



JRC TECHNICAL REPORTS

JRC Statistical Audit of the 2022 Commitment to Reducing Inequality index

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2022



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Report completed in September 2022.

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JRC131019

EUR 31259 EN

PDF ISBN 978-92-76-57750-8 ISSN 1831-9424 [doi:10.2760/5642](https://doi.org/10.2760/5642) KJ-NA-31-259-EN-N

Luxembourg: Publications Office of the European Union, 2022

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How to cite this report: Caperna, G., Smallembroek, O., Kovacic, M. and Papadimitriou, E., *JRC Statistical Audit of the 2022 Commitment to Reducing Inequality index*, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/5642, JRC131019

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Abstract

The 2022 Commitment to Reducing Inequality Index (CRI) is a multidimensional index which ranks 161 countries for their policy performance across three pillars covering public services, progressive taxation and labour rights.

The statistical audit presented herein was performed by the European Commission's Joint Research Centre and aims to contribute to ensuring the transparency of the index methodology and the reliability of the results. The report touches upon data quality issues, the conceptual and statistical coherence of the framework, and the impact of modelling assumptions on the results. The analysis suggests that meaningful inferences can be drawn from the index for the vast majority of countries. CRI ranks are shown to be representative of a plurality of scenarios and sufficiently robust to changes in the aggregation method and pillar weights. Despite the good properties of the CRI index, some suggestions are made for possible refinements.

1 Introduction

The Commitment to Reducing Inequality Index (CRI) aims at measuring the extent to which governments are undertaking the task of reducing inequality. It is a multidimensional index composed of nine different sub-pillars organized into three pillars, each of which corresponds to a policy area found to be critical in reducing inequality:

- i. Public services;
- ii. Taxation, and
- iii. Labour rights (previously known as “Worker rights”).

As in the previous edition each pillar is arranged to track:

- i. The policies that each government has enacted in the pillar area;
- ii. The implementation or coverage of these policies in practice, and
- iii. The impact of these policies on reducing income inequality (as measured by their impact on the respective Gini coefficient).

This “three-tiered” structure has been introduced to better identify the impact of the government’s policy commitments while considering its implementation efforts. The index is developed by Development Finance International and Oxfam International. Each pillar carries the same weight in the overall score of the index. Within each pillar, the policy score is weighted equally with the implementation and impact scores. To compute a pillar’s policy or implementation score, all indicators making up that pillar’s scores are averaged or weighted equally. Because the number of indicators making up each policy or implementation score varies, the weight of each individual indicator in the overall index varies as well.

The CRI framework is well constructed and a lot of thought has clearly been put into it. However, conceptual and practical challenges are inevitable when trying to summarise with a single composite indicator the commitment of countries to reducing inequality. An analysis is needed to ensure and validate the statistical soundness of any composite index. This audit was performed by the European Commission’s Competence Centre on Composite Indicators and Scoreboards at the Joint Research Centre (JRC) and was conducted upon the invitation of the developers. The analysis herein aims at shedding light on the transparency and reliability of the CRI Index 2022, enabling policymakers to derive more accurate and meaningful conclusions, and to potentially guide choices on priority setting and policy formulation.

In general, statistical soundness should be regarded as a necessary, yet not a sufficient, condition for a sound index, since the correlations underpinning the majority of the statistical analyses carried out herein not necessarily represent the real influence of the individual indicators on the described phenomenon. The development of any index must thus be nurtured by an iterative dialogue between the statistical and conceptual soundness.

The assessment of the CRI Index focuses on three main points: the quality of data, the statistical coherence of the structure, and the impact of key modelling assumptions on the CRI ranks. The analysis related to the first two points has been carried out using the R software, and the code developed by JRC-COIN.¹

¹ Becker, W., Caperna, G., Del Sorbo, M., Norlén, H., Papadimitriou, E., Saisana, M. (2022). COINr: An R package for developing composite indicators. *Journal of Open Source Software*, 7(78), 4567, <https://doi.org/10.21105/joss.04567>

2 Conceptual framework

The CRI is based on three pillars, each of which relates to one policy area found to be critical in reducing inequality: public services; taxation; and labour rights. The CRI, in the version analysed in this document, includes 18 indicators grouped within 9 sub-pillars (Table 1). Some of the indicators in this document are already the result of the aggregation of different variables. For details on these indicators, the reader could refer to the official report of the CRI or to the previous JRC audit,² where the topic was treated.

Table 1. Conceptual framework of the 2022 CRI.

Pillar	Sub - pillar		Indicator	Code
PUBLIC SERVICES	PS1 Policy		Education spending % budget	PS1A
			Health spending % budget	PS1B
			Social protection spending % budget	PS1C
	PS2 Implementation		Education coverage (% completion by poorest quintile of upper secondary)	PS2A
			Universal Health Coverage & Catastrophic household spending	PS2B
			Social Protection coverage	PS2C
PS3 Impact		Impact of Spending on the Gini coefficient	PS3_i	
TAX	T1 Policy	T1a	VAT rate	T1aVAT
			Progressivity of Personal Income Tax (PIT)	T1aPIT
		Corporate income tax Rate (CIT)	T1aCIT	
		T1b	Harmful Tax Practices (HTP)	T1bHTP
	T2 Implementation		Tax productivity	T2_i
	T3 Impact		Impact of Tax on the Gini coefficient	T3_i
LABOUR RIGHTS	L1 Policy		Labour Rights	L1a
			Women's Rights	L1b
			Minimum Wage legislation	L1c
	L2 Coverage		Unemployment & Vulnerable Employment	L2_i
	L3 Impact		Wages Gini	L3_i

Source: Developers of the Index and European Commission's Joint Research Centre, 2022.

JRC-COIN wants to draw special attention to the definition of T1 and T2 components since they are based on similar elements but used in formulas that may create a statistical conflict. In particular, using nominal tax rates as the denominator in T2 and as the numerator in T1 creates a negative relation between the two indicators. This causes a conflict within the pillar. This potential issue is discussed in the section relative to statistical coherence. The index is aggregated at each level using a simple weighted arithmetic average. It is a well-established practice in composite indicators' construction; it implies

² Caperna, G., Papadimitriou, E. and Kovacic, M., JRC Statistical Audit of the 2020 Commitment to Reducing Inequality index, EUR 30319 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-20902-7, doi:10.2760/082450, JRC121452

perfect substitutability of the elements of the aggregation (a lack in one variable could be covered by a good performance in another).

The CRI hierarchical framework is conceptually well justified, and its three-pillared structure allows for meaningful conclusions to be made.

3 Data quality and availability

3.1 Data coverage

The data coverage of the 162 countries is very good.³ Most indicators contain no missing values for any country. There are only five indicators with missing values, none with more than four missing values (

Table 2). The reduced number of missing values is also connected with some technical aspects that may be worth addressing. First of all, some variables are collected from different years and sources. The data-age seems relevant in the Public Service pillar, where five-year old data makes up 40% and 68% of PS2A and a sub-indicator of PS2B (i.e. OOP sub-indicator) respectively. The presence of old information is not an issue by definition, and it could be unavoidable when dealing with such a large number of countries. In this case, the issue depends on the absence of recent updates at the source level. So, considering the conceptual importance of the indicators, the developers prefer to keep the old data rather than excluding it entirely.

Table 2. Summary statistics of the indicators included in the 2022 CRI.

Pillar	Code	n. missing	Mean	Min	Max	% Unique	Skew	Kurtosis
Public Services	PS1A	0	14.06	4.34	25.85	0.98	0.22	-0.46
	PS1B	0	11.15	1.07	24.21	0.98	0.30	-0.04
	PS1C	0	18.38	0.62	46.55	0.99	0.42	-1.20
	PS2A	0	0.45	0.00	1.00	0.91	0.06	-1.55
	PS2B	0	76.31	49.94	92.86	1.00	-0.52	-0.50
	PS2C	0	58.93	0.04	100.00	0.73	-0.27	-1.64
	PS3_i	0	-0.08	-0.41	0.00	0.99	-1.41	1.63
Tax	T1aPIT	0	0.04	0.00	0.23	0.90	1.69	4.38
	T1aCIT	0	23.38	0.00	40.00	0.27	-0.85	1.09
	T1aVAT	0	7.85	0.00	25.00	0.30	0.40	-0.66
	T1bHTP	1	1.37	0.00	8.00	0.15	1.82	3.62
	T2_i	1	0.35	0.06	0.86	1.00	0.34	-0.13
	T3_i	1	0.01	-0.06	0.15	1.00	1.69	7.11
Labour Rights	L1a	4	3.40	0.00	10.00	0.91	1.14	1.02
	L1b	0	0.75	0.08	1.00	0.84	-1.73	3.24
	L1c	0	0.47	0.00	1.96	0.93	1.43	2.37
	L2_i	0	44.72	7.54	94.36	1.00	0.29	-1.18
	L3_i	4	0.50	0.22	0.84	0.98	0.53	-0.55

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

Several indicators of the public services and tax pillars are collected from three or more sources. Multiple sources are unavoidable given the large number of countries covered. However, care must be taken to ensure the data-sources measure the same phenomenon and use similar methodologies as is done for the Tax pillar. In this respect, Indicator PS2A deserves special attention. This indicator, representing education coverage (as % completion of upper secondary by the poorest quintile), has a relevant, but not critical,

³ The audit was performed on a dataset of 162 countries, while the final version of the CRI index only on 161. The difference is caused by the decision of the developers to exclude Colombia due to data concerns.

presence of missing values (almost 13%). In the present version of the CRI, the missing observations are imputed using the standardised values of two other variables used as proxies (the general percentage of completion of the upper secondary and the gross graduation ratio for upper secondary). The authors and JRC-COIN delved into the topic to find a possible alternative to the use of proxies, which is not very common in the management of missing data. For future editions, JRC-COIN suggests the imputation through any statistical imputation method. A possible option could be the k-Nearest Neighbours method (but it is not the only one), where other - available - variables, such as proxies or other elements of the aggregate, are used to identify the closest countries to the one showing the missing values, and use their value of the indicator to find a good estimate.⁴

A crucial note here is needed. The developers are aware of the issues related to the PS2A indicator PS2A, which also existed in the 2020 index but kept the indicator to ensure consistency. These issues are mainly due to the lack of updates from the main source of this indicator. Since 2020, the data source has improved and reduced the scale of the problem. Moreover, they are planning to further reduce the problem by seeking more national sources and eliminating one of the proxy indicators in future editions.

As in the previous edition of the Index,⁵ for reasons of transparency and replicability, the CRI developing team opted not to estimate the missing values when only a few are missed, but defined clear rules of exclusion in the case of insufficient coverage. For instance, countries lacking sufficient or reliable data for at least one indicator for each pillar were excluded from the Index.

3.2 Management of outliers

The presence of outliers, which could potentially bias the effect of the indicators on the aggregates, was investigated. The JRC recommends an approach for outlier identification based on the skewness and kurtosis values⁶, i.e., when the variables have simultaneously absolute skewness greater than 2.0 and kurtosis greater than 3.5. As shown in

Table 2, none of the main indicators used in the calculation of the CRI Index show critical values.

3.3 Normalisation

The indicators are rescaled to a 0–1 scale, with 0 as the lowest score for progressivity achieved by countries, and 1 as the highest, which is common and good practice in the composite indicators' construction. In the CRI case, though, the results of the aggregations (sub-pillars, pillars, and the CRI itself) are again normalised to (0,1).

While the (0,1) normalisation (also called MIN-MAX normalisation), allows for clarity and readability of the index, the implications of its use at every level of aggregation should always be considered. This point was discussed in the previous edition of the JRC-Audit.⁷

Concisely, the sub-pillars and pillars of the CRI require re-normalisation in each step to achieve similar ranges among elements of the same aggregation. This similarity could also be achieved by improving the correlation between the elements that are aggregated. Further details are available in the following section.

⁴ The use of k-nearest neighbours (with k=1) was tested by JRC-COIN. In such a simulation, the CRI rank of seven countries would change by five or more positions (counting both negative and positive rank changes).

⁵ Lawson, M., & Martin, M. (2020). Fighting Inequality in the time of COVID-19: The Commitment to Reducing Inequality Index 2020.

⁶ Groeneveld, R. A. and Meeden, G., "Measuring Skewness and Kurtosis," Journal of the Royal Statistical Society, Series D, vol. 33, pp. 391–99, 1984

⁷ Caperna, G., E. Papadimitriou, and M. Kovacic, 2020. JRC Statistical Audit of the 2020 Commitment to Reducing Inequality index, EUR 30319 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-20902-7, doi:10.2760/082450, JRC121452

4 Statistical coherence

The statistical coherence consists of a multi-level analysis of the correlations of variables and a comparison of CRI rankings with its pillars and with other indicators measuring the actual level of inequality.

4.1 Correlation analysis

The statistical coherence of an index should be considered a necessary but not a sufficient condition for a sound index. Given that the statistical analysis is mostly based on correlations, the correspondence of the CRI Index to a real world phenomenon needs to be critically addressed because “correlations do not necessarily represent the real influence of the individual indicators on the phenomenon being measured” (OECD & JRC, 2008).⁸ This relies on the interplay between both conceptual and statistical soundness. The degree of coherence between the conceptual framework and the statistical structure of the data is an important factor for the reliability of an index, among other things.

The correlation analysis is used to address to what extent the data support the conceptual framework. In the ideal case, there should be positive correlations within every level of the index. This effectively ensures that the overall index scores adequately reflect the underlying indicator values.

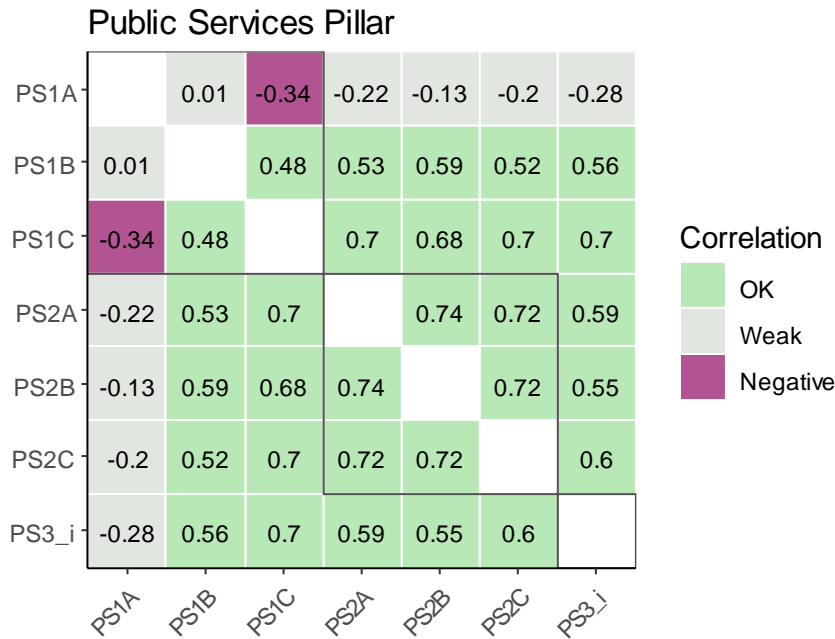
Redundancy should be avoided in the framework because if two indicators are collinear, this may amount to double counting (and therefore over-weighting) the same phenomenon.

4.1.1 Correlation analysis between indicators and aggregates

Table 3 shows the correlations between indicators of the Public Services pillar, while the black lines emphasize the indicators forming the single sub-pillars. Overall, the correlation structure is good, showing medium (0.48) to high (0.82) correlations between indicators. The exception is the PS1A indicator – education spending as a percent of total spending. This indicator is weakly or negatively correlated to other indicators. These low correlations constitute an opportunity to reflect on the meaning of the single indicator and its role in the aggregate. It is common that the indicators conflicting with the surrounding elements are also poorly represented in the higher aggregations. This is the case with PS1A, which has a negative, albeit weak, correlation with the PS pillar and the CRI (see Table 6). Nevertheless, the presence of low correlation does not come as a surprise, being the indicators of sub-pillar PS1 somehow competing for public expenditures. So, the conceptual meaning could be considered sufficiently relevant for the aggregation of poorly correlated elements. Nevertheless, the JRC team suggests to take the correlation aspect into account when interpreting the role of indicator PS1A in the overall index. It’s conflictual relation with the other elements of PS1 implies that it cannot be well represented in the final aggregation.

⁸ OECD/EC JRC (Organisation for Economic Co-operation and Development/European Commission, Joint Research Centre). 2008. Handbook on Constructing Composite Indicators: Methodology and User Guide. Paris: OECD.

Table 3. Correlations between Indicators of the Public Services Pillar



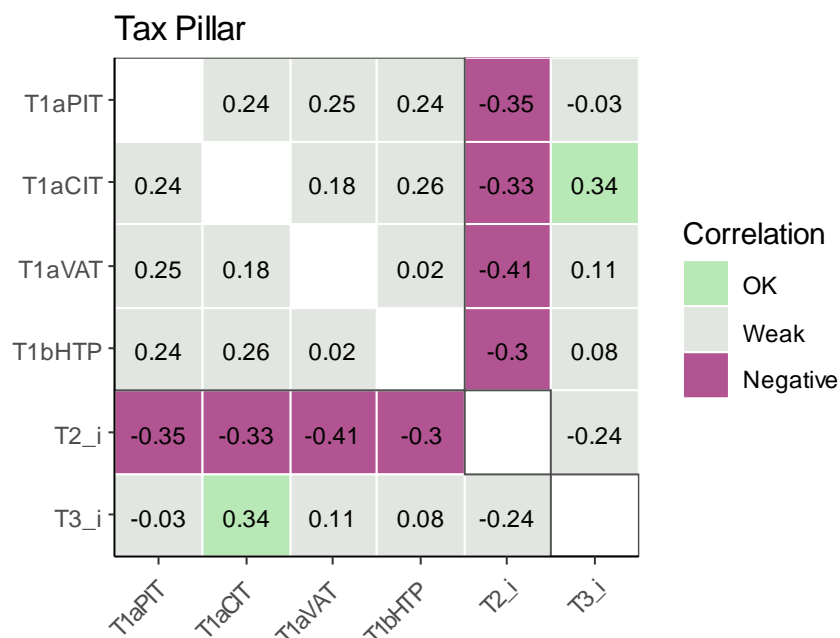
Source: European Commission’s Joint Research Centre, 2022.

Table 4 shows the correlations between indicators of the Tax pillar. The overall correlation structure between indicators of the tax pillar shows mostly weak or negative values. It may suggest that the “Tax progressivity” concept may not be a unidimensional concept. The elements of T1 are weakly related, but their relationship is often close to the minimal level of 0.3 that JRC-COIN suggests as a threshold to check whether to elements share a relevant amount of their variability. According to this threshold, only two of the six indicators are adequately correlated, namely T3_i and T1aCIT. These results fit with the interpretation given by the developers which is transparently discussed in the CRI report in its reasons. It is important to notice how the low and negative correlations have a strong effect on the ability of each indicator to be represented in the higher-level aggregates, as stated in the previous paragraph. Given the weak and negative correlations, it is likely that some information in these indicators is lost during aggregation and is not reflected in the final ranking. The correlations between sub-pillars are further investigated in section 4.1.3.

The correlation structure suggests that these indicators are good candidates to be reworked or re-organized in case of revision to improve the statistical coherence and the impact of Taxation information in the overall aggregate.

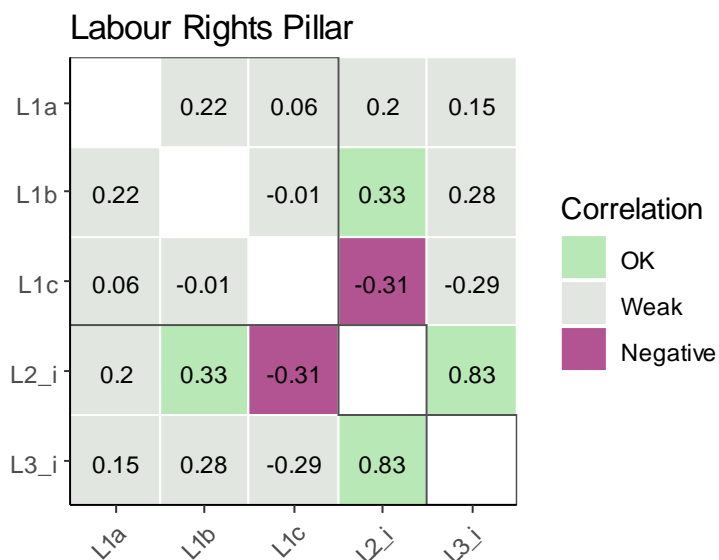
One way to achieve this may be acting on the formulas of T1, T2 and T3. The current formulas combine the same information in a way that ensures a negative correlation structure. In particular, the T2 and T1 indicators use the same information, namely the nominal tax rates, but use different ways of processing it. The nominal CIT is the T1aCIT indicator. The same nominal CIT is the denominator in the CIT component of T2_i. A correlation will seldom be positive when information is used in one variable as a denominator and the same information is used as numerator in the other variable. Similarly, T3_i uses the nominal rates in the denominator for each type of tax before summing, again creating a negative correlation between T2 and T3. Despite the arithmetic and statistical aspects related to the low or negative association among the elements of the Taxation pillar, the developers of the CRI and the literature, are very clear in identifying the elements that should constitute this pillar. Significant changes in the formulas in the direction of a higher correlation would be considered incorrect from a conceptual perspective. Nevertheless, the JRC team suggests to take the structure of the Taxation pillar into account when interpreting the results of the CRI.

Table 4. Correlations between Indicators of the Tax Pillar



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

Table 5. Correlations between Indicators of the Labour Rights Pillar



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

Table 5 shows the correlations between indicators of the Labour Rights pillar. L2_i and L3_i are well correlated. However, the correlations between components of the first sub-pillar, L1, are weak, despite not being significantly negative. L1c is the least correlated of the sub-pillar, and also its relation with the other elements of the pillar is negative (approx. -0.3).

4.1.2 Correlation analysis between indicators and aggregates

Table 6 shows the correlation coefficients between indicators and their corresponding sub-pillars, pillars and the index. Most correlations are significant and positive. However, a few problematic cases are identified:

- The indicator on Education coverage (PS1A) does not contribute meaningfully to its corresponding sub-pillar and, moving upwards in the aggregation, it becomes even more silent, having a slightly negative correlation with the pillar and the CRI Index. As per our previous suggestion, it is suggested to pay special attention to this indicator and its meaning in the index.
- All the indicators of T1 correlate well with their respective sub-pillars. However, two out of six indicators of the Tax Pillar correlate weakly within the overall pillar, while their relation to the index is negative. Additionally, three other indicators, T1aCIT, T1bHTP and T3_i, have a weak correlation to the overall index, indicating they are not meaningfully represented in the CRI. Some of the issues related to indicators T1aCIT, T1aVAT, and T1bHTP may come from their definition, as suggested in the previous section. But, a crucial role could be played by their poorly-quantitative nature. These three indicators present a very low proportion of unique values. This property has a sure effect on their correlations and their role in an aggregation.
- Among the elements of the Labour Pillar, only the indicator on Minimum Wage legislation (L1C) shows a weakly negative correlation with the pillar and index, thus JRC-COIN suggests keeping it under scrutiny.

Table 6. Pearson correlation coefficients between indicators, and their corresponding aggregates.

PS1A	0.25	-0.14	-0.15
PS1B	0.79	0.71	0.65
PS1C	0.75	0.84	0.8
PS2A	0.91	0.85	0.76
PS2B	0.88	0.83	0.82
PS2C	0.92	0.85	0.82
PS3_i	1	0.84	0.78
T1aPIT	0.57	0.16	-0.32
T1aCIT	0.57	0.39	-0.12
T1aVAT	0.54	0.17	-0.51
T1bHTP	0.77	0.44	-0.12
T2_i	1	0.31	0.71
T3_i	1	0.51	0.12
L1a	0.79	0.39	0.31
L1b	0.6	0.47	0.45
L1c	0.52	-0.14	-0.2
L2_i	1	0.93	0.87
L3_i	1	0.9	0.79
	SubPillar	Pillar	Index

Correlation

- High
- OK
- Weak
- Negative

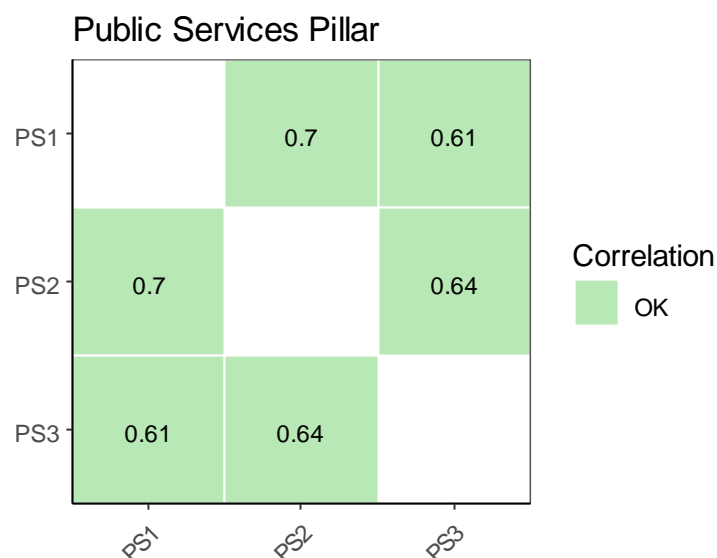
Source: European Commission’s Joint Research Centre, 2022

4.1.3 Correlation analysis between aggregates and with the index

The values in Table 7 to Table 11 represent the correlations between the aggregates. This level is the most important as it represents the consistency of the general concepts.

The PS pillar appears consistent, with the sub-pillars being well correlated with each other (Table 7), with the pillar and the CRI (Table 10). A remark would be on the strong correlation (0.93) between sub-pillar PS2 and pillar PS, suggesting that PS2 is dominating the pillar in relation to the other two sub-pillars. However, this is not a major issue since the others also have a high correlation (0.84).

Table 7. Correlations between Public Services sub-pillars.



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

The internal structure of Tax pillar is very similar to the previous edition of the index. The sub-pillars T1 and T2 are negatively correlated (-0.50) (Table 8). Negative correlations may reduce the ability of an aggregate to discriminate between countries, as they effectively cancel out each other's scores. The stronger the negative correlation, the stronger the conflicting effect. Indeed, Table 10 shows T1 has a significant negative correlation with the overall index, indicating that the index describes something conflicting with the message of sub-pillar T1.

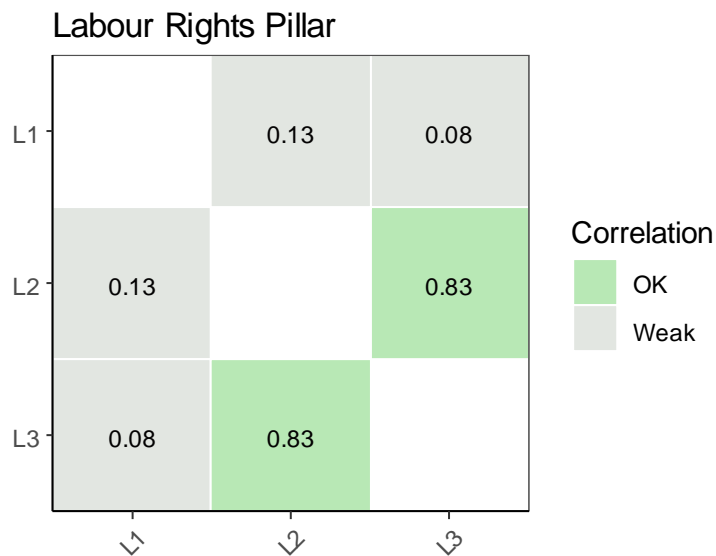
The correlations between the Labour rights sub-pillars reflect the inter-relations between its components. Although L3 and L2 are highly correlated (0.83), L1 is weakly correlated to L3 (0.13) and L2 (0.08). Nevertheless, all three sub-pillars do have an adequate correlation with the pillar and the CRI. However, the L1 sub-pillar has a substantively smaller correlation with L than the other two pillars resulting in it contributing less to the overall index, as indicated by its weak correlation with the overall index.

Table 8. Correlations between Taxation sub-pillars.



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

Table 9. Correlations between Labour sub-pillars.



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

Given the correlation between its elements and its weak relation with the other pillars, the Tax pillar contributes much less information to the index (0.39) compared to the other pillars (PS - 0.94, L - 0.89), as seen in Table 10 and Table 11. This is mainly due to a combination of the negative relation of sub-pillar T2 with T1 and the non-significant correlation between T1 with T2 and T3, together with the relation of this elements with the other pillars. JRC-COIN suggests a revision of the Tax pillar, with the aim of improving its role and reliability within the Index. Lastly, Table 11 also shows that both the Public

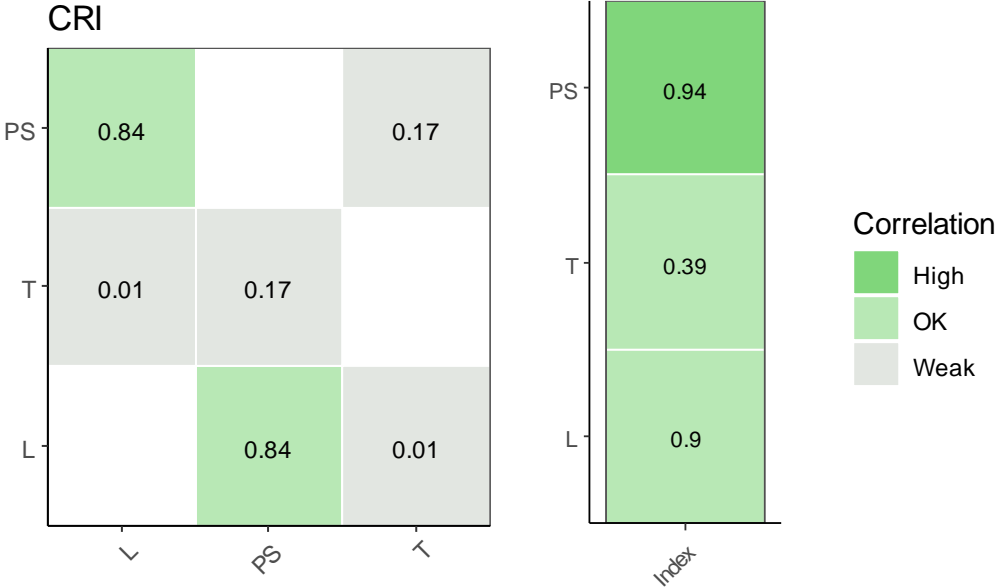
Spending and the Labour Rights pillars have a strong correlation with the overall index. These results show how the Tax pillar is less represented in the overall index score.

Table 10. Correlations between sub-pillars with pillars and index.



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

Table 11. Correlations between pillars and with the index.



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

4.2 Added value of the Commitment to Reducing Inequality index

High statistical reliability among the main components of an index can be the result of redundancy of information. This is clearly not the case with the CRI index. For at least 32.1% of the countries included in the index, the CRI ranking and any of the three pillar rankings differ by more than 15 positions (see Table 12). This suggests that the CRI ranking highlights aspects of countries' efforts to reduce inequality that do not emerge by looking into the three pillars separately. At the same time, this result points to the value of examining individual pillars and indicators on their own merit.

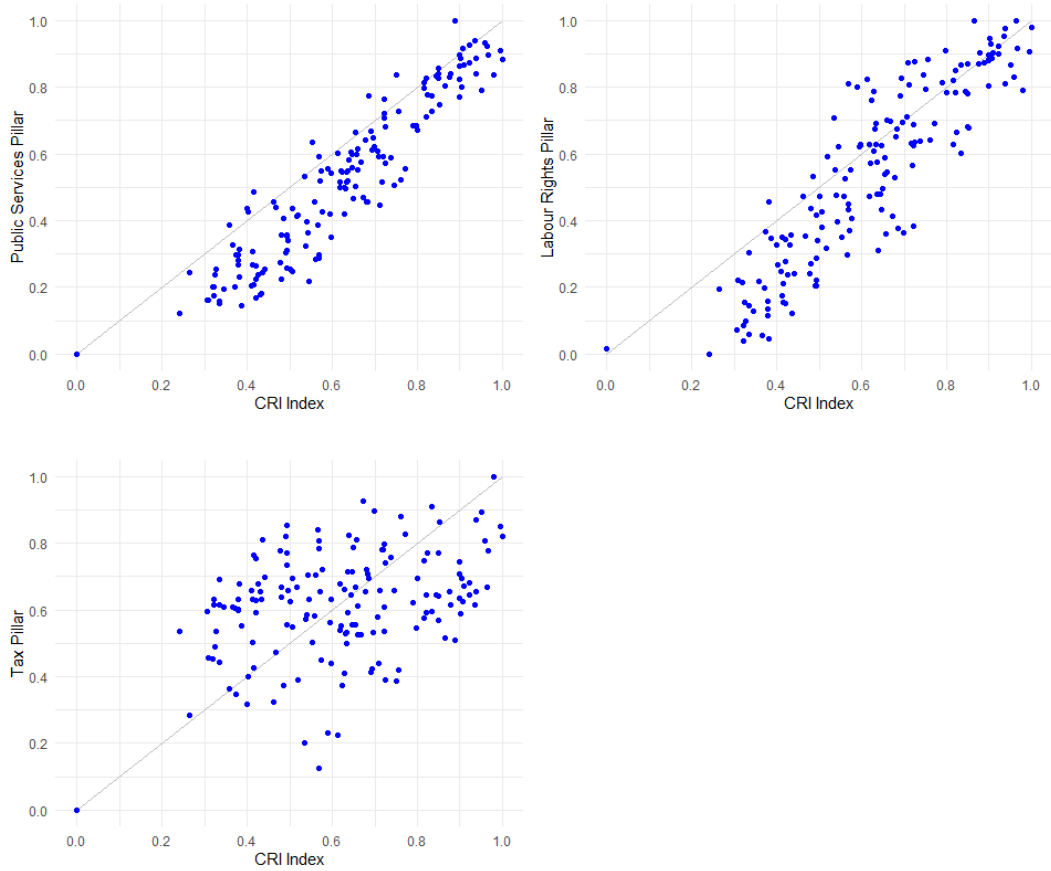
It is interesting to look further into the relationship between the three components and the CRI index: the Public Services pillar, the Tax pillar, and the Labour rights pillar. Figure 1 depicts these relationships by plotting the pillar scores on the y axis and the index scores on the x axis. A perfect relationship between the two scores would fall along the diagonal line. The first and third pillars are linearly associated with the Index, as can be deduced from the clear pattern in the graphs. On the other hand, the graph of Taxation shows a very poor relation between the pillar and the Index. The taxation graph shows that high-scoring countries on the taxation pillar can be found anywhere along the score of the overall index. In other words, countries that score the best and those that score the worst on the taxation pillar can be found with similar ranks on the index. The graph clearly shows that the taxation pillar does not 'count in the same direction' as the other pillars, meaning that it ranks countries in a substantively different way from the other two pillars. This aspect reduces the ability of the index to keep the information carried by the taxation pillar. This is likely due to the negative correlation structure between this pillar and the other two.

Table 12. Distribution of rank differences between pillars and CRI rankings

Rank Difference	Labour Rights	Public Services	Tax
More than 30	12.3%	8.0%	63%
More than 15 to 30	32.7%	24.1%	16.7%
More than 5 to 15	29.6%	38.9%	11.7%
More than 0 to 5	23.5%	23.5%	8.6%
0	1.9%	5.6%	0.0%

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

Figure 1. Relationship between the pillars and the CRI index.



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

5 Impact of modelling assumptions on the CRI results

Assessing the effect of different modelling assumptions on the scores and country rankings is a fundamental step in the statistical analysis of a composite indicator. Despite the efforts in the development process, there is an unavoidable subjectivity (or uncertainty) in the resulting choices. This subjectivity can be explored by comparing the results obtained under different (alternative) assumptions.

The literature on this topic⁹ suggests to assess the robustness of the index by means of a Monte Carlo simulation and by applying a multi-modelling approach, assuming 'error free' data as eventual errors have already been corrected in the preliminary stage of the index construction.

The Commitment to Reducing Inequality Index, like most composite indicators, is the outcome of several choices concerning, among other things, the underlying theoretical framework, the indicators selected, the normalisation method, the weights assigned, and the aggregation method. Some of these choices may be based on expert opinion or other considerations, driven by statistical analysis or by the need to ease communication or to draw attention to specific issues.

This section aims to test the impact of varying some of these assumptions within a range of plausible alternatives in an uncertainty analysis. The objective is, therefore, to try to quantify the uncertainty in the ranks of the CRI, which can demonstrate the extent to which countries can be differentiated by their scores.

The modelling issues considered in the robustness assessment of the CRI Index are mainly the aggregation formula, the normalisation procedure and the pillar weights. Given that the good data coverage is excellent in this edition of the index, no alternative assumption has been considered for the imputation method. Nevertheless, further details on the topic are available in section 3.

Aggregation formula. For this edition of the index, the CRI team opted for the arithmetic averaging of the three pillars, which implies strong compensability, allowing for an outstanding performance in some aspects to balance the weaknesses in others and vice-versa. This approach puts countries with both high and low results in different pillars at the same level, with more "balanced" countries showing average results in all pillars. To assess the impact of this choice, the JRC included in the analysis a comparison with the geometric mean. The comparison of the two aggregation approaches should be able to highlight countries with unbalanced profiles since the geometric mean tends to penalize low values, especially in the presence of other values that are not so low (unbalanced profiles).

Normalisation. This edition of the CRI Index normalizes scores at all levels of aggregation, meaning at the indicator, sub-pillar, and pillar levels, as done in the previous edition. It is not a common approach, but it is useful in the CRI, given the presence of aggregates with different ranges in the index. Nonetheless, multiple normalisation is likely to have an impact on country rankings. Therefore, normalisation at all levels is compared to the standard approach of normalizing only the indicators.

⁹ Saisana, M., B. D'Hombres, and A. Saltelli. 2011. 'Rickety Numbers: Volatility of University Rankings and Policy Implications'. *Research Policy* 40: 165–77.

Saisana, M., A. Saltelli, and S. Tarantola. 2005. 'Uncertainty and Sensitivity Analysis Techniques as Tools for the Analysis and Validation of Composite Indicators'. *Journal of the Royal Statistical Society A* 168 (2): 307–23.

Weights. Monte Carlo simulation comprised 1,000 runs of different set of weights for the three pillars constituting the CRI Index. The weights are the result of a random extraction based on uniform continuous distributions centred in the reference value (1/3) plus or minus 20% of this value.

Four models were tested, comparing the different combinations of aggregation formula and normalisation, which resulted in a total of 4,000 runs of simulations.

Table 13. Alternative assumptions considered in the analysis.

	Reference	Alternative
I. Normalisation	Minmax at every level	Minmax of elementary indicators
I. Aggregation formula	Arithmetic average	Geometric average
II. Weighting system	Equal weights (0.33)	Varying: U [0.26; 0.40]
Public Services	0,33	U[0,26;0,40]
Taxation	0,33	U[0,26;0,40]
Labour	0,33	U[0,26;0,40]

Source: European Commission, Joint Research Centre, 2022.

The main results obtained from the robustness analysis are shown in Figure 2, with median ranks and 90% intervals computed across the 4,000 Monte Carlo simulations. Countries are ordered from best to worst according to their CRI rank, where the blue dots represent the median rank among the iterations. For each country, the error bars represent the 90% interval across all simulations, that is, from the 5th to the 95th percentile.

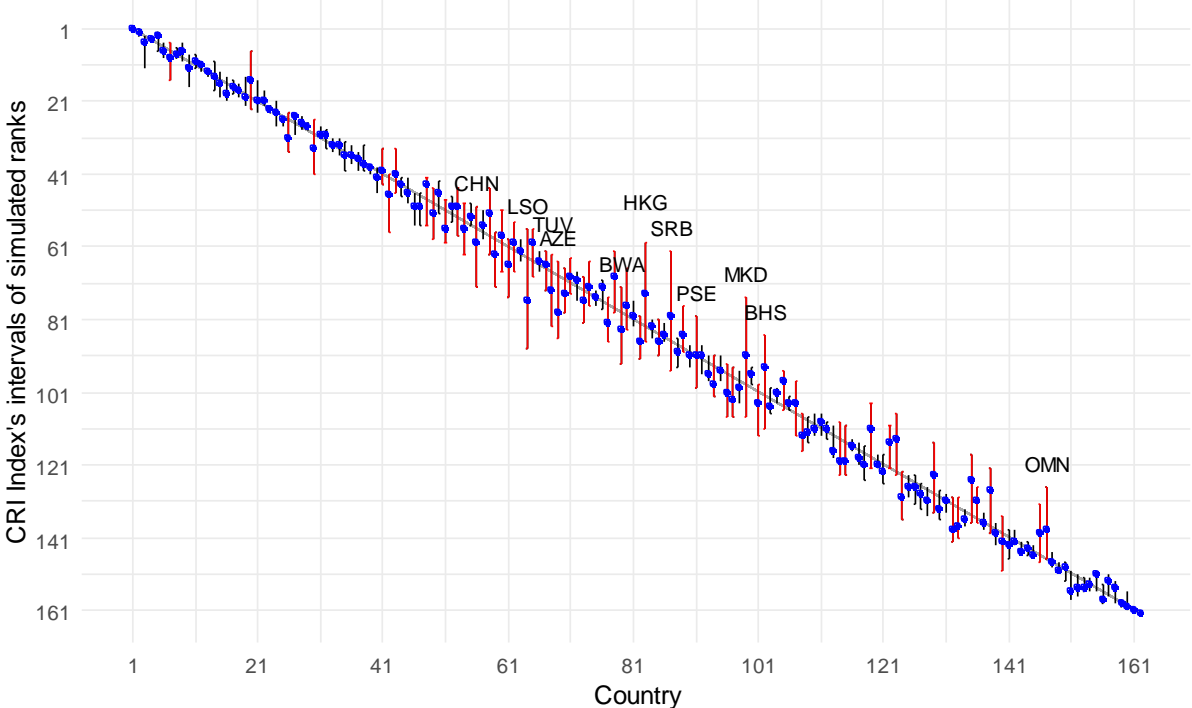
CRI ranks are shown to be representative of a plurality of scenarios and robust to changes in the aggregation method and pillar weights. If one considers the median rank across the simulated scenarios as being representative of these scenarios, then the fact that the CRI rank is close to the median rank (less than five positions away) for 125, or 77% of the countries, suggests that CRI is a good summary measure.

The simulation based on the test of aggregation and normalisation shows that the CRI Index is not free from fluctuations. Eleven countries show a simulated interval larger than 20 positions. These are: China, Lesotho, Tuvalu, Hong Kong, Azerbaijan, Botswana, Serbia, Palestine, North Macedonia, Bahamas, and Oman. There are 61 countries, or 38%, that change 10 or more ranks across simulations. One can observe from Figure 2 that the intervals are generally wider for mid-ranking countries, and narrower for top and bottom-ranking countries, which is normal in the context of composite indicators. In the case of the CRI, some exceptions to this common result are visible for the countries with nominal ranks between the 121st and the 151st.

Overall, country ranks in CRI seem robust to changes in the normalisation, pillar weights, and the aggregation formula for the top-ranking countries. However, the ranking of a non-negligible number of countries in the CRI may be related to the modelling assumptions. For full transparency and information, Table 14 reports the CRI country ranks together with the simulated intervals (central 90 percentiles observed among the 4,000 scenarios) in order to better appreciate the robustness of these ranks to the computation methodology and to analyse the behaviour of specific countries in respect to perturbations.

The uncertainty analysis is also complemented by a sensitivity exercise in which the CRI ranking is compared with the rankings resulting from specific changes in the modelling assumptions.

Figure 2. Robustness analysis on ranks (CRI rank vs median rank and 90% intervals).

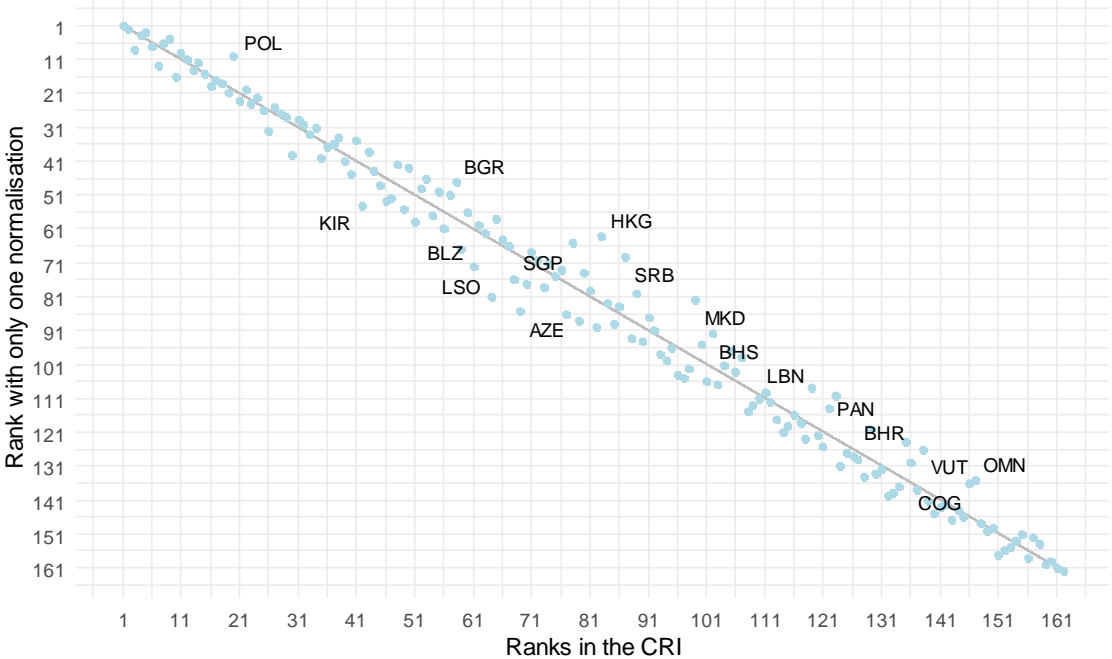


Source: European Commission, Joint Research Centre, 2022.
 Note: Rank intervals coloured in red have a length of 10 minimum. Labelled countries show a 90% rank interval of at least 20.

In Figure 3, it is possible to compare the ranks derived from CRI with the ranks that would have been obtained by changing the normalisation procedure. This comparison allows us to inquire whether the variability in the rank intervals originates from the modelling assumption of repeated normalisation.

Figure 3 indicates a close fit between the two normalization procedures at the top of the rankings. However, there are five countries that drop at least 10 ranks with the alternative normalisation method that are between the 42nd and 69th rank in the CRI. Additionally, there are 10 countries that gain at least 10 ranks with the alternative normalisation, which fall between the 83rd and 147th rank in the CRI. There is a systematic impact of the normalization method on the rankings of countries. Additionally, we can observe that the countries in the middle of the CRI are further away from the diagonal line than others. This confirms that many of the countries showing a large interval in the robustness analysis had their rankings influenced by the alternative normalisation method.

Figure 3. Sensitivity Analysis: Comparison of ranks according to only pillar normalization and sub-pillar, pillar normalization.



Source: European Commission, Joint Research Centre, 2022.
 Note: Labelled countries show a shift of at least 10 positions between the two aggregation formulas.

Table 14. CRI rank and 90% interval of all countries from robustness analysis based on aggregation, normalisation and weights.

Country	CRI Ranks	Interval	Country	CRI Ranks	Interval
NOR	1	[1,2]	VCT	82	[80,92]
DEU	2	[1,3]	HKG	83	[60,87]
AUS	3	[3,12]	PRY	84	[81,85]
BEL	4	[3,4]	DZA	85	[81,91]
DNK	5	[2,7]	MYS	86	[81,87]
JPN	6	[5,9]	SRB	87	[62,96]
CAN	7	[5,15]	EGY	88	[86,94]
SVN	8	[6,9]	TTO	89	[77,90]
FIN	9	[5,10]	LCA	90	[87,94]
NZL	10	[8,17]	PSE	91	[80,101]
FRA	11	[8,12]	FJI	92	[88,96]
CZE	12	[10,13]	VNM	93	[91,98]
LUX	13	[13,14]	MAR	94	[90,102]
IRL	14	[10,18]	PER	95	[91,98]
SWE	15	[13,20]	KEN	96	[91,108]
ISL	16	[14,21]	KHM	97	[94,108]
AUT	17	[15,19]	HND	98	[94,104]
EST	18	[16,20]	MKD	99	[75,111]
GBR	19	[14,22]	JAM	100	[94,99]
POL	20	[7,23]	MMR	101	[99,113]
ISR	21	[15,24]	BHS	102	[85,113]
HRV	22	[18,22]	IDN	103	[100,107]
PRT	23	[22,24]	PHL	104	[100,104]
SVK	24	[21,28]	IRN	105	[95,107]
USA	25	[25,28]	GTM	106	[102,106]
KOR	26	[24,35]	DOM	107	[98,115]
NLD	27	[25,30]	BGD	108	[107,117]
BLR	28	[25,29]	LKA	109	[108,115]
ITA	29	[27,29]	SLB	110	[107,114]
ZAF	30	[26,41]	STP	111	[106,113]
CHE	31	[28,32]	TLS	112	[107,114]

UKR	32	[29,34]	NPL	113	[109,119]
LVA	33	[31,35]	ZMB	114	[108,124]
LTU	34	[31,36]	DJI	115	[110,125]
CHL	35	[32,40]	SEN	116	[114,118]
ARG	36	[33,38]	BTN	117	[111,121]
RUS	37	[35,40]	MWI	118	[116,125]
MLT	38	[33,40]	LBN	119	[104,122]
ESP	39	[38,41]	MOZ	120	[117,123]
MDV	40	[39,46]	TGO	121	[118,127]
HUN	41	[34,45]	SWZ	122	[110,122]
KIR	42	[41,57]	PAN	123	[107,125]
GRC	43	[34,47]	IND	124	[123,136]
SYC	44	[42,52]	RWA	125	[124,130]
KGZ	45	[42,49]	PAK	126	[124,132]
TJK	46	[46,55]	YEM	127	[126,133]
MNG	47	[45,55]	GHA	128	[127,135]
CYP	48	[42,55]	TON	129	[114,134]
NAM	49	[44,59]	AGO	130	[128,137]
KAZ	50	[43,52]	GMB	131	[129,134]
TUN	51	[48,60]	MLI	132	[130,142]
CRI	52	[47,54]	TZA	133	[130,141]
ROU	53	[45,59]	PNG	134	[133,138]
JOR	54	[49,63]	BHR	135	[118,138]
MUS	55	[49,55]	MRT	136	[127,137]
CHN	56	[50,72]	BFA	137	[134,139]
URY	57	[51,59]	VUT	138	[122,141]
BGR	58	[45,64]	AFG	139	[137,144]
SLV	59	[57,73]	IRQ	140	[121,150]
MDA	60	[51,69]	ZWE	141	[139,147]
BLZ	61	[59,75]	BEN	142	[139,143]
UZB	62	[54,69]	COD	143	[141,147]
MEX	63	[59,65]	LAO	144	[142,146]
LSO	64	[55,89]	ETH	145	[143,147]
BRB	65	[56,70]	COG	146	[132,148]
BRA	66	[62,68]	OMN	147	[127,149]
GUY	67	[62,73]	BDI	148	[145,149]
TUV	68	[62,83]	CMR	149	[148,151]
AZE	69	[64,86]	GNB	150	[148,153]
CPV	70	[66,79]	NER	151	[149,158]
BOL	71	[64,74]	TCD	152	[150,157]
TUR	72	[68,76]	UGA	153	[152,156]
THA	73	[69,82]	SLE	154	[152,156]
GEO	74	[65,77]	CIV	155	[150,156]
ALB	75	[72,77]	CAF	156	[154,159]
ARM	76	[70,78]	MDG	157	[151,157]
ECU	77	[73,87]	HTI	158	[153,159]
SGP	78	[62,81]	GIN	159	[158,160]
BWA	79	[72,93]	LBR	160	[156,160]
ATG	80	[67,87]	NGA	161	[161,161]
WSM	81	[76,83]	SSD	162	[162,162]

Source: European Commission, Joint Research Centre, 2022.

5.1.1 Robustness analysis of aggregation and weights only.

Considering the results of the previous paragraph, it is clear how normalisation is a key choice in the definition of the CRI. This choice is motivated by a clear intention to have all elements preserving the same opportunity to matter in the index, addressing the differences in range due to the correlation structure among their elements. While the main suggestion of JRC-COIN remains a revision of the Taxation pillar, in order to assure it a more prominent role, in this section the robustness of the CRI is tested against changes in weights and aggregation, excluding the normalisation method. The aim here is to study the robustness while considering the normalisation as a consequence of the conceptual framework, and hence not including it in the list of testable assumptions. Hence, this simulation compares only two alternative aggregation methods and their interactions with the same 1000 simulated weights used in the previous robustness analysis. Table 15 reports the details of this simulation.

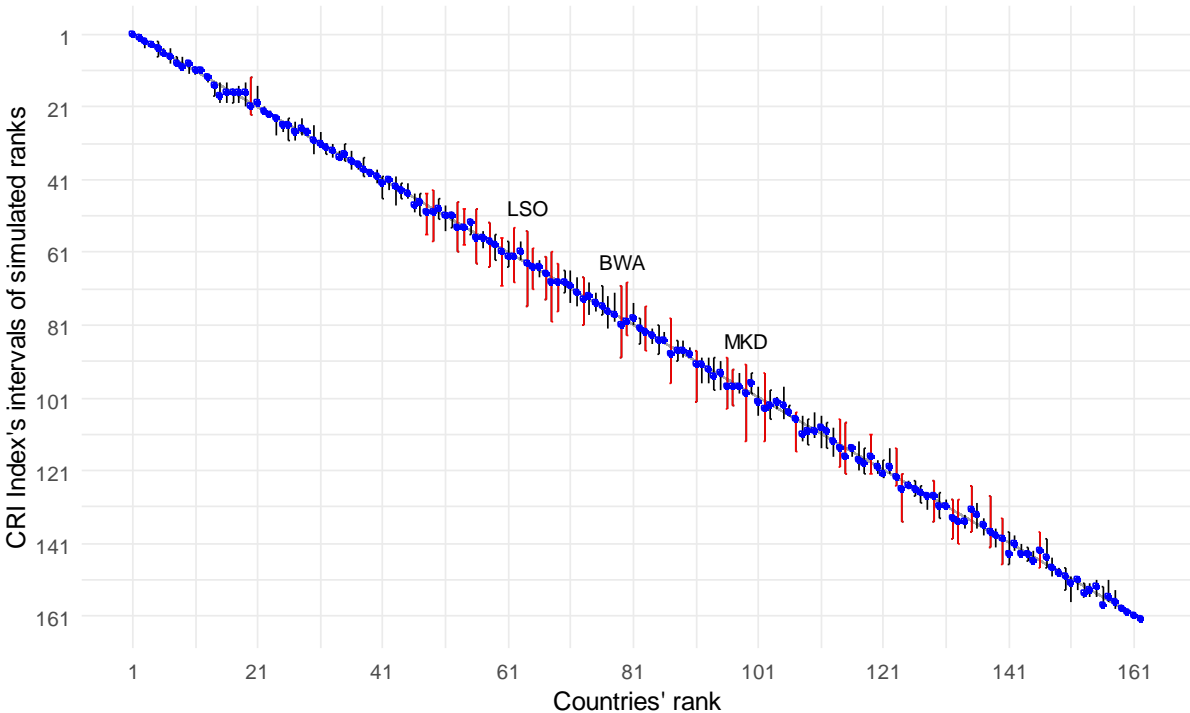
Table 15. Alternative assumptions considered in the analysis.

	Reference	Alternative
I. Aggregation formula	Arithmetic average	Geometric average
II. Weighting system	Equal weights (0.33)	Varying: U [0.26; 0.40]
Public Services	0,33	U[0,26;0,40]
Taxation	0,33	U[0,26;0,40]
Labour	0,33	U[0,26;0,40]

Source: European Commission, Joint Research Centre, 2022.

In this case, the CRI is shown to be very robust. There are no countries whose ranks in the CRI differ more than 5 positions from the median of the simulations. The index is also robust against changes in rank. There are 37 countries, or 23%, that change 10 or more ranks across simulations, and only 3 countries show a simulated interval larger than 20 positions, and these are: Lesotho, Botswana, and North Macedonia. Table 16 shows the complete list of countries with their CRI ranks and 90% rank intervals across simulations. **Table 16.** CRI rank and 90% interval of all countries from robustness analysis based on aggregation and weights. Comparing this robustness analysis with the previous one makes clear that the normalization methods in conjunction with the other assumptions have a large impact on the uncertainty of country’s ranks.

Figure 4. Robustness analysis on ranks (CRI rank vs median rank and 90% intervals).



Source: European Commission, Joint Research Centre, 2022.

Note: Rank intervals coloured in red have a length of 10 minimum. Labelled countries show a 90% rank interval of at least 20.

Table 16. CRI rank and 90% interval of all countries from robustness analysis based on aggregation and weights.

Country	CRI Ranks	Interval	Country	CRI Ranks	Interval
NOR	1	[1,2]	VCT	82	[79,86]
DEU	2	[1,2]	HKG	83	[76,88]
AUS	3	[3,5]	PRY	84	[82,86]
BEL	4	[3,4]	DZA	85	[81,89]
DNK	5	[3,7]	MYS	86	[83,86]
JPN	6	[5,7]	SRB	87	[79,97]
CAN	7	[5,9]	EGY	88	[85,91]
SVN	8	[7,9]	TTO	89	[85,90]
FIN	9	[7,10]	LCA	90	[87,90]
NZL	10	[8,12]	PSE	91	[88,102]
FRA	11	[10,12]	FJI	92	[90,97]
CZE	12	[11,12]	VNM	93	[90,97]
LUX	13	[13,14]	MAR	94	[90,99]
IRL	14	[14,18]	PER	95	[91,99]
SWE	15	[14,20]	KEN	96	[90,104]
ISL	16	[14,20]	KHM	97	[93,103]
AUT	17	[16,20]	HND	98	[94,100]
EST	18	[15,20]	MKD	99	[92,113]
GBR	19	[14,21]	JAM	100	[94,100]
POL	20	[13,23]	MMR	101	[98,106]
ISR	21	[15,21]	BHS	102	[94,113]
HRV	22	[21,22]	IDN	103	[99,107]
PRT	23	[22,23]	PHL	104	[101,104]
SVK	24	[24,29]	IRN	105	[98,107]
USA	25	[25,28]	GTM	106	[103,106]
KOR	26	[24,30]	DOM	107	[105,116]
NLD	27	[25,30]	BGD	108	[106,113]
BLR	28	[24,29]	LKA	109	[107,114]
ITA	29	[27,29]	SLB	110	[105,112]
ZAF	30	[26,34]	STP	111	[106,115]
CHE	31	[28,32]	TLS	112	[108,115]
UKR	32	[31,34]	NPL	113	[109,117]
LVA	33	[31,35]	ZMB	114	[107,120]
LTU	34	[33,36]	DJI	115	[108,122]
CHL	35	[31,36]	SEN	116	[114,117]
ARG	36	[33,38]	BTN	117	[113,121]
RUS	37	[36,38]	MWI	118	[115,122]
MLT	38	[35,40]	LBN	119	[111,122]
ESP	39	[38,40]	MOZ	120	[118,122]
MDV	40	[38,42]	TGO	121	[118,123]
HUN	41	[40,46]	SWZ	122	[115,122]
KIR	42	[41,44]	PAN	123	[115,125]
GRC	43	[40,48]	IND	124	[122,135]
SYC	44	[42,46]	RWA	125	[124,126]
KGZ	45	[42,46]	PAK	126	[124,128]
TJK	46	[45,50]	YEM	127	[125,130]
MNG	47	[45,51]	GHA	128	[127,132]
CYP	48	[45,56]	TON	129	[124,135]
NAM	49	[44,58]	AGO	130	[127,134]
KAZ	50	[46,52]	GMB	131	[129,132]
TUN	51	[48,55]	MLI	132	[129,140]
CRI	52	[50,54]	TZA	133	[129,141]
ROU	53	[47,61]	PNG	134	[133,137]
JOR	54	[49,59]	BHR	135	[125,138]
MUS	55	[52,56]	MRT	136	[130,137]
CHN	56	[49,64]	BFA	137	[134,139]
URY	57	[55,60]	VUT	138	[128,142]
BGR	58	[53,65]	AFG	139	[137,142]
SLV	59	[56,63]	IRQ	140	[134,147]
MDA	60	[57,70]	ZWE	141	[138,147]
BLZ	61	[58,65]	BEN	142	[139,143]
UZB	62	[54,69]	COD	143	[141,145]
MEX	63	[58,63]	LAO	144	[142,146]
LSO	64	[55,76]	ETH	145	[143,147]
BRB	65	[60,71]	COG	146	[138,148]
BRA	66	[63,68]	OMN	147	[140,148]

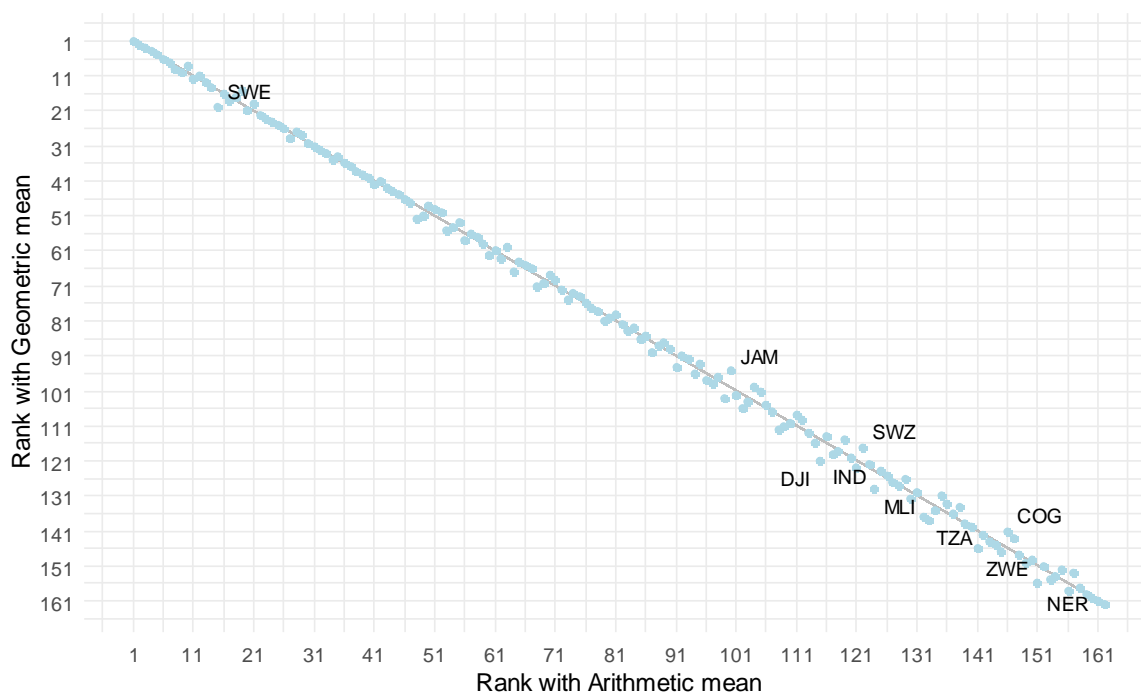
Country	CRI Ranks	Interval	Country	CRI Ranks	Interval
GUY	67	[62,74]	BDI	148	[145,150]
TUV	68	[61,80]	CMR	149	[148,150]
AZE	69	[64,77]	GNB	150	[148,154]
CPV	70	[66,72]	NER	151	[150,157]
BOL	71	[66,75]	TCD	152	[151,154]
TUR	72	[68,76]	UGA	153	[152,156]
THA	73	[68,81]	SLE	154	[152,156]
GEO	74	[69,78]	CIV	155	[151,156]
ALB	75	[72,77]	CAF	156	[153,158]
ARM	76	[70,78]	MDG	157	[151,157]
ECU	77	[73,82]	HTI	158	[154,159]
SGP	78	[72,80]	GIN	159	[158,159]
BWA	79	[70,90]	LBR	160	[160,161]
ATG	80	[69,84]	NGA	161	[160,161]
WSM	81	[75,81]	SSD	162	[162,162]

Source: European Commission, Joint Research Centre, 2022.

The second sensitivity exercise compares rankings resulting from the aggregation method. Figure 5 compares the ranks derived from the CRI, which uses arithmetic aggregation, with the ranks that would derive from a geometric aggregation. This comparison allows us to inquire whether the variability in the rank intervals originates from the modelling assumptions in aggregation.

Figure 5 indicates a close fit between the two aggregation procedures in the rankings. There are only four countries that increase 5 ranks and six countries that lose at least 5 ranks. The countries that change rankings are mostly situated at the bottom of the CRI ranking, indicating that these countries likely have an unbalanced profile in the pillars, which is penalized more by the geometric mean. This sensitivity analysis also shows that the CRI is much more robust against changes in aggregation than changes in normalisation.

Figure 5. Sensitivity Analysis: Comparison of ranks according aggregation formula



Source: European Commission, Joint Research Centre, 2022.

Note: Labelled countries show a shift of at least **5 positions** between the two aggregation formulas.

6 Conclusions

The JRC statistical audit delves into the extensive work carried out by the developers of the 2022 Commitment to Reducing Inequality Index with the aim of suggesting improvements in terms of data characteristics, structure, and methods used. The analysis aims to ensure the transparency of the index methodology and the reliability of the results.

The data coverage of the framework is very good. Most indicators contain no missing values, and none of them present outliers. Given the complexity of the framework and the population covered, it is a common issue to have aged information or sources only partially the countries of interest. With respect to the use of proxies, JRC-COIN suggests considering statistical methods for the imputation of missing data as a possible alternative to the use of proxy data. In the discussion, the developers proven to be already working on this point trying to enhance data coverage.

According to the coherence analysis, the CRI is statistically correlated with its pillars in general. However, the Taxation pillar is less represented because of its internal structure and its correlation with the other two pillars. There are mostly positive correlations between indicators and their corresponding sub pillars, pillars and the index, thus suggesting that most of the indicators provide meaningful information on the variation of the scores.

However, two issues were identified: First, considering the Tax pillar, the JRC team noticed that the statistical relations in it can be loose, as the indicators do not correlate internally and correlate weakly or negatively with the index. At the sub-pillar level, Tax Implementation (T2) shows a negative relationship with Tax Policy (T1). Moreover, Tax Policy (T1) has a significant negative correlation with the CRI index. As a consequence of these points, the information from the Tax pillar contributes much less to the index compared to the other two pillars. Given its conceptual importance in the framework, JRC would recommend to always keep a special attention to the scores of this pillar, pointing out how the information it carries is not represented largely in the overall score. The observation of the results of the single pillars, in addition to the index, may be helpful in dealing with this point. Second, in the Labour rights pillar, the Labour rights Policy (L1) sub-pillar does not correlate with the other two, and it is the only one of three that contributes very little (0.30) to the overall score. Additionally, the indicators of L1 are weakly correlated. For that reason, the indicator and the sub-index would be a good option for future refinement.

JRC analysed a series of different choices that were made during the index construction. The assumptions tested with the uncertainty analysis are related to the aggregation formula, normalisation procedure, and weights. This edition of the Audit, included normalisation in the uncertainty to test its effect in interaction with the other assumptions. The normalisation of the aggregates at each level was tested against the normalisation only at the base level. As described in the text, the results show that normalisation is a significant source of uncertainty. The JRC team suggests keeping the normalisation of the pillars as it is (and as suggested in the previous audit) because it has a structural role in managing the different ranges of the sub-pillars and pillars due to the different magnitude of internal correlation shown by the elements of the aggregate.

In order to understand the robustness of the index excluding the normalisation's role, JRC-COIN performed a second robustness analysis including only aggregation and weights. The results of the uncertainty analysis reveal that the CRI is a robust summary measure and, for most countries, the confidence intervals are narrow enough for meaningful inferences to be drawn from the index. The shift between the nominal rank and the median rank in the simulation is fewer than 5 positions for all the countries included in the index. Furthermore, only three countries have a 90% interval greater than 20 positions (they

were nine in the previous audit), implying that the rankings vary significantly with changes in weights or aggregation method. It implies that it is not advisable to draw inferences from the nominal rank of these few countries.

The JRC suggested some possible directions for future refinement while recognising the CRI as a useful tool to provide insights for measuring the commitment to reduce inequalities. In general, the present audit confirms that the CRI Index is reliable and transparent and acknowledges the important efforts made by the developers' team for the definition of a coherent framework.

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