Appendix II
Joint Research Centre (JRC) statistical audit of the 2023 Global Innovation Index

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Conceptual and practical challenges are inevitable when trying to understand and model the fundamentals of innovation at the national level worldwide. Now in its 16th edition, the Global Innovation Index (GII) 2023, considers these conceptual challenges and deals with practical issues relating to data quality and methodological choices.

This appendix summarizes the main conclusions of the audit, conducted for the 13th consecutive year by the European Commission's Competence Centre on Composite Indicators and Scoreboards (COIN) at the Joint Research Centre (JRC), concerning the statistical soundness and assumptions used to arrive at the final index rankings of the GII 2023. The independent statistical assessment of the GII provided by the JRC-COIN guarantees the transparency and reliability of the index for both policymakers and other stakeholders, thus facilitating more accurate priority setting and policy formulation in the innovation field.

As in past GII reports, the JRC-COIN analysis complements the economy rankings with confidence intervals for the GII, the Innovation Input Sub-Index and the Innovation Output Sub-Index, in order to allow a better appreciation of the robustness of these rankings to the choice of computation methodology. Finally, the JRC-COIN analysis also includes an assessment of the added value of the GII and a measure of "distance to the efficiency frontier" of innovation by using data envelopment analysis.

This is a shortened version of the audit. The full audit is available at www.wipo.int/global_innovation_index/en/2023.

Main conclusions

The JRC-COIN analysis suggests that the conceptualized multilevel structure of the GII 2023 – with its 80 indicators, 21 sub-pillars, seven pillars and two sub-indices comprising the overall index – is statistically sound and balanced: that is, each sub-pillar makes a similar contribution to the variation of its respective pillar. The refinements made by the developing team over the years have helped to enhance an already strong statistical coherence within the GII framework, in which the capacity of the 80 indicators to distinguish between economies' performances is maintained at the sub-pillar level or lower in all but four cases.

The decision not to impute missing values, which is common in comparable contexts and justified on the grounds of transparency and replicability, can at times have an undesirable impact on some economies' scores, with the additional negative side-effect that it might encourage economies not to report low data values. The GII team's adoption, in 2016, of a more stringent data coverage threshold (at least 66 percent data availability for each of the input- and output-related indicators) has notably improved confidence in the economy ranking for the GII and the two sub-indices.

Additionally, the GII team's decision, in 2012, to use weights as scaling coefficients during index development constitutes a significant departure from the traditional, yet erroneous, vision of weights as a reflection of indicators' importance in a weighted average. It is hoped that such an approach will be adopted by other developers of composite indicators to avoid situations where bias sneaks in when least expected.

Strong correlations between the GII components are proven not to be a sign of redundancy of information within the GII. For more than 34 percent (up to 70 percent) of the 132 economies included in the GII 2023, the GII ranking and the rankings of any of the seven pillars differ by 10 positions or more. This demonstrates the added value of the GII ranking, which helps to highlight other components of innovation not immediately apparent from a separate analysis of each pillar. At the same time, this finding points to there being value in duly considering the merits of the GII pillars, sub-pillars and their constituent indicators individually. By doing so,

economy-specific strengths and bottlenecks in innovation can be identified and serve as an input for evidence-based policymaking.

To test the impact of the GII modeling assumptions, a number of different models were tested in this audit, based on different approaches to imputing of missing data, aggregation at the pillar level and assignment of weights. Using these models, the 90 percent confidence intervals relating to the ranking positions that an economy might have had under different model assumptions were computed. For the vast majority of economies, these intervals are sufficiently narrow to allow meaningful inferences to be drawn: there is a shift of 10 or fewer positions for 89 of the 132 economies. However, it is also true that a few economies experience significant changes in rank with variations in weights and aggregation formula and when imputing missing data. Five economies – Bahrain, Belarus, Botswana, Brunei Darussalam and Zimbabwe – have 90 percent confidence interval widths of more than 20 positions (21, 24, 21, 41 and 21 positions, respectively). Consequently, their GII rankings (67th, 80th, 85th, 87th and 117th, respectively) in the GII classification should be interpreted cautiously and certainly not taken at face value. However, this is a remarkable improvement compared to GII versions up to 2016, when more than 40 economies had confidence interval widths of more than 20 positions. The improvement in the confidence that can be placed in the GII 2023 ranking is the direct result of the decision to adopt a more stringent criterion for an economy's inclusion since 2016, which now requires at least 66 percent data availability within each of the two sub-indices. Some caution is also warranted in regard to the Input Sub-Index for one economy – Brunei Darussalam – which has a 90 percent confidence interval width of more than 20 positions (22). A similar degree of caution is needed in the Output Sub-Index for three economies – Botswana, Côte d'Ivoire and Ghana – which have 90 percent confidence interval widths of more than 20 positions (up to 24 for Ghana). Compared to the GII 2019, the higher data availability in the Output Sub-Index this year has led to a much lower number of countries with very wide intervals (three compared to 13 in the GII 2019 edition), which is a noteworthy improvement.

Although the rankings for a few economies, in the GII 2023 overall or in the two sub-indices, appear to be sensitive to methodological choices, the published rankings for the vast majority can be considered as representative of the plurality of scenarios simulated in this audit. Taking the median rank as the benchmark for an economy's expected rank in the realm of the GII's unavoidable methodological uncertainties, 80 percent of the economies are found to shift fewer than three positions with respect to the median rank in the GII and the Input Sub-Index; however, the percentage for the Output Sub-Index is lower, at 62 percent.

In order to offer full transparency and complete information, Appendix Table 2 reports the GII 2023 Index and Input and Output Sub-Indices' economy ranks together with the simulated 90 percent confidence intervals to allow a better appreciation of the robustness of the results to the choice of weights and aggregation formula and the impact of estimating missing data (where applicable).

All things considered, the present JRC-COIN audit findings confirm that the GII 2023 meets international quality standards for statistical soundness, which indicates that the GII is a reliable benchmarking tool for innovation practices at the economy level around the world.

Finally, the "distance to the efficiency frontier" measure, calculated using data envelopment analysis, can be used both as a measure of efficiency and as a suitable approach to benchmarking economies' multidimensional performance on innovation, without imposing a fixed and common set of weights that may be unfair to a particular economy. The decision made by the GII team to abandon the efficiency ratio (ratio of Output to Input Sub-Index) is particularly laudable. In fact, ratios of composite indicators (Output to Input Sub-Index in this case) come with much higher uncertainty than the sum of the components (Input plus Output Sub-Index, equivalent to the GII). For this reason, developers and users of indices alike need to approach efficiency ratios of this nature with great care. The GII should not be considered as the ultimate and definitive ranking of economies with respect to innovation. On the contrary, the GII best represents an ongoing attempt to find metrics and approaches that capture the richness of innovation more effectively, continuously adapting the GII framework to reflect the improved availability of statistics and the theoretical advances in the field. In any case, the GII should be regarded as a sound attempt, based on the principle of transparency, matured over 16 years of constant refinement, to pave the way for better and more informed innovation policies worldwide.

Appendix Table 2 GII 2023 and Input/Output Sub-Indices: rankings and 90 percent confidence intervals

	GII 2023		Input Sub-Index		Output Sub-Index	
	Rank	**Interval**	**Rank**	**Interval**	**Rank**	**Interval**
Switzerland	1	[1, 1]	3	[2, 4]	1	[1, 1]
Sweden	2	[2, 3]	4	[2, 5]	3	[3, 3]
United States	3	[2, 4]	2	[2, 5]	4	[4, 6]
United Kingdom	4	[3, 6]	6	[6, 9]	2	[2, 2]
Singapore	5	[4, 9]	1	[1, 1]	12	[12, 13]
Finland	6	[4, 6]	5	[4, 5]	9	[9, 10]
Netherlands (Kingdom of the)	7	[5, 8]	10	[8, 10]	5	[5, 8]
Germany	8	[7, 10]	13	[13, 15]	6	[5, 6]
Denmark	9	[8, 10]	7	[6, 8]	10	[9, 10]
Republic of Korea	10	[7, 10]	12	[10, 13]	7	[7, 8]
France	11	[11, 13]	17	[14, 21]	11	[11, 11]
China	12	[11, 14]	25	[24, 26]	8	[4, 8]
Japan	13	[13, 15]	11	[11, 12]	14	[13, 16]
Israel	14	[12, 18]	21	[14, 22]	13	[13, 15]
Canada	15	[14, 18]	9	[7, 11]	20	[19, 24]
Estonia	16	[15, 18]	14	[12, 19]	16	[16, 18]
Hong Kong, China	17	[11, 22]	8	[6, 10]	24	[13, 30]
Austria	18	[14, 18]	18	[16, 21]	15	[13, 16]
Norway	19	[19, 25]	15	[14, 20]	28	[26, 29]
Iceland	20	[19, 21]	20	[17, 21]	25	[23, 25]
Luxembourg	21	[18, 24]	22	[16, 23]	23	[21, 27]
Ireland	22	[18, 24]	26	[24, 26]	18	[17, 20]
Belgium	23	[19, 25]	23	[22, 23]	22	[21, 26]
Australia	24	[22, 25]	16	[15, 21]	30	[29, 30]
Malta	25	[20, 26]	27	[27, 27]	17	[14, 20]
Italy	26	[25, 28]	35	[33, 35]	19	[18, 20]
New Zealand	27	[26, 31]	24	[24, 26]	31	[31, 35]
Cyprus	28	[27, 29]	33	[30, 33]	21	[21, 26]
Spain	29	[28, 30]	28	[28, 29]	26	[25, 27]
Portugal	30	[30, 31]	31	[30, 34]	29	[28, 29]
Czech Republic	31	[26, 31]	34	[30, 35]	27	[19, 28]
United Arab Emirates	32	[31, 39]	19	[18, 22]	54	[54, 57]
Slovenia	33	[32, 35]	29	[28, 31]	38	[37, 39]
Lithuania	34	[32, 35]	32	[31, 35]	37	[36, 37]
Hungary	35	[32, 36]	36	[36, 37]	33	[31, 34]
Malaysia	36	[35, 37]	30	[28, 32]	46	[45, 46]
Latvia	37	[37, 40]	38	[37, 38]	39	[38, 40]
Bulgaria	38	[36, 40]	45	[42, 47]	34	[33, 35]
Türkiye	39	[36, 42]	52	[48, 55]	32	[31, 33]
India	40	[37, 43]	46	[44, 51]	35	[32, 37]
Poland	41	[39, 42]	50	[42, 51]	36	[35, 38]
Greece	42	[40, 44]	42	[39, 43]	41	[39, 41]
Thailand	43	[41, 45]	44	[40, 49]	43	[41, 43]
Croatia	44	[42, 44]	43	[41, 45]	44	[41, 44]
Slovakia	45	[44, 46]	51	[46, 51]	45	[45, 48]
Viet Nam	46	[44, 47]	57	[53, 58]	40	[40, 43]
Romania	47	[46, 50]	55	[52, 57]	47	[47, 49]
Saudi Arabia	48	[47, 54]	37	[36, 38]	67	[64, 70]
Brazil	49	[48, 53]	59	[53, 61]	49	[49, 50]
Qatar	50	[49, 65]	39	[39, 40]	70	[69, 79]
Russian Federation	51	[48, 55]	58	[51, 61]	53	[51, 53]
Chile	52	[49, 53]	48	[45, 49]	56	[56, 60]
Serbia	53	[49, 67]	41	[40, 51]	64	[62, 72]
North Macedonia	54	[51, 59]	49	[47, 60]	58	[57, 61]
Ukraine	55	[48, 56]	78	[70, 78]	42	[42, 44]
Philippines	56	[51, 59]	69	[64, 71]	52	[50, 54]
Mauritius	57	[49, 69]	40	[39, 51]	72	[70, 80]
Mexico	58	[54, 63]	77	[73, 77]	51	[51, 54]
South Africa	59	[57, 65]	71	[68, 73]	57	[57, 61]
Republic of Moldova	60	[53, 65]	81	[78, 82]	50	[47, 52]
Indonesia	61	[59, 66]	64	[62, 67]	63	[62, 65]
Iran (Islamic Republic of)	62	[57, 75]	87	[85, 100]	48	[45, 48]
Uruguay	63	[56, 68]	56	[52, 62]	73	[64, 74]
Kuwait	64	[61, 72]	67	[65, 73]	65	[63, 69]
Georgia	65	[56, 70]	54	[52, 60]	77	[66, 77]
Colombia	66	[62, 72]	63	[57, 63]	71	[69, 73]
Bahrain	67	[60, 81]	47	[43, 58]	86	[84, 96]
Mongolia	68	[58, 75]	79	[79, 84]	60	[51, 68]

Appendix Table 2   Continued

	GII 2023		Input Sub-Index		Output Sub-Index	
	Rank	**Interval**	**Rank**	**Interval**	**Rank**	**Interval**
Oman	69	[67, 74]	65	[61, 67]	78	[73, 79]
Morocco	70	[64, 76]	90	[86, 91]	55	[55, 58]
Jordan	71	[68, 77]	70	[66, 71]	76	[73, 81]
Armenia	72	[63, 75]	83	[81, 85]	62	[55, 62]
Argentina	73	[65, 79]	84	[80, 87]	59	[58, 65]
Costa Rica	74	[65, 78]	66	[61, 70]	81	[69, 82]
Montenegro	75	[70, 77]	62	[59, 65]	83	[74, 83]
Peru	76	[72, 84]	60	[55, 68]	84	[84, 93]
Bosnia and Herzegovina	77	[73, 86]	75	[72, 79]	80	[80, 86]
Jamaica	78	[72, 82]	82	[77, 86]	69	[65, 74]
Tunisia	79	[71, 83]	96	[89, 96]	61	[59, 63]
Belarus	80	[58, 82]	88	[77, 92]	66	[54, 69]
Kazakhstan	81	[78, 84]	68	[65, 70]	87	[83, 94]
Uzbekistan	82	[78, 84]	72	[71, 76]	88	[82, 90]
Albania	83	[80, 87]	73	[70, 76]	94	[87, 94]
Panama	84	[82, 88]	93	[86, 96]	75	[73, 84]
Botswana	85	[83, 104]	61	[58, 63]	110	[107, 129]
Egypt	86	[82, 92]	99	[94, 100]	74	[73, 76]
Brunei Darussalam	87	[72, 113]	53	[42, 64]	125	[112, 126]
Pakistan	88	[84, 100]	113	[103, 113]	68	[66, 79]
Azerbaijan	89	[85, 96]	76	[71, 78]	104	[101, 107]
Sri Lanka	90	[85, 98]	103	[100, 105]	79	[76, 80]
Cabo Verde	91	[87, 99]	74	[73, 86]	106	[90, 107]
Lebanon	92	[80, 93]	86	[82, 91]	95	[78, 95]
Senegal	93	[88, 99]	95	[92, 99]	93	[85, 97]
Dominican Republic	94	[90, 95]	89	[85, 92]	96	[95, 98]
El Salvador	95	[89, 98]	102	[98, 103]	90	[84, 90]
Namibia	96	[92, 104]	80	[79, 86]	111	[108, 112]
Bolivia (Plurinational State of)	97	[91, 105]	91	[86, 99]	101	[100, 103]
Paraguay	98	[91, 102]	101	[97, 106]	92	[85, 94]
Ghana	99	[90, 110]	107	[105, 114]	85	[84, 108]
Kenya	100	[91, 104]	104	[103, 105]	91	[89, 99]
Cambodia	101	[97, 104]	97	[96, 104]	100	[94, 100]
Trinidad and Tobago	102	[95, 106]	92	[86, 97]	108	[105, 109]
Rwanda	103	[95, 110]	85	[84, 100]	113	[102, 113]
Ecuador	104	[95, 104]	98	[94, 99]	99	[92, 100]
Bangladesh	105	[96, 108]	114	[114, 122]	89	[85, 92]
Kyrgyzstan	106	[100, 108]	94	[87, 96]	112	[106, 112]
Madagascar	107	[101, 120]	125	[121, 128]	82	[81, 98]
Nepal	108	[103, 110]	106	[104, 111]	103	[98, 103]
Nigeria	109	[104, 120]	116	[113, 119]	98	[98, 116]
Lao People's Democratic Republic	110	[106, 117]	100	[100, 103]	120	[109, 123]
Tajikistan	111	[105, 114]	109	[105, 112]	107	[100, 115]
Côte d'Ivoire	112	[108, 122]	112	[107, 119]	102	[102, 125]
United Republic of Tanzania	113	[110, 120]	105	[103, 118]	123	[112, 124]
Togo	114	[111, 117]	120	[116, 120]	105	[105, 112]
Nicaragua	115	[112, 121]	110	[108, 114]	118	[116, 120]
Honduras	116	[109, 118]	115	[106, 116]	114	[111, 117]
Zimbabwe	117	[108, 129]	127	[122, 128]	97	[96, 115]
Zambia	118	[112, 120]	111	[107, 119]	122	[110, 123]
Algeria	119	[110, 121]	118	[106, 119]	116	[110, 121]
Benin	120	[114, 126]	108	[105, 114]	128	[127, 130]
Uganda	121	[115, 122]	117	[115, 122]	121	[118, 121]
Guatemala	122	[110, 122]	121	[117, 122]	115	[104, 117]
Cameroon	123	[120, 124]	123	[120, 125]	117	[116, 121]
Burkina Faso	124	[122, 128]	119	[117, 121]	127	[124, 129]
Ethiopia	125	[121, 127]	130	[130, 131]	109	[101, 119]
Mozambique	126	[123, 131]	128	[124, 131]	124	[122, 129]
Mauritania	127	[124, 130]	122	[122, 126]	129	[127, 130]
Guinea	128	[124, 129]	131	[126, 132]	119	[114, 128]
Mali	129	[125, 129]	129	[124, 129]	126	[123, 126]
Burundi	130	[129, 131]	126	[126, 130]	130	[127, 131]
Niger	131	[125, 132]	124	[124, 128]	131	[122, 132]
Angola	132	[131, 132]	132	[131, 132]	132	[131, 132]

Source: European Commission, Joint Research Centre, 2023.
Notes: Confidence intervals are calculated over 4,000 simulated scenarios combining simulated weights, imputation versus no imputation of missing values, and geometric versus arithmetic average at the pillar level.