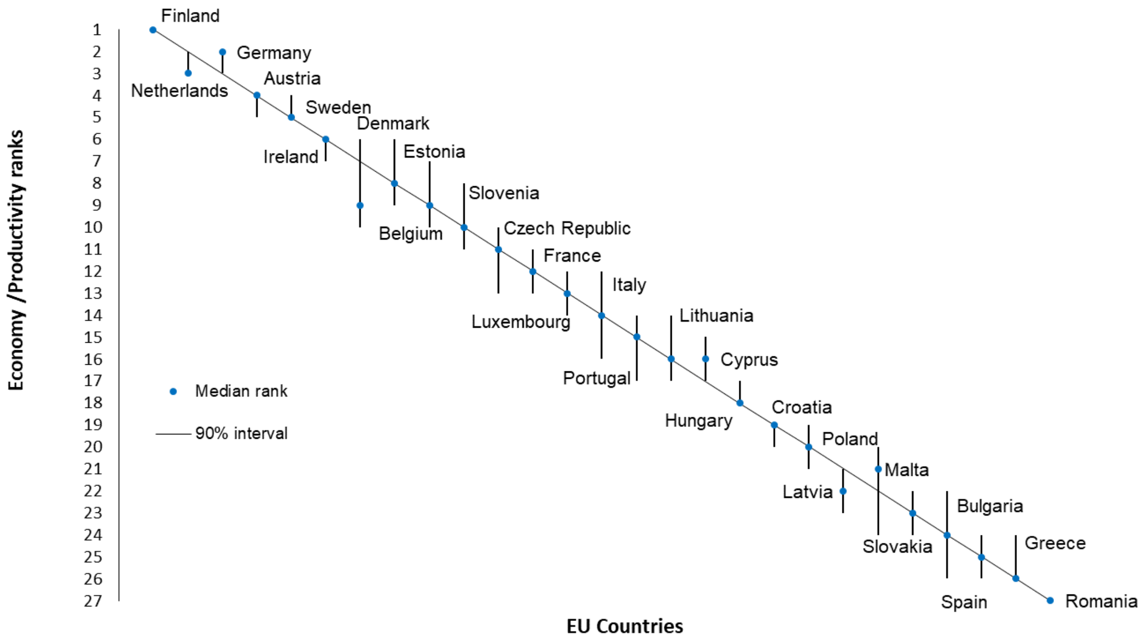
Four models were tested based on the combination of no imputation versus EM imputation at the indicator level, arithmetic versus geometric average at the sub-dimension and dimension levels. Combined with 1,000 simulations per model (random weights versus fixed weights), a total of 4,000 simulations for the Competitive Sustainability Index were run.

For full transparency and information, the main results of the robustness analysis are shown in Figure 4 with median ranks and the 90% confidence intervals computed across the 4,000 Monte Carlo simulations for the Competitive Sustainability Index and its four dimensions. EU Member States are ordered from higher to lower performance according to their reference rank (black line), the dot being the median rank over the simulations.

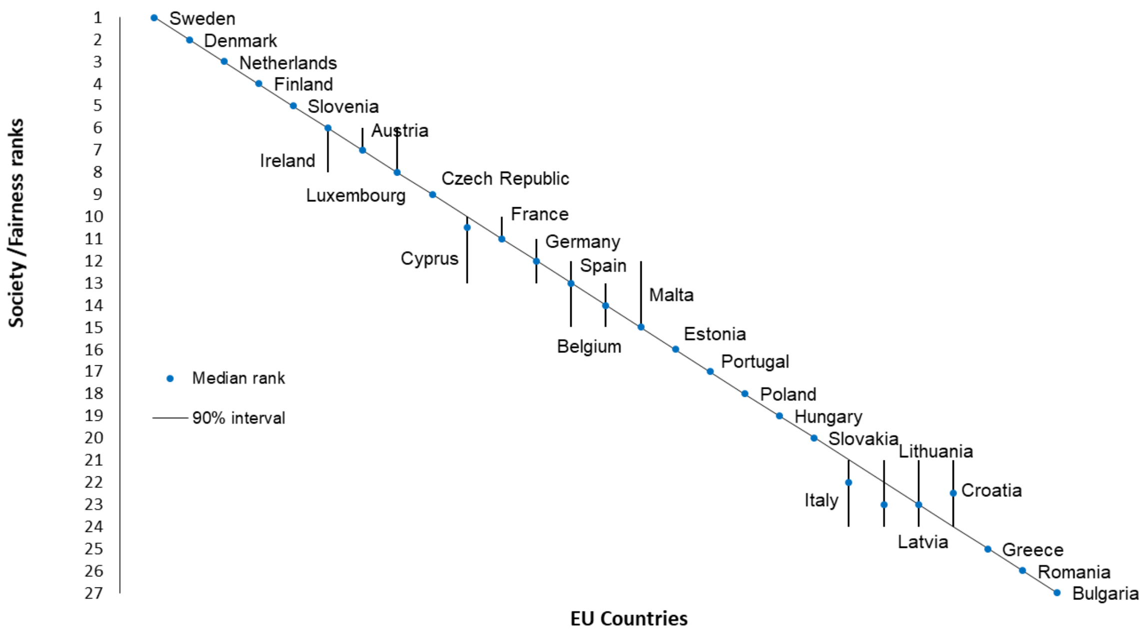
All published Competitive Sustainability Index ranks lay within the simulated 90% confidence intervals, and for all EU Member States these ranks can be considered as representative of the plurality of scenarios simulated herein. Taking the median rank as the yardstick for a country's expected rank in the realm of the unavoidable methodological uncertainties, almost all EU Member States are found to shift 1 position or no shift with respect to the median rank in the Competitive Sustainability Index (with the exception of Cyprus that shifts 2 positions compared to the median rank in the simulations). Furthermore, for 25 of the 27 EU Member States the simulated rank intervals are narrow enough for meaningful inferences to be drawn. For these countries, there are fewer than 4 positions shift. Yet, two countries experience significant changes in rank with variations in weights and aggregation formula and because of the estimation of missing data. These two countries – Cyprus and Malta – have 90 percent confidence interval widths around 7-8 positions. Consequently, their Competitive Sustainability Index ranks – at the 18th position for Cyprus and 21st for Malta – should be interpreted cautiously and certainly not taken at face value. The uncertainty analysis results for the four dimensions of competitive sustainability are also reassuring. For most countries, there are fewer than 4 positions shift across all four dimensions of competitive sustainability, except for Malta (6 positions in the Governance/Stability dimension), and Italy and Croatia (6 and 5 positions, respectively, in the Green/Environment dimension).

Figure 4. Robustness analysis in the Competitive Sustainability Index and its four dimensions

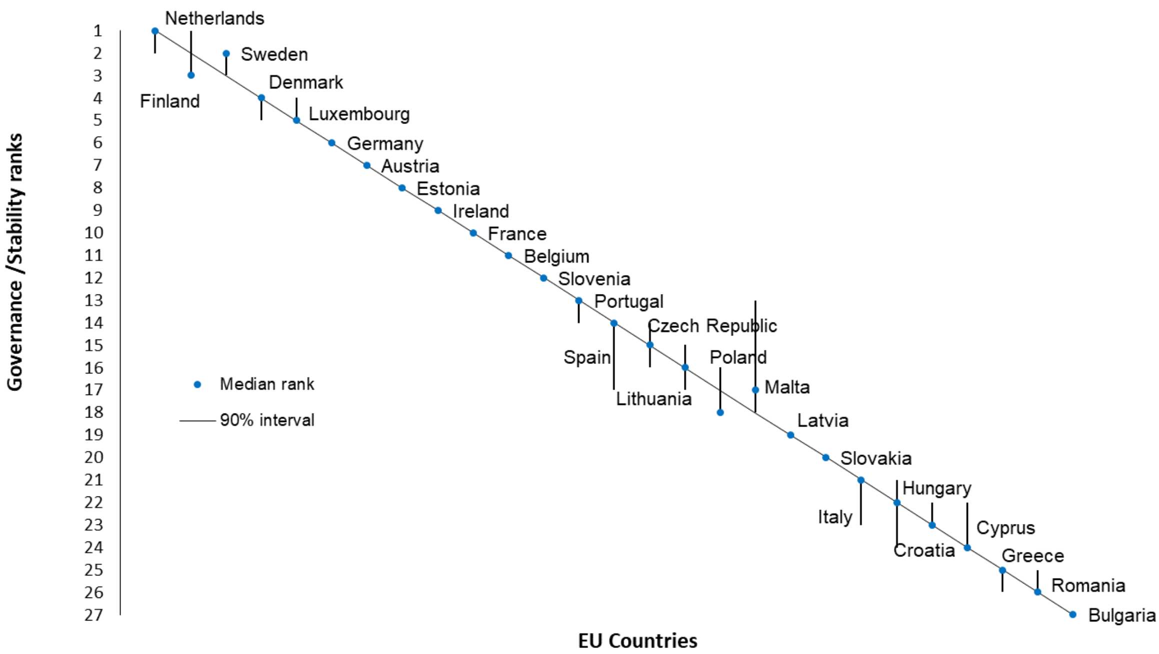


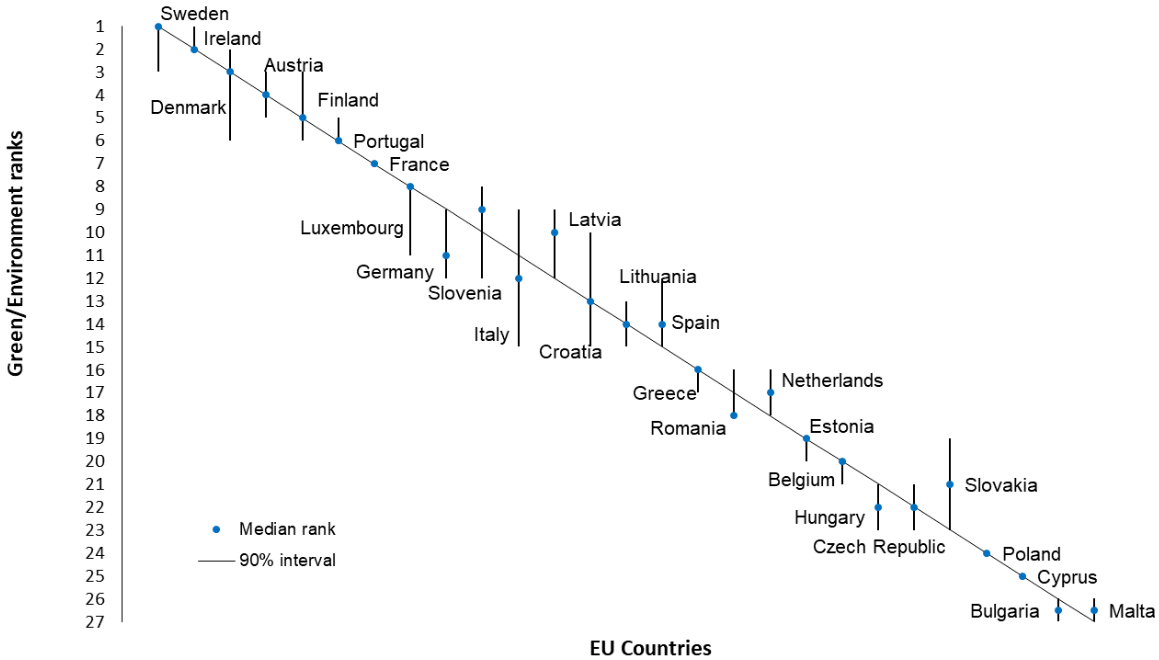


Economy /Productivity ranks
EU Countries
Median rank
90% interval
Finland
Germany
Netherlands
Austria
Sweden
Denmark
Ireland
Estonia
Slovenia
Belgium
Czech Republic
France
Italy
Luxembourg
Lithuania
Cyprus
Portugal
Hungary
Croatia
Poland
Malta
Latvia
Bulgaria
Slovakia
Greece
Spain
Romania



Society /Fairness ranks
EU Countries
Median rank
90% interval
Sweden
Denmark
Netherlands
Finland
Slovenia
Austria
Ireland
Czech Republic
Luxembourg
France
Cyprus
Germany
Spain
Malta
Belgium
Estonia
Portugal
Poland
Hungary
Slovakia
Lithuania
Croatia
Italy
Latvia
Greece
Romania
Bulgaria





Notes: Median ranks and intervals are calculated over 4,000 simulated scenarios based on imputing (or not) missing values, random weights plus/minus 25% around the reference weights, and aggregation formula at the sub-dimension and dimension level (see Table 3 for the uncertainty parameters). The Spearman rank correlation between the median rank of the simulations and the overall Competitive Sustainability Index and any of its four dimensions in greater than 0.994.

Source: European Commission's Joint Research Centre, 2022.

Next, the impact of not estimating missing values in the Competitive Sustainability Index is analysed in more detail. The 2015-2021 dataset has very good coverage: 94.7% data available across the 27 EU Member States and 84 indicators. It is reassuring that none of the 5.3% missing values (120 missing data points) are found to have a strong impact either on the Competitive Sustainability Index ranks or any of its dimensions. In all cases, the imputed values by the JRC (using the EM algorithm, as described earlier) result in shifts in country ranks up to 3 positions (for Croatia in the Society/Fairness dimension) and 4 positions (for Slovakia in the Green/Environment dimension).

Concluding, the Competitive Sustainability Index ranks (and those of the four dimensions) are reliable and for all EU Member States the simulated 90% confidence intervals are narrow enough for meaningful inferences to be drawn. Some caution is only needed when interpreting the performance of Cyprus and Malta in the overall Competitive Sustainability Index, of Malta in the Governance/Stability dimension, and of Italy and Croatia in the Green/Environment dimension because of a relatively higher impact of the uncertainty assumptions.

For the readers and policy analysts of the Competitive Sustainability Index report, the recommendation is to consider country ranks for the overall index and its four dimensions within the 90% confidence intervals in order to better appreciate to what degree an EU Member State's rank depends on the three key modelling choices accounted for, namely the estimation of missing data, weights and aggregation formula (at the sub-dimension and dimension level).

4 Added value of the Competitive Sustainability Index: Measuring competitive sustainability with one number?

This last section aims at touching upon the added value of the Competitive Sustainability Index as a summary measure of the four dimensions.

Table 3 shows that Competitive Sustainability Index ranking differs from any of the four dimension rankings by 4 positions or more in at least 11% of the 27 EU Member States, peaking at 52% of the EU Member States in the case of the Green/Environment dimension. This is a desired outcome because it evidences the added value of the Competitive Sustainability Index ranking, which helps to highlight aspects of a country's competitive sustainability that do not emerge directly by looking into the four dimensions separately. At the same time, this result also points towards the value of duly taking into account the individual indicators, components, sub-dimensions and dimensions of Competitive Sustainability on their own merit in order to see which components are driving a country's competitive sustainability.

Table 3. Distribution of differences between the Competitive Sustainability Index rankings and its four dimensions

	Dimensions of Competitive Sustainability			
Rank differences with respect to the Competitive Sustainability Index	**Economy / Productivity**	**Society / Fairness**	**Governance / Stability**	**Green / Environment**
6 or more positions	7%	11%	4%	44%
4 or 5 positions	19%	22%	7%	7%
4 or more positions *	**26%**	**33%**	**11%**	**52%**
3 positions	15%	11%	19%	7%
1 or 2 positions	52%	37%	41%	30%
0 positions	7%	19%	30%	11%
Total	100%	100%	100%	100%
Spearman rank correlation coefficient with the Competitive Sustainability Index	0.91	0.91	0.96	0.70

Note: * This row is the sum of the two rows above.
Source: European Commission's Joint Research Centre, 2022.

Conclusions

The Competitive Sustainability Index, developed by the Cambridge Institute for Sustainability Leadership (CISL), enables analysts, academics and other interested stakeholders to measure and benchmark EU Member States on a number of aspects that together provide a representative profile of the competitive sustainability. With a view to maximise the reliability and transparency of the Competitive Sustainability Index, CISL invited the JRC to assess the statistical coherence and the impact of the methodological choices made in the development of the index. More specifically, in the present report, the JRC delves into the statistical properties of the data and the methodology used in the construction of the Competitive Sustainability Index and provides advice for further improvements. Overall, the analysis herein confirms that the Competitive Sustainability Index framework is well-designed, and that a lot of thought and preparation has been undertaken by the index developers to identify the multiple determinants of an EU Member State's competitive sustainability and the best available data sources to measure this concept.

The key findings of the JRC's statistical assessment of the Competitive Sustainability Index can be summarised as follows:

> *1*
>
> *Competitive Sustainability Index: A statistically coherent monitoring framework*
>
> The analysis of the correlation structure finds the conceptual grouping of the 84 indicators into 31 components, 10 sub-dimensions, 4 dimensions and one overall index, largely justifiable from a statistical point. It also shows that the overall Competitive Sustainability Index, which is the average of four key dimensions measuring Economy/Productivity, Society/Fairness, Governance/Stability, and Green/Environment is unidimensional and has high statistical reliability (Cronbach

alpha 0.84) well above the recommended threshold (0.7) for a reliable aggregate. The vast majority of the 31 components in the Competitive Sustainability framework are also found to be influential all the way up to the index level.

2

Some competitive sustainability components to be kept under the spotlight

Eight of the 31 components are found to have a transversal impact across three dimensions of Competitive sustainability. Although assigned to one dimension in the conceptual framework, these eight components – Innovation readiness, Human capital, Education, Social Mobility, Fundamental rights, Transparency, Institutional efficacy, and Citizen engagement – are found to correlate strongly to the dimensions capturing Economy/Productivity, Society/Fairness, and Governance/Stability. Consequently, they are also found to be the best predictors for a country's competitive sustainability in the European Union.

Three components of competitive sustainability do not correlate significantly either with the respective dimension, or with the overall index. These are Entrepreneurial activity (within Economy/Productivity), and Resource productivity and Biodiversity (within Green/Environment). This means that EU Member States may achieve high Competitive Sustainability scores despite of poor performance in Entrepreneurial activity, Resource productivity, and Biodiversity. On one hand, the poor correlation between Entrepreneurial activity and the Competitive Sustainability Index may be attributed to the calculation of the indicators underlying Entrepreneurial activity. The JRC recommendation to the developing team is to consider whether a different formulation or different data sources for these indicators may be more appropriate. On the other hand, the poor correlation between Resource productivity and Biodiversity (and to some extent also Renewable energies, and Natural resources) with the overall Competitive Sustainability Index is more worrisome, yet not surprising. This finding, which is in line with relevant scientific literature, evidences that up until 2021 there has not been sufficient integration of environmental priorities into EU Member States' growth and competitiveness plans.

3

Negligible impact of missing data on shifts in the Competitive Sustainability rankings

The Competitive Sustainability dataset has very good data coverage: 94.7% of the data available in 2015-2021 across 84 indicators and 27 EU Member States. Uncertainty and sensitivity analysis have shown that none of the 5.3% missing values (120 missing data points) are found to have a strong impact either on the Competitive Sustainability Index ranks or any of its dimensions. In all cases, the statistical estimates for the missing values result in shifts in country ranks up to 3 positions (for Croatia in the Society/Fairness dimension) and 4 positions (for Slovakia in the Green/Environment dimension).

4

The Competitive Sustainability Index allows to reliably benchmark national competitive sustainability in the vast majority of the EU Member States

Compared to the reference Competitive Sustainability rank, 25 of the 27 EU Member States are found to have simulated rank intervals less than 4 positions wide over 4,000 simulations. Some caution is needed for two countries – Cyprus and Malta – that have confidence interval widths around 7-8 positions, and their index ranks should thereafter not be taken at face value. The uncertainty analysis results for the four dimensions of competitive sustainability are also reassuring. For most countries, there are fewer than 4 positions shift across all four dimensions of competitive sustainability, except for Malta (6 positions in the Governance/Stability dimension), and Italy and Croatia (6 and 5 positions, respectively, in the Green/Environment dimension). Thereafter, the Competitive Sustainability Index and its four dimensions allow to reliably benchmark competitive sustainability at national level in the vast majority of the EU Member States.

5

The Competitive Sustainability Index offers new insights on EU Member States competitive sustainability, while at the same time receives external statistical validity

Last but not least, there is an added value in referring to the Competitive Sustainability Index results in order to identify aspects of EU competitive sustainability that do not directly emerge by looking into the four dimensions separately. In fact, the Competitive Sustainability Index ranking and any of the four dimension rankings differ by 4 positions or more for at least 11% up to 52% of the 27 EU Member States.

Also, the external statistical validity testing of the Competitive Sustainability Index confirms the high degree of association (correlation ≈ 0.8 to 0.9) to the latest releases of four relevant international indices: the IMD World Global Competitiveness Ranking, the Cornell University, INSEAD, and WIPO's Global Innovation Index, the European House Ambrosetti's Global Attractiveness Index, and the INSEAD's Global Talent Competitiveness Index. At the same time, one finds that 30% up to 59% of the EU Member States that feature in these four international indices differ in ranking by more than 4 positions when comparing the Competitive Sustainability Index with the recent releases of these international indices. This latter finding means that the Competitive Sustainability Index offers additional insights into national competitive sustainability across the EU that complement and go beyond the findings of other international indices.

6

The JRC audit confirms that the Competitive Sustainability Index sufficiently meets international quality standards for statistical soundness

Overall, the JRC audit confirms that the Competitive Sustainability Index sufficiently meets international quality standards for statistical soundness. Consequently, the Competitive Sustainability Index by the Cambridge Institute for Sustainability Leadership offers a sound starting point for more informed discussions on national competitive sustainability in the EU. Academics and policy analysts should also check the Competitive Sustainability Index results beyond the index scores (and ranks) as the 84 indicators, 31 components, 10 sub-dimensions and four dimensions can offer more in-depth insights on the areas to be more carefully addressed for policy action.

The Competitive Sustainability Index represents a well-designed operational indicator framework that can help to stimulate public interest and help focus policy discussions on the multiple aspects that shape a country's competitive sustainability. Still, the Competitive Sustainability Index, as any other indicator framework aimed at capturing a complex, multidimensional and evolving reality, needs to remain open to improvement. The Competitive Sustainability Index developers intend to keep improving the indicator framework in line with the theoretical advancement in the field and the availability of new (and relevant) data.

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