Appendix III:
JRC Statistical Audit of the 2020 Network Readiness Index

JRC Statistical Audit of the 2020 Network Readiness Index

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1. Introduction

The redesigned Network Readiness Index 2020 (NRI 2020) aims to reflect ICT deployment issue better than the NRI 2016 without losing continuity with previous exercises. It has the additional goal of being future-proof in capturing the integration of people and technology, its governance, and its economic impact. The challenges of the emerging information society and economy and the increasing importance of technology, artificial intelligence and data motivates the NRI and its goals.

NRI 2020 is composed of four pillars: Technology, People, Governance, and Impact. Technology seeks to assess the level of technology in a given country; People is concerned with the application of ICT by individuals, businesses, and governments; Governance assess the national environment in terms of trust, regulation, and inclusion; and Impact tries to capture the economic, social, and human impact of participation in the network economy. Each pillar has the same weight in the computation of the index. All pillars are composed of three sub-pillars that are weighted equally. The number of indicators making up each sub-pillars varies. They are equally weighted in each sub-pillar, therefore the weight of each individual indicator in the overall index varies.

NRI 2020 is timely in tackling how technology benefits the general population and the economy and in its approach highlighting the importance of regulations, economic benefits, well-being and the achievement of SDGs. The NRI 2020 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 complexity of the emerging economic order within the information society, its regulation and its economic impact. Challenges are even more complicated when considering the changing nature of Technology and NRI's future-proof ambitions.

The European Commission's Competence Centre on Composite Indicators and Scoreboards at the Joint Research Centre (JRC) has performed this audit upon the invitation of the developers. The analysis herein aims at shedding light on the consistency, transparency and reliability of the NRI 2020 and thus to enabling policymakers to derive accurate, meaningful and consistent conclusions. The JRC assessment of the NRI 2020 presented here focuses on two main issues: the statistical coherence of the structure, and the impact of key modelling assumptions. The statistical analysis is based on the adequacy of aggregating indicators into pillars, and pillars into the overall index. Finally, the JRC analysis complements the reported country rankings for the NRI index 2020 with estimated intervals, in order to better appreciate the robustness of these ranks to the modelling choices.

2. Conceptual framework

The structure of the NRI is summarized in Table 1. Variables were selected for their relevance to a specific pillar on the basis of the literature review, expert opinion, country coverage, and timeliness.

In view of further evolution of the index, the developers may consider further exploration of the Network economy specific measures, which would make the framework more consistent with the changing nature of technology and NRI's goal of being future-proof. Many aspects of the digital economy and its conceptualization, its economic benefits, drawbacks and consequent governance are still under discussion and beyond current state of knowledge. This makes NRI future-proof goal difficult to conceptualize and audit. Some notable conceptualization efforts are being done from social scientists and developers may consider them in future editions. Far from aiming to make a complete literature review we suggest few references on conceptualizing[1] and quantifying[2] specific aspects of the digital economy.

[1] Martens, B., 2016, An economic policy perspective on online platforms, Institute for Prospective Technical Studies Digital Economy Working Paper 2016/05.
Pedraza Garcia, P. de and Vollbracht, I., (2019) The semicircular flow of the data economy, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-09232-2, doi: 10.2760/40733.
Khan, L. M. 2017. Amazon's Antitrust Paradox. The Yale Law Journal, vol. 126, number 3, pp. 710-805

[2] Liem, C., and Petropoulos, G., 2016, 'The economic value of personal data for online platforms, firms and consumers', Bruegel blogspot, 14 January
Steel, E., 2013, 'Companies scramble for consumer data', Financial Times, 12 June h
Steel, E., Locke, C., Cadman, E. and Freese, B., 2013, 'How much is your personal data worth? Use our calculator to check how much multibillion-dollar data broker industry might pay for your personal data', Financial Times, 12 June

TABLE 1. CONCEPTUAL FRAMEWORK OF THE NRI 2020

Pillar	Sub-pillar	Indicator
1. TECHNOLOGY	1.1 Access	Mobile tariffs
		Handset prices
		Internet access
		4G mobile network coverage
		Fixed-broadband subscriptions
		International Internet bandwidth
		Internet access in schools
	1.2 Content	GitHub commits
		Wikipedia edits
		Internet domain registrations
		Mobile apps development
	1.3 Future Technology	Adoption of emerging technologies
		Investment in emerging technologies
		ICT PCT patent applications
		Computer software spending
		Robot density
2. PEOPLE	2.1 Individuals	Internet users
		Active mobile-broadband subscriptions
		Use of virtual social networks
		Tertiary enrolment
		Adult literacy rate
		ICT skills
	2.2 Business	Firms with website
		Ease of doing business
		Professionals
		Technicians and associate professionals
		Business use of digital tools
		R&D expenditure by businesses
	2.3 Governments	Government online services
		Publication and use of open data
		Government promotion of investment in emerging technologies
		R&D expenditure by governments and higher education
3. GOVERNANCE	3.1 Trust	Secure Internet servers
		Cybersecurity
		Online access to financial account
		Internet shopping
	3.2 Regulation	Regulatory quality
		ICT regulatory environment
		Legal framework's adaptability to emerging technologies
		e-commerce legislation
		Privacy protection by law content
	3.3 Inclusion	E-Participation
		Socioeconomic gap in use of digital payments
		Availability of local online content
		Gender gap in Internet use
		Rural gap in use of digital payments

4. IMPACT	4.1 Economy	Medium and high-tech industry
		High-tech exports
		PCT patent applications
		Labour productivity per employee
		Prevalence of gig economy
	4.2 Quality of life	Happiness
		Freedom to make life choices
		Income inequality
		Healthy life expectancy at birth
	4.3 SDG Contribution	SDG 3: Good Health and Well-Being
		SDG 4: Quality Education
		SDG 5: Gender Equality
		SDG 7: Affordable and Clean Energy
		SDG 11: Sustainable Cities and Communities

Source: Elaborated by European Commission's Joint Research Centre from the NRI, 2020.

3. Data quality and availability

Regarding data coverage, the general practice is to establish a threshold above which an indicator is excluded from the framework. For the NRI development, the inclusion of countries and indicators is based on the double threshold approach. In terms of country coverage, this means that only countries with data available for at least 70% of all indicators are included in the NRI. In addition, countries need to pass a sub-pillar level data availability of at least 40%. In terms of indicator coverage, only indicators with availability of at least 50% of countries are included in the NRI. Despite the absence of an absolute golden standard, the JRC-team suggest to include only indicators with maximum one-third of missing values (33%). When an indicator represents a very specific and central concept, also a looser threshold of 40% missing countries could be integrated in the structure.

Following this principle, seven indicators (ind. 07, 14, 16, 41, 45, 49, and 57) are showing poor coverage. These indicators could be the focus of future refinement, with the aim of improving their coverage or excluding/modifying them.

The presence of outliers, which could potentially bias the effect of the indicators on the aggregates, was properly tackled by developers. They identified outliers when the variables have simultaneously absolute skewness greater than 2.0 and kurtosis greater than 3.5 and treated values accordingly. Six indicators were treated via winsorization. Moreover, three indicators, cases when the outliers are at least five, were treated via logarithmic transformation. After the treatment implementation, none of the indicators used in the calculation of the NRI Index shows critical skewness and kurtosis values.

Some indicators represent other composite indicators, whose composition, methodology and statistical coherence are not audited here.

3.1 NORMALISATION

The indicators are rescaled to a 0–100 scale using the MIN-MAX formula, with 0 as the lowest score achieved by countries, and 100 as the highest, which is a common and usually desired practice in the composite indicators' construction. The normalisation formula is selected in order to obtain always higher scores representing better outcomes. The direction of some indicators may not be extremely intuitive for a non-expert reader, we suggest to reconsider the naming of some of the variables or be sure to supply clear explanations in the report. Here are some examples.

First, according to developers, only two indicators were consider to have a negative effect on the network economy before normalisation: indicator 58 (4.2.3 SDG 5: Income inequality) and indicators 59 (4.3.4 SDG 7: Affordable and Clean Energy). Developers may consider whether name assigned to indicator 59 is misleading.

Second, from a conceptual point of view, higher tariffs (indicators 1, 1.1.1 mobile tariffs) and prices (indicator 2, 1.1.2 handset prices) make technological devices less affordable and, in principle, should be considered negative. However, correlations show that both are positively correlate to other indicators. This situation may be pointing to the fact that, for example, better 4G and internet infrastructure are found in countries with higher prices and taxes. Future editions can explore this issue further and, for instance, consider the use of purchasing power parity.

Third, some consideration may be needed for indicators measuring different kinds of gaps and inequalities in sub-pillar 3.3 Inclusion. First, the definition of gap is not consistent across indicators, some are defined as ratios and some as differences. Gender gap (3.3.4) is defined as: Ratio of female over male population in using the Internet. It takes values above one in some countries. This means that, if considered positive, the bigger the gap between women and men the better, in case women are more connected. Similar situation occurs with SDG5 Gender equality that shows the female HDI (Human Development Index) as a percentage of the male HDI (4.3.3). The developers may consider exploring further UNDP's Gender Development, and the way its developers communicate it. Is positive discrimination generally accepted as good? Rural gap (3.3.5) is defined as: Difference between (percentages) of rural and total population that made or received digital payments in the past year where some countries also score above 1. Again, the higher the difference the better in case rural areas are more connected.

Finally, socioeconomic gap in use of digital payments (3.3.2) measures the difference between rich (i.e. richest 60%) and poor (i.e. poorest 40%) income groups that made or received digital payments in the past year. While, this indicator may be reflecting high internet penetration across socio economic groups, it may be also driven by inequality. Considering it as a positive indicator may represent a confusing element of the index.

4. Statistical coherence

The statistical coherence is based on a multi-level analysis of the correlations of indicators and aggregates, and a comparison of the index's rankings with the ranks defined by the pillars.

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 coherence is mostly based on correlations, the correspondence of each composite indicator 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)[3]. 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 significant 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

The exploration of correlations among indicators in the same sub-pillar shows that most of the sub-pillars are statistically consistent especially with very high but not excessive correlations. Only two relevant exceptions are found in pillar 4 related to Impact.

In sub-pillar 4.2 quality of life, the correlation between indicator 54, Income inequality, and 53, freedom to make choices, is very low (0.13).Both indicators show good correlations with the other indicators in the sub-pillar, so there is no absolute evidence of incoherence. The best practice in this case could be the monitoring of these indicators, especially ind. 54 because of its lower coverage (9% of missing values). In sub-pillar 4.3, SDG contribution, indicator 59 shows no correlation with indicators 57 and 58. This may depend on the intrinsic meaning of the indicators, representing different goals, respectively Affordable and Clean Energy (59), Quality Education (57), and Gender Equality (58). In general, indicator 59 is poorly correlate with all the elements of the sub-pillar. This behaviour of Ind. 59 makes, from a statistical point of view, sub-pillar 4.3 weaker than the others included in the framework.

In sub-pillar 3.2 regulation, the correlation between indicators 41 privacy protection, and 39 legal framework adaptability to emerging technologies is low (0,21). It may be important recalling that indicator 41 also suffers from availability problems. This result may not be expected because both indicators seem to be very close from a conceptual point of view. Developers may consider the improvement of the coverage in indicator 41 as a priority, or alternatively consider excluding it. In sub-pillar 3.3, inclusion, indicator 46 that measure rural gap is not strongly correlated with indicators 42, and 45 gender gap. Whilst the level of correlation is below the threshold of 0.30, this is hardly a severe problem. The suggestion is to keep a special attention for the way gaps have been calculated.

The exploration of correlation coefficients between indicators and their corresponding sub–pillar shows that all correlations are significant and positive. All the correlations are usually very high, some of them even higher than 0.92 which sometime represents an over-representation of the element in the aggregate. Most indicators are also very

[3] 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.

highly correlated with other sub-pillars and pillars. From a correlation point of view, many of them could be included in several sub-pillars and pillars. There are hardly any indicators with low correlations. The lowest correlation of an indicators with its sub-pillar is 0.50 which is acceptable. It is found between indicator 59, SDG7 affordable clean energy and its sub-pillar 4.3, SDG contribution. The main source of concern in the statistical framework is represented by the risk of redundancy, suggested by the numerous indicators with correlation over 0.92. This kind of result does not represent an error per-se but may suggest the presence of redundant elements in the structure. So, it suggests the option of simplification and reduction of the index.

Correlations of indicators with pillars and overall index are in general very high, especially in the first two pillars **(Table2).** Some indicators, although significant, are associated to the overall index in a lower extend than the majority of the indicators (between 0.4 and 0.5). That is the case of several indicators in pillars 3 such as indicator 38, ICT regulatory environment, indicator 41, privacy protection and indicator 46, rural gap. Similarly, in pillar 4 indicator 48, high-tech exports, and indicators, 53, and 54, freedom to make choices, income inequality respectively have lower, but still significant, correlation with its pillar and the overall index than most of the indicators. In the case of Indicator 59 correlations with its pillar (4. Impact) and the overall NRI, are 0.34 and 0.29 respectively (table 3). Which implies that indicator 59 is not contributing to the overall index in a significant way.

Few indicators display very high correlation with the overall index and tend to dominate it, having correlation higher than 0.91. This is the case of indicators 11, Apps development and 12, adoption of emerging technologies in pillar 1; 33, secure internet and 44, availability of internet content in pillar 2; and 36 internet shopping in pillar 3.

TABLE 2. CORRELATIONS BETWEEN INDICATORS, PILLARS AND OVERALL INDEX.

Indicator name		1. Technology	2. People	3. Governance	4. Impact	NRI
Mobile tariffs	ind.01	0.78	0.78	0.78	0.76	0.80
Handset prices	ind.02	0.84	0.81	0.81	0.81	0.84
Internet access	ind.03	0.86	0.89	0.84	0.82	0.87
4G mobile network coverage	ind.04	0.73	0.75	0.71	0.70	0.74
Fixed-broadband subscriptions	ind.05	0.81	0.78	0.79	0.76	0.80
International Internet bandwidth	ind.06	0.65	0.66	0.64	0.65	0.67
Internet access in schools	ind.07	0.83	0.82	0.80	0.78	0.83
GitHub commits	ind.08	0.85	0.74	0.79	0.77	0.81
Wikipedia edits	ind.09	0.87	0.85	0.82	0.84	0.87
Internet domain registrations	ind.10	0.83	0.70	0.74	0.73	0.77
Mobile apps development	ind.11	0.92	0.91	0.88	0.89	0.92
Adoption of emerging technologies	ind.12	0.91	0.90	0.87	0.87	0.92
Investment in emerging technologies	ind.13	0.81	0.76	0.75	0.76	0.79
ICT PCT patent applications	ind.14	0.89	0.86	0.81	0.85	0.88
Computer software spending	ind.15	0.72	0.63	0.64	0.65	0.68
Robot density	ind.16	0.71	0.70	0.64	0.72	0.72
Internet users	ind.17	0.84	0.89	0.82	0.84	0.87
Active mobile-broadband subscriptions	ind.18	0.73	0.80	0.74	0.74	0.77
Use of virtual social networks	ind.19	0.70	0.77	0.68	0.76	0.74
Tertiary enrollment	ind.20	0.74	0.82	0.76	0.74	0.78
Adult literacy rate	ind.21	0.68	0.72	0.63	0.67	0.70

ICT skills	ind.22	0.82	0.83	0.76	0.79	0.82
Firms with website	ind.23	0.79	0.83	0.77	0.78	0.81
Ease of doing business	ind.24	0.79	0.82	0.83	0.75	0.82
Professionals	ind.25	0.84	0.82	0.80	0.79	0.83
Technicians and associate professionals	ind.26	0.82	0.82	0.80	0.78	0.83
Business use of digital tools	ind.27	0.84	0.88	0.85	0.80	0.87
R&D expenditure by businesses	ind.28	0.72	0.75	0.67	0.71	0.73
Government online services	ind.29	0.76	0.83	0.82	0.76	0.81
Publication and use of open data	ind.30	0.78	0.80	0.79	0.77	0.81
Government promotion of investment in emerging technologies	ind.31	0.76	0.78	0.71	0.74	0.77
R&D expenditure by governments and higher education	ind.32	0.68	0.68	0.67	0.60	0.68
Secure Internet servers	ind.33	0.91	0.89	0.90	0.86	0.91
Cybersecurity	ind.34	0.75	0.80	0.83	0.71	0.79
Online access to financial account	ind.35	0.72	0.70	0.79	0.65	0.74
Internet shopping	ind.36	0.91	0.87	0.91	0.87	0.92
Regulatory quality	ind.37	0.90	0.85	0.90	0.85	0.90
ICT regulatory environment	ind.38	0.48	0.47	0.60	0.43	0.51
Legal framework's adaptability to emerging technologies	ind.39	0.90	0.89	0.86	0.85	0.90
e-commerce legislation	ind.40	0.49	0.48	0.58	0.55	0.54
Privacy protection by law content	ind.41	0.37	0.34	0.49	0.38	0.41
E-Participation	ind.42	0.74	0.81	0.80	0.75	0.80
Socioeconomic gap in use of digital payments	ind.43	0.72	0.70	0.81	0.67	0.75
Availability of local online content	ind.44	0.90	0.91	0.88	0.89	0.92
Gender gap in Internet use	ind.45	0.48	0.51	0.56	0.55	0.54
Rural gap in use of digital payments	ind.46	0.44	0.43	0.53	0.41	0.46
Medium and high-tech industry	ind.47	0.70	0.71	0.69	0.73	0.73
High-tech exports	ind.48	0.40	0.39	0.34	0.51	0.41
PCT patent applications	ind.49	0.75	0.75	0.67	0.74	0.75
Labor productivity per employee	ind.50	0.90	0.85	0.85	0.86	0.89
Prevalence of gig economy	ind.51	0.70	0.70	0.66	0.68	0.70
Happiness	ind.52	0.78	0.75	0.77	0.83	0.80
Freedom to make life choices	ind.53	0.47	0.45	0.49	0.57	0.50
Income inequality	ind.54	0.49	0.48	0.45	0.53	0.50
Healthy life expectancy at birth	ind.55	0.82	0.85	0.81	0.88	0.86
SDG 3: Good Health and Well-Being	ind.56	0.81	0.86	0.79	0.84	0.85
SDG 4: Quality Education	ind.57	0.79	0.74	0.79	0.79	0.81
SDG 5: Gender Equality	ind.58	0.49	0.53	0.55	0.56	0.54
SDG 7: Affordable and Clean Energy	ind.59	0.29	0.28	0.25	0.34	0.29
SDG 11: Sustainable Cities and Communities	ind.60	0.78	0.74	0.75	0.79	0.78

Numbers represent the Pearson correlation coefficients. Good correlations (i.e. Pearson correlation coefficients greater than 0.30 and lower than 0.92) are written in black. Correlations with low values (between -0.30 and 0.30) are written in **grey.** Correlations at risk of redundancy (here >0.91) are written in **green.** Correlations with meaningful negative value (here -0.30) are written in **red**. Source: Elaborated by European Commission's Joint Research Centre, 2020.

4.1.2 Correlation analysis between sub-pillars, pillars and index

The values in **Table 3** represent the correlation between the aggregates. This level is the most important as it represents the consistency of the general concepts. All pillars appear consistent, with the sub-pillars being well correlated with each other. Correlations between sub-pillars and pillars and the index show again that the NRI has a strong correlation structure being too high correlations the main concern.

First, some sub-pillars dominate their pillar. That is the case of sub-pillar 1.2 Content and pillar 1 (0.95), sub-pillar 2.2 business (0.94) and pillar 2, and 3.1 trust and pillar 3 (0.96). However, also the other sub-pillars and pillars have a high correlation. The highest aggregation step, from pillars to NRI, could be the main focus for future development of the index.

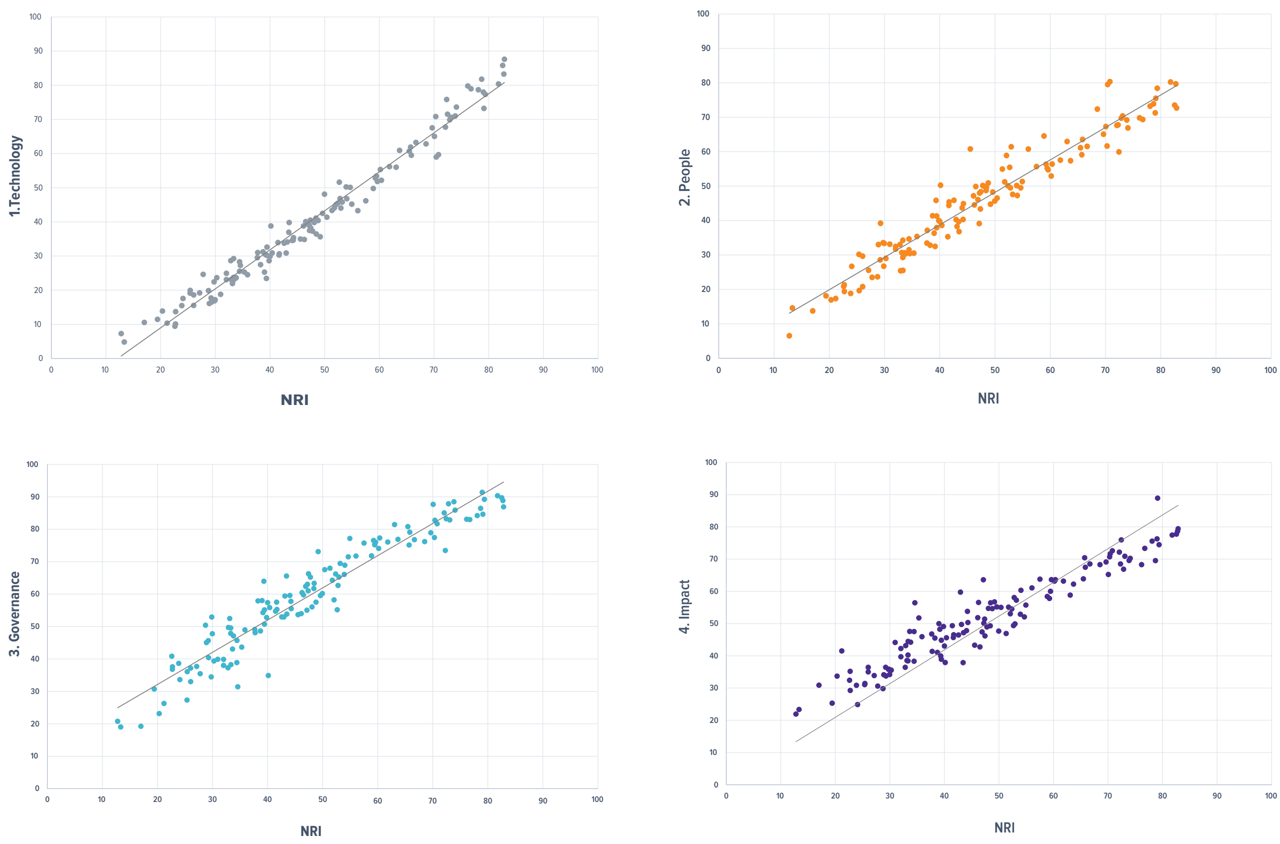
High statistical reliability among the main components can be the result of redundancy of information. In overall, NRI indicators, pillars and sub-pillars seem to be measuring similar phenomena. In **Figure 1** the relation between pillars and the index is visualised. The structure of the NRI Index allows for a dual narrative. On the one hand, it's a strong index in terms of statistical consistency that shows that ICT deployment is a multifaceted phenomenon where technology, users and several aspects of ICT regulation go hand in hand, especially in developed economies with high quality of life. On the other hand, taking into account several generally accepted problematics of ICT deployment, the picture may reflect the repetition of some concepts and even double counting of them. Possible suggestion for the future may be centred on the exploration of new indicators capturing vaster and more specific aspects of ICT deployment aspects. For instance, Artificial intelligence transparency, data portability, data sharing, and anti-trust concerns digital economy paradoxes.

TABLE 3. CORRELATIONS BETWEEN SUB-PILLARS, PILLARS AND OVERALL INDEX.

Indicator name		1. Technology	2. People	3. Governance	4. Impact	NRI
1.1 Access	sp.01	0.92	0.92	0.89	0.88	0.93
1.2 Content	sp.02	0.95	0.88	0.88	0.88	0.92
1.3 Future Technology	sp.03	0.86	0.78	0.78	0.81	0.83
2.1 Individuals	sp.04	0.82	0.90	0.81	0.84	0.86
2.2 Busineses	sp.05	0.91	0.94	0.89	0.86	0.92
2.3 Governments	sp.06	0.89	0.92	0.89	0.86	0.92
3.1 Trust	sp.07	0.92	0.91	0.96	0.88	0.94
3.2 Regulation	sp.08	0.84	0.81	0.90	0.82	0.87
3.3 Inclusion	sp.09	0.86	0.88	0.94	0.84	0.91
4.1 Economy	sp.10	0.85	0.82	0.78	0.87	0.85
4.2 Quality of life	sp.11	0.83	0.83	0.82	0.91	0.87
4.3 SDG Contribution	sp.12	0.82	0.81	0.81	0.87	0.85
1. Technology	p.01	1.00				0.99
2. People	p.02	0.95	1.00			0.97
3. Governance	p.03	0.94	0.93	1.00		0.96
4. Impact	p.04	0.94	0.92	0.91	1.00	0.95

Numbers represent the Pearson correlation coefficients. Good correlations (i.e. Pearson correlation coefficients greater than 0.30 and lower than 0.92) are written in **black**. Correlations with low values (between -0.30 and 0.30) are written in **grey.** Correlations at risk of redundancy (here >0.91) are written in **green**. Correlations with meaningful negative value (here -0.30) are written in **red.** Source: Elaborated by European Commission's Joint Research Centre, 2020.

FIGURE 1. RELATIONSHIP BETWEEN THE PILLARS AND THE NRI.



4.2 ADDED VALUE OF THE NETWORK READINESS INDEX

The high statistical reliability and coherence of an Index may sometime determine a partial overlap among the concepts represented by the pillars. From 12% to 22% of the countries included in the index, the NRI ranking and the pillar's rankings differ by 10 positions or more (see Table 4). This suggests that the NRI ranking highlights aspects of countries' network readiness that do not emerge by looking into the four pillars separately, but only for a minority of countries. This result suggests a strong concordance among the aggregates, and implies the presence of room for simplification. In such a situation, the developers may consider excluding some elements of the index, and hence improve readability, without jeopardise the integrity of the pillars and overall Index.

TABLE 4. DISTRIBUTION OF DIFFERENCES BETWEEN PILLARS AND NRI RANKINGS

Shift respect to NRI	Technology	People	Governance	Impact
More than 30 positions	2%	2%	7%	8%
11 to 20 positions	10%	16%	13%	14%
More than 10 positions	12%	18%	20%	22%
6 to 10 positions	25%	24%	26%	27%
Up to 5 positions	57%	51%	48%	41%
0 positions	6%	7%	6%	10%

Source: *European Commission's Joint Research Centre, 2020.*

5. Impact of modelling assumptions on the NRI results

A fundamental step in the statistical analysis of a composite indicator is to assess the effect of different modelling assumptions on the scores and country rankings. Despite the efforts at 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 topic[4] 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 NRI 2020, as 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 and 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 NRI 2020, which can demonstrate the extent to which countries can be differentiated by their scores.

The modelling issues considered in the robustness assessment of the NRI 2020 are the aggregation formula, method of missing data imputation and pillars' weights.

Imputation of missing values. The NRI development team, for transparency and replicability, opted not to estimate the missing data. The 'no imputation' choice, which is common in similar contexts, might encourage countries not to report low data values. The consequence of the 'no imputation' choice in an arithmetic average is that it is equivalent to replacing an indicator's missing value for a given country with the respective mean of the other indicators that are being aggregated. Hence, the available data (indicators) in the incomplete pillar may dominate, sometimes biasing the ranks up or down. To test the impact of this assumption, the JRC team estimated missing data using the K-Nearest Neighbour (kNN) algorithm[5].

Aggregation formula. For this edition of the index, the NRI team opted for the arithmetic averaging of the four pillars, which implies a strong compensability allowing for an outstanding performance in some aspects to balance the weaknesses in others and vice-versa. This approach puts at the same level countries with both high and low results with more "balanced" countries showing average results. 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).

Weights. The simulation comprised 1,000 runs of different set of weights for the pillars constituting the Index. In the 1,000 runs, the weights are the result of a random extraction based on uniform continuous distributions centred in the reference value (1/4) plus or minus 25% of this value. All simulated 1,000 runs are then used in all the scenaria determined by the other assumptions.

As summarised in **Table 5**, four models were tested comparing the different aggregation formulas, the different imputation methods and applying the 1,000 runs of different sets of weights resulting in a total of 4,000 runs of simulations.

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[4] 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.

[5] In the kNN algorithm, the missing value of a country is imputed as the weighted average of the values of the k closest countries. In the estimations reported here k = 5, and the closeness depends on the variables that are observed within the same sub-pillar of the missing value.

TABLE 5. ALTERNATIVE ASSUMPTIONS CONSIDERED IN THE ANALYSIS.

	Reference	Alternative
I. Imputation method	No Imputation	K- Nearest Neighbour
II. Aggregation formula	Arithmetic average	Geometric average
III. Weighting system	Equal weights	Varying
Technology	0,25	U [0.1875; 0.3125]
People	0,25	U [0.1875; 0.3125]
Governance	0,25	U [0.1875; 0.3125]
Impact	0,25	U [0.1875; 0.3125]

Source: *European Commission, Joint Research Centre, 2020.*

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 NRI rank where the blue dots represent the median rank among the simulations. For each country, the error bars represent the 90% interval across all simulations, that is, from the 5th to the 95th percentile of the countries' rank among all the simulations.

NRI ranks are shown to be representative of a plurality of scenarios and extremely robust to changes in the assumptions. Considering the median rank across the simulated scenarios, as being representative of these scenarios, then the fact that the NRI rank is close to the median rank (less than five positions away) for 100% of the countries suggests that NRI is a suitable and stable summary measure. Furthermore, the majority of the countries' ranks hardly vary across simulations (less than 10 positions for all countries but Laos). These results imply that the NRI ranks are robust to changes in the pillars' weights, aggregation formula and imputation of data.

Only Laos is showing a simulated interval larger than 10 positions. Considering the correlation structure among pillars and Index it is not surprising to have very stable intervals for all countries. The source of the uncertainty of Laos is investigated in the sensitivity analysis.

Overall, country ranks in NRI are highly robust to changes for all the countries considered, enough to allow for meaningful inferences to be drawn. For full transparency and information, **Table 6** reports the NRI 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 ease the analysis of the behaviour of specific countries respect to perturbations.

FIGURE 2. ROBUSTNESS ANALYSIS ON RANKS (NRI RANK VS MEDIAN RANK AND 90% INTERVALS).

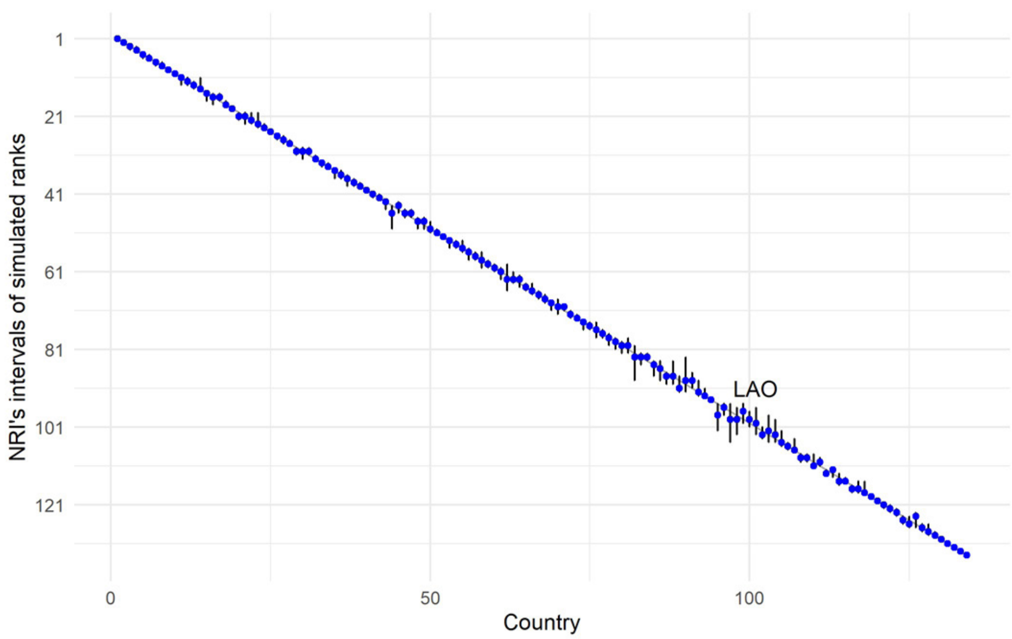


TABLE 6. NRI RANK AND 90% INTERVAL OF ALL COUNTRIES.

Country	NRI ranks	Interval
Sweden	1	[1-1]
Denmark	2	[2-2]
Singapore	3	[3-4]
Netherlands	4	[3-4]
Switzerland	5	[5-6]
Finland	6	[5-6]
Norway	7	[7-8]
United States	8	[7-8]
Germany	9	[9-9]
United Kingdom	10	[10-10]
Luxembourg	11	[11-13]
Australia	12	[11-13]
Canada	13	[12-14]
South Korea	14	[11-14]
Japan	15	[15-17]
New Zealand	16	[15-18]
France	17	[15-17]
Austria	18	[17-18]
Ireland	19	[19-19]
Belgium	20	[20-22]
Iceland	21	[20-23]
Hong Kong (China)	22	[20-23]
Estonia	23	[20-24]
Israel	24	[23-24]
Spain	25	[25-25]
Malta	26	[26-27]
Slovenia	27	[26-28]
Czech Republic	28	[27-28]
Lithuania	29	[29-31]
United Arab Emirates	30	[29-32]
Portugal	31	[29-31]
Italy	32	[31-32]
Poland	33	[33-34]
Malaysia	34	[33-34]
Slovakia	35	[35-37]
Cyprus	36	[35-37]
Latvia	37	[36-39]
Qatar	38	[37-39]
Hungary	39	[38-39]
China	40	[40-40]
Saudi Arabia	41	[41-42]
Bahrain	42	[41-42]

Country	NRI ranks	Interval
Croatia	43	[43-45]
Oman	44	[44-50]
Greece	45	[43-46]
Bulgaria	46	[45-47]
Uruguay	47	[45-47]
Russia	48	[47-50]
Romania	49	[47-50]
Chile	50	[48-51]
Thailand	51	[50-51]
Serbia	52	[52-52]
Kuwait	53	[53-55]
Costa Rica	54	[53-55]
Armenia	55	[53-56]
Kazakhstan	56	[55-58]
Turkey	57	[56-58]
Montenegro	58	[56-60]
Brazil	59	[58-60]
Argentina	60	[59-61]
Mauritius	61	[60-63]
Vietnam	62	[59-66]
Mexico	63	[61-64]
Ukraine	64	[62-65]
Belarus	65	[64-66]
Azerbaijan	66	[64-67]
North Macedonia	67	[66-68]
Georgia	68	[67-69]
Jordan	69	[69-71]
Jamaica	70	[68-72]
Moldova	71	[70-71]
Colombia	72	[71-73]
Indonesia	73	[72-73]
Philippines	74	[74-76]
Dominican Republic	75	[74-76]
South Africa	76	[74-78]
Panama	77	[76-78]
Albania	78	[77-80]
Iran	79	[78-81]
Peru	80	[79-82]
Trinidad and Tobago	81	[78-82]
Kenya	82	[80-89]
Sri Lanka	83	[82-85]
Egypt	84	[82-84]

Country	NRI ranks	Interval
Ecuador	85	[84-88]
Cabo Verde	86	[84-89]
Bosnia and Herzegovina	87	[87-90]
India	88	[84-90]
Mongolia	89	[88-92]
Lebanon	90	[83-92]
Tunisia	91	[87-91]
Paraguay	92	[89-93]
Morocco	93	[91-93]
Kyrgyzstan	94	[94-94]
El Salvador	95	[95-102]
Rwanda	96	[95-98]
Laos	97	[95-105]
Ghana	98	[96-103]
Botswana	99	[95-100]
Senegal	100	[97-101]
Bolivia	101	[96-103]
Honduras	102	[101-104]
Namibia	103	[98-105]
Cambodia	104	[99-105]
Bangladesh	105	[102-106]
Guatemala	106	[105-107]
Algeria	107	[104-107]
Venezuela	108	[108-110]
Tajikistan	109	[108-110]

Country	NRI ranks	Interval
Tanzania	110	[108-111]
Pakistan	111	[109-111]
Benin	112	[112-113]
Nepal	113	[112-114]
Uganda	114	[113-116]
Côte d'Ivoire	115	[114-115]
Zambia	116	[116-118]
Nigeria	117	[115-118]
Cameroon	118	[115-118]
Gambia	119	[119-119]
Guinea	120	[120-120]
Lesotho	121	[121-122]
Eswatini	122	[121-123]
Mali	123	[122-124]
Madagascar	124	[124-126]
Burkina Faso	125	[124-127]
Zimbabwe	126	[123-127]
Malawi	127	[126-128]
Mozambique	128	[126-129]
Ethiopia	129	[128-129]
Burundi	130	[130-130]
Angola	131	[131-131]
Yemen	132	[132-132]
Democratic Republic of the Congo	133	[133-133]
Chad	134	[134-134]

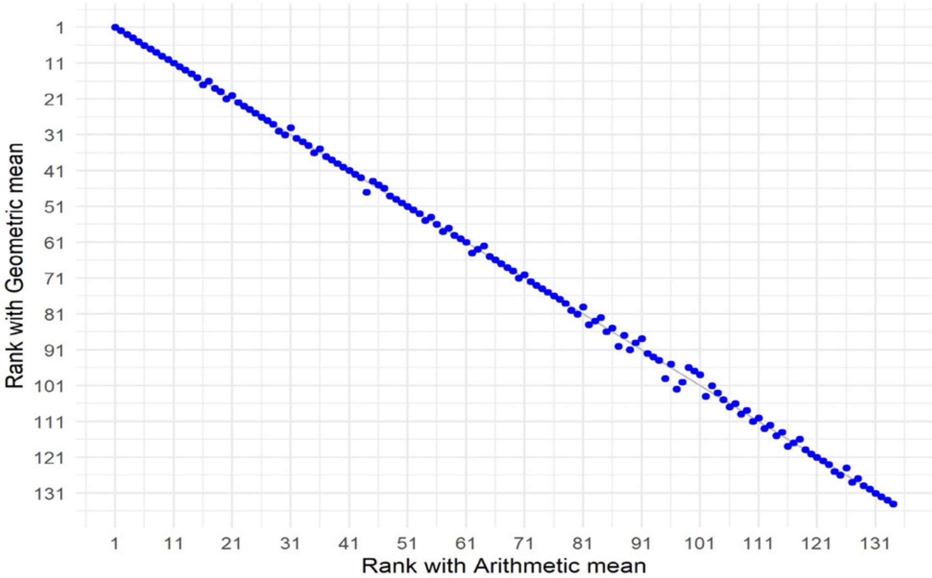
Source: *European Commission, Joint Research Centre, 2020.*

The uncertainty analysis is also complemented by a sensitivity exercise, in which the NRI ranking is compared with the rankings resulting from specific changes in the modelling assumptions separately so to better identify sources of uncertainty.

Figure 3 compares the ranks derived from NRI 2020 with the ranks obtained by changing the aggregation procedure from arithmetic to geometric mean. This comparison allows us to inquire whether the variability in the rank intervals is originating from the modelling assumptions underlying the aggregation procedure or by the weights' perturbation. When countries are placed under the main diagonal their values are worse in rank positions when computed with the geometric mean. This is probably the case of countries penalised by the geometric mean because of their unbalanced profiles. In any case, the aggregation formula is not a very relevant assumption in the NRI 2020. This result is mainly determined by the very strong correlation structure of the Index described in section 4.1 above. Basically, when the pillars are so correlated it is difficult to have countries with unbalanced values, hence the result obtained from the arithmetic mean and the geometric mean do not differ very much and the later does not penalise any country.

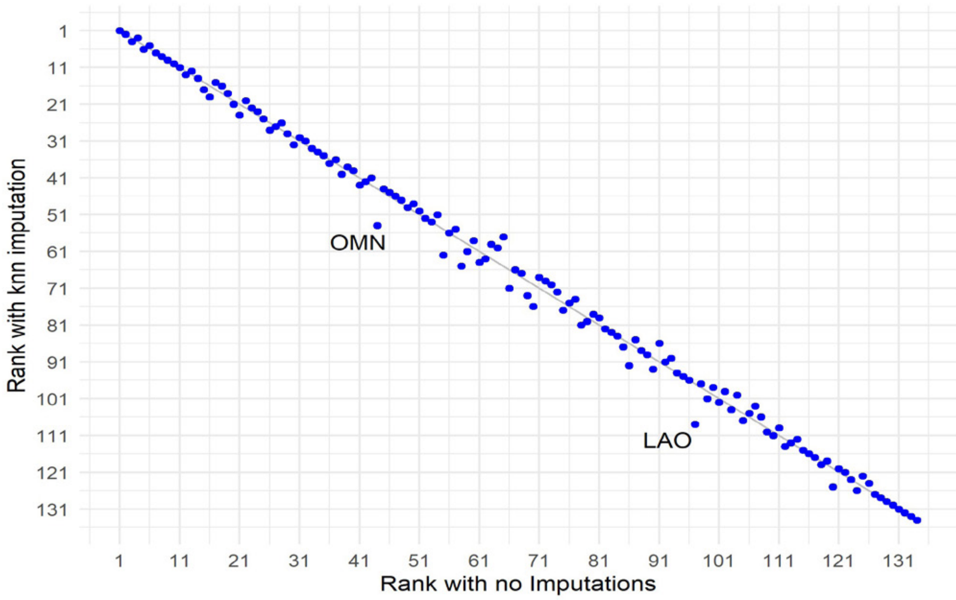
Figure 4 compares NRI ranks with ranks obtained after imputation of missing data. The differences among the two rankings are not significantly large. Only Laos and Oman show a difference of ranks above the ten positions, probably due to their low data coverage (respectively 78.3% and 81.7% of indicators available). Other countries with similar data coverage are not meaningfully affected by use of the KNN method as opposed to no imputation.

FIGURE 3. SENSITIVITY ANALYSIS: COMPARISON OF RANKS ACCORDING TO ARITHMETIC AND GEOMETRIC MEAN.



Source: *European Commission, Joint Research Centre, 2020.*
Note: *countries are labelled when they show a shift of at least 10 positions between the two aggregation formulas*

FIGURE 4. SENSITIVITY ANALYSIS: COMPARISON OF RANKS WITH AND WITHOUT IMPUTATION OF MISSING DATA.



Source: *European Commission, Joint Research Centre, 2020.*
Note: *countries are labelled when they show a shift of at least 10 positions between the two treatments of missing data.*

The uncertainty analysis and sensitivity analysis portray the NRI as a deeply stable index. This result allows for inference on the ranks and suggests also the presence of similar concepts across the pillars. Thanks to the correlation structure of the index, the developers could consider simplifying the framework excluding some indicators, often described by the other indicators of the same sub-pillars and pillars, without any worries about the coherence of the index.

6. Conclusions

The JRC statistical audit delves into the extensive work carried out by the developers of the NRI 2020 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 NRI 2020 is a strong index in terms of conceptual and statistical consistency. It shows that ICT deployment is a multifaceted phenomenon where technology, users and several aspects of ICT regulation go hand in hand.

The data coverage of the framework is good. Most indicators contain no or very few missing values. Some indicators, 8 out of 60, may be candidates for special attention as their percentage of missing values is above what is normally recommended. Developers decided not to impute them. The sensitivity analyses showed how such this assumption do not significantly affect results with respect to an alternative non-parametric imputation method (k-Nearest Neighbour).

The index is statistically well balanced with respect to its indicators, sub-pillars and pillars. Correlations between each pillar and the respective sub-pillar are mostly significant and positive. Most of the indicators are meaningfully correlated with the index and relative pillars. The possible presence of redundancy is the only concern in the analysis of the NRI. The suggestion is to use the very stable and correlated structure of the index to explore and open to some even more specific aspects of the network economy.

Treatment of outliers conducted by the NRI developers is appropriate. Finally, assumptions regarding aggregation method and weights do not significantly affect results.

JRC analysed a series of different choices that are made during the index construction. The results of the uncertainty analysis reveal that NRI is a robust summary measure in general, the present audit confirms that the NRI 2020 Index is reliable, with a statistically coherent framework and acknowledges the important efforts done by the developers' team. The Index can serve as a tool to provide insights for measuring the ICT deployment issues.

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