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JRC statistical audit of the Mobile Connectivity Index

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Contents

Abstract

This technical report summarizes the statistical audit of the Mobile Connectivity Index (MCI). The MCI is thoroughly considered by experts in the GSM Association (GSMA), its methodology is coherent and follows well the OECD-JRC (2008) recommendations for constructors of composite indicators. Further refinement of the MCI indicator set, which has been already on the agenda of the GSMA and the planned replacement of proxies by better indicators can later surely help improve the statistical qualities of the MCI, once data availability allows it. The unification of the normalisation procedure for all indicators may enhance the integrity of the index. The overall implications of the uncertainty analysis are that the uncertainty in the rankings is manageable, and allows meaningful conclusions to be drawn from the index. As recommended frequently by the JRC team in its statistical audits, it would be worthwhile to publish confidence intervals alongside the index scores and rankings in case of the MCI.

1. Introduction

The statistical audit discussed in this document constitutes the first collaboration between the GSM Association (GSMA) and the European Commission's Joint Research Centre (JRC) related to the Mobile Connectivity Index (MCI).

The statistical assessment of the MCI has been undertaken between March 2021 and June 2021 by the Competence Centre on Composite Indicators and Scoreboards (COIN) team of the JRC. The pre-audit notes were shared with the index developers in March 2021. These notes focused on indicators, framework, data issues and statistical coherence. The aim was to flag issues that need careful consideration. This document summarizes the recommendations in the pre-audit and presents the results in the uncertainty analysis, which was not part of the initial pre-audit. The final version of the JRC audit was scheduled to be publish simultaneously with the update of the MCI by the GSMA in June 2022.

The GSM Association (GSMA) represents the interests of mobile operators worldwide, uniting more than 750 operators with nearly 400 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies. The GSMA was formed in 1995 as the 'GSM MoU Association' as a body to support and promote mobile operators using the GSM (Global System for Mobile communications) standard for cellular networks. .Headquartered in Brussels, Belgium, GSMA Europe represents and leads mobile network operators in Europe, Russia and Commonwealth of Independent States (CIS). In this region more than 200 mobile network operators provide connections to 710 million unique subscribers. GSMA Europe also facilitates regional and local collaboration around key topics of strategic relevance for its members in Europe. One example of this is the European Identity Group (EIG), formed in late 2019 at the request of a number of European Mobile Network Operators (MNOs) engaged in identity services.

GSMA Europe contributes to the building the EU Single Digital Market. The GSMA's member companies are the investors in the key digital infrastructure that is the enabling platform for Europe's economy to benefit from the €260 billion additional GDP per year that the Commission estimates as the "digital dividend".

The GSMA develops the Mobile Connectivity Index,. which measures the enablers of mobile internet connectivity. It is therefore an input index integrating a number of indicators that lead to an important outcome, in particular, it aims at measuring why people are (or are not) using mobile internet connectivity. By developing the index the GSMA contributes to the measurement on how the digital single market develops in Europe and in comparison to other continents

The MCI focuses specifically on mobile internet connectivity rather than internet connectivity in general (including fixed-line connectivity). As the index is focused on mobile internet connectivity, the majority of the underlying indicators are unique to the MCI (GSMA, 2020). The MCI has been designed to ensure that it does not replicate any other related indices (for example the Global Connectivity Index, Inclusive Internet Index, ICT Development Index, etc.).

The MCI is calculated as the geometric average of its four pillars, which are driven by a total of 14 headline indicators. Each indicator is given a score between 0 (low connectivity) and 100 (maximum connectivity). The indicators are aggregated by using the arithmetic formula at the pillar level.

Our audit found that the MCI is thoroughly considered by experts in the GSM Association. The MCI's methodology is well structured, coherent and follows well the OECD-JRC (2008) recommendations for constructors of composite indicators.

The MCI is in the phase of development currently. The MCI methodology is carefully defined, though we recommend adding easy-to-understand formulas of data transformations into the methodology document, as this may further improve transparency and clarity. The continuous refinement of the MCI indicator set, which has been already on the agenda of the GSMA and the planned replacement of proxies by better indicators can later surely help improve the statistical qualities of the MCI, once data availability allows it.

To cross-check the calculations of the MCI we put the index to several consistency tests. For example, we rebuilt its four pillars and the index itself from the 14 headline indicators. The recalculation results are in line with the index methodology.

We recommend publishing the number/share of imputed values alongside the index, its pillars and indicators. To allow for comparisons of index scores over time, the minimum and maximum for each indicator is fixed. Some of the indicator maxima has been adjusted where there are likely to be increases during the next few years. We find that the contribution of pillars and indicators to the MCI could be constrained and somewhat biased by the differences in normalisation. Hence, the unification of the normalisation procedure for all indicators may enhance further the reliability of the index. For example, applying an equal ceiling (equally 90 scores) for all indicators could help to adjust the scales of scores and create a level playing field across all indicators.

MCI pillars are positively correlated with the index and correlations of pillars are balanced. The pairwise correlations at the indicator level are in the range [0.4-0.9] recommended by the OECD-JRC (2008) for input indicators of meaningful composite indices. The correlation of indicators within pillars is also balanced in Pillar 1 (Infrastructure) and in Pillar 3 (Consumer readiness), but not as much in Pillar 2 (Affordability). Relatively low correlation of some indicators (for example taxation, inequality) influenced developers' choice to add less weight to the weakly correlating indicator (20% compared to 30%-40% of other indicators). Furthermore, these two indicators show low level of correlation with all of the other indicators. Hence, the omission of these indicators from the MCI could be considered.

Our correlation analysis confirms the adequacy of equal weights of MCI pillars (25%), correlation coefficients between the pillars and the final index score are high and balanced. Weights within the pillars are not very different from equal weights, except for pillar 3 and pillar 4. For the sake of simplicity and communication, equal weights could be considered by the developers.

As recommended frequently by the JRC team in its statistical audits, it would be worthwhile to publish confidence intervals alongside the index scores and rankings in case of the MCI.

The aims of the JRC's audit are to:

- Investigate the characteristics of the underlying data and check for eventual errors in calculation
- Assess the associations between indicators and see to what extent they agree with the conceptual framework
- Review the methodology used to treat, weight, and aggregate data
- Assess the impact of modelling assumptions and robustness of MCI ranks and scores
- Eventually recommend modifications based on the conclusions of the above.

In particular, the JRC analysis complements the reported MCI values for the covered jurisdictions with estimated confidence intervals, in order to better appreciate the robustness of these ranks to some modelling choices (such as the choice of indicators, the weighting scheme and the aggregation formula). Importantly, the construction of a composite indicator is a balance between statistical "rigour" and conceptual considerations, which can frequently

contradict each other. This audit aims to investigate and analyse the statistical side of the equation, and only aims to offer conceptual suggestions from the statistical point of view. In general, conceptualisation is better left to experts in mobile connectivity, they could strike balance between statistics and the concept.

2. Construction of the Mobile Connectivity Index

The GSMA developed the MCI index to measure multiple enablers of the complex reality necessary for delivering mobile internet connectivity in any country. The enablers of mobile internet connectivity that inform the indicators selected for the Index pillars are:

1. **Infrastructure:** The availability of high-performance mobile internet network coverage.

2. **Affordability:** The availability of mobile services and devices at price points that reflect the level of income across a national population.

3. **Consumer readiness:** Citizens with the awareness and skills needed to value and use the internet.

4. **Content and Services:** The availability of secure online content and services accessible and relevant to the local population.

Although the indicators included in the Mobile Connectivity Index have all been carefully chosen based on statistical criteria of the OECD, JRC (2008) (relevance, accuracy, coverage, timeliness), there are some cases where data constraints required the use of proxy indicators. For example, Indicators such as international bandwidth per user, number of secure servers and number of Internet Exchange Points (IXPs) are included as proxies for the quality of a country's backhaul and core network. There is currently no data in the area of digital skills or awareness. More traditional skills indicators are therefore used to measure consumers' ability to effectively use and engage with digital technology (for example, literacy and years of schooling).

Developers ensure that each country has data on at least 75% of indicators overall and at least half the indicators within each enabler.

MCI dataset is treated so as to deal with outliers and impute missing data. For some of the indicators, data is only updated every few years (or sometimes less frequently). This applies to the following indicators in the MCI: Access to electricity, Income inequality, Education indicators and their gender ratio counterparts For these variables, if data exists in the period since 2014 then the most recent value is used, otherwise imputation technics are applied.

As the majority of the indicators with high skewness and kurtosis are skewed to the right, a logarithmic transformation is used to bring the indicator within the specified ranges.

3. Scoring and normalisation

The MCI Indicators are normalised to adjust for different units of measurement and different ranges of variation across the indicators. The developers used the min-max method and the boundaries on the lower and upper bounds of the indicator scales to make indicators comparable and ready for aggregation. In this way, the rescaled data became easy to communicate to a wider public and to compare across all indicators.

For most indicators, the minimum and maximum used for normalisation are based on the actual minimum and maximum for that indicator. To allow for comparisons of index scores over time, the minimum and maximum for each indicator are fixed. Some of the indicator maxima have therefore been adjusted where there are likely to be increases during the next few years. This choice may, however influence index values as the scale of some indicators is compressed into a narrower range. Previous sensitivity analyses of the MCI also showed that the rankings were not sensitive to other types of normalisation, for example z-scores.

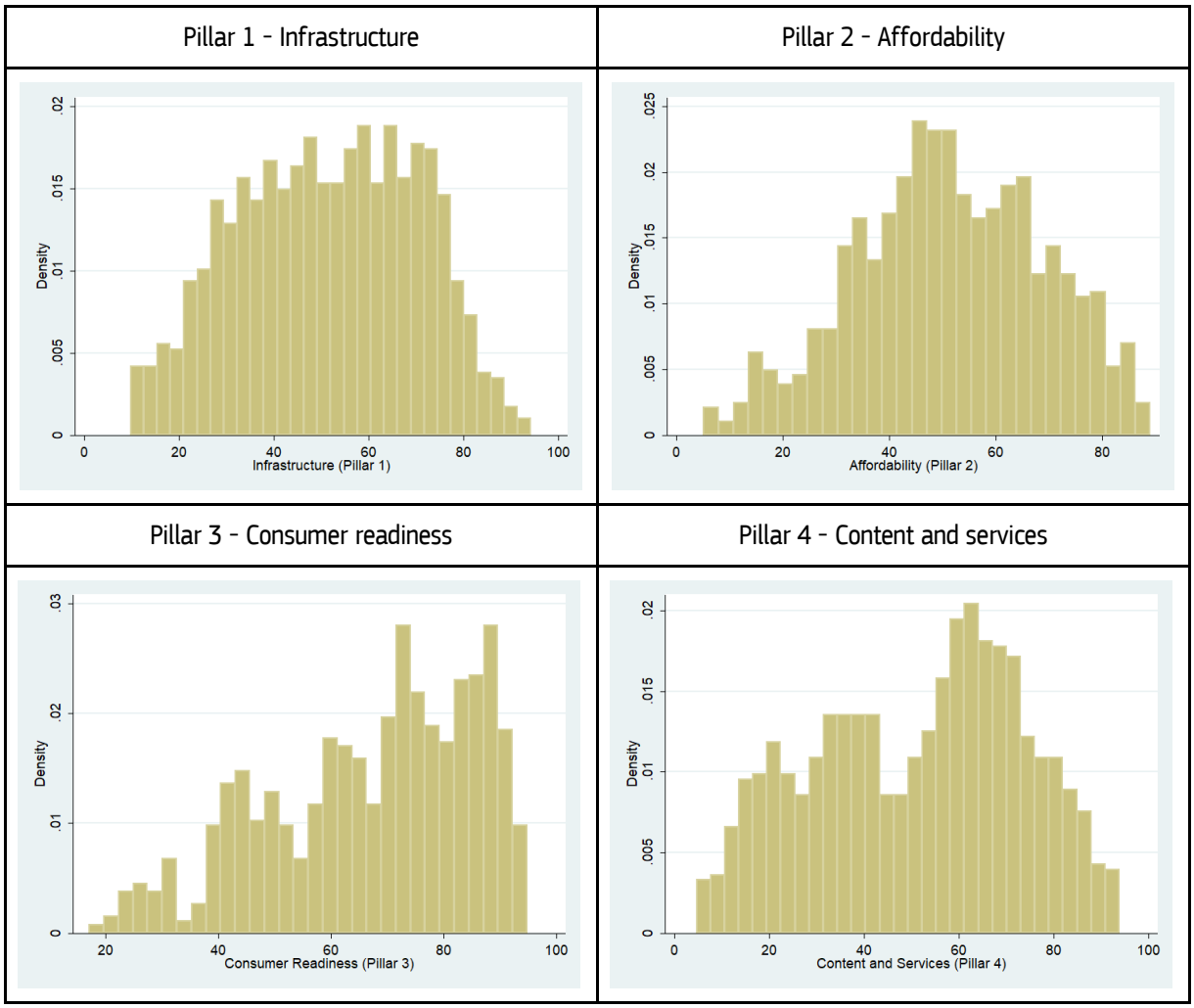
Unification of the normalisation procedure for all indicators may enhance further the reliability of the index. For example, applying an equal ceiling (equally 90 scores) for all indicators could help to adjust the scales of scores and create a level playing field across all indicators.

Table 1 Descriptive statistics of the pillars and headline indicators of the MCI

Index components	Obs	Mean	Std. Dev.	Min	Max
MCI Index	1020	54.3	18.2	12.2	90.5
MCI Pillar1 - Infrastructure	1020	51.5	18.8	9.8	94.3
MCI Pillar2 - Affordability	1020	51.4	17.7	5.2	89
MCI Pillar 3 - Consumer Readiness	1020	67.2	18.2	17.2	94.9
MCI Pillar4 - Content and Services	1020	51.5	22	4.7	94
Network coverage	1020	70.5	23.4	16.6	100
Network performance	1020	36.6	22.2	0	96.5
Other enabling infrastructure	1020	57.6	19.7	2.6	99.1
Spectrum	1020	39.2	19.7	7.1	98
Mobile tariffs	1020	46.9	25	0	100
Handset price	1020	45.6	23.6	0	100
Taxation	1020	64.2	23.7	0	100
Inequality	1020	53.9	22.7	0	100
Basic Skills	1020	59.2	20.6	7.2	97.2
Gender Equality	1020	72.7	18.5	7.8	96
Mobile ownership	1020	72.2	19.9	12.5	100
Local relevance	1020	50.9	21.9	1	90.1
Availability	1020	58.1	28.5	1.4	100
Online security	1020	39.6	26.4	0	93.1

The histograms of the MCI pillars on **Figure 1** reveal that outliers and some of the undesired properties of the indicators are well treated by transformations (winsorisation and logarithmic transformation). The histograms Pillar 3 and Pillar 4 also suggest that there are clusters in the sample and some skewness still remains to a certain degree.

Figure 1 Histograms of the MCI pillars



4. Correlation structure

MCI pillars are positively correlated with the index and correlations of pillars are balanced. The pairwise correlations are in the range [0.4-0.9] recommended by the OECD-JRC (2008) for input indicators of meaningful composite indices. The correlation of indicators within pillars is also balanced in Pillar 1 (Infrastructure) and in Pillar 3 (Consumer readiness), but not as much in Pillar 2 (Affordability), suggesting that mobile tariffs and prices are not strongly driven by the tax burden. Relatively low correlation of some indicators (for example taxation, inequality) influenced developers' choice to add less weight to the weakly correlating indicator (20% compared to 30%-40% of other indicators). Furthermore, these two indicators show low level of correlation with all of the other indicators.

Table 2 Pearson correlation of MCI pillars and headline indicators

		Pillars					Infrastructure				Affordability				Consumer Readiness			Content and Services		
		MCI Index	MCI Pillar1 - Infrastructure	MCI Pillar2 - Affordability	MCI Pillar3 - Cons. Read.	MCI Pillar4 - Cont. and Serv.	Network coverage	Network performance	Other enabling infrastructure	Spectrum	Mobile tariffs	Handset price	Taxation	Inequality	Mobile ownership	Basic Skills	Gender Equality	Local relevance	Availability	Online security
	MCI Index	1																		
Pillars	MCI Pillar1 - Infrastructure	0.9	1																	
Pillars	MCI Pillar2 - Affordability	0.9	0.8	1																
Pillars	MCI Pillar3 - Consumer Readiness	0.9	0.8	0.8	1															
Pillars	MCI Pillar4 - Content and Services	0.9	0.8	0.8	0.8	1														
Infrastructure	Network coverage	0.9	0.9	0.8	0.8	0.8	1													
Infrastructure	Network performance	0.8	0.9	0.6	0.6	0.7	0.7	1												
Infrastructure	Other enabling infrastructure	0.9	0.9	0.8	0.9	0.8	0.8	0.7	1											
Infrastructure	Spectrum	0.7	0.8	0.5	0.6	0.6	0.6	0.5	0.6	1										
Affordability	Mobile tariffs	0.9	0.8	0.9	0.8	0.8	0.8	0.7	0.8	0.5	1									
Affordability	Handset price	0.9	0.8	0.9	0.8	0.8	0.7	0.6	0.8	0.6	0.8	1								
Affordability	Taxation	0.4	0.3	0.5	0.3	0.3	0.3	0.2	0.3	0.2	0.3	0.3	1							
Affordability	Inequality	0.3	0.3	0.5	0.2	0.2	0.2	0.3	0.3	0.1	0.3	0.2	0.2	1						
Consumer Readiness	Mobile ownership	0.9	0.8	0.8	0.9	0.8	0.8	0.6	0.9	0.6	0.8	0.8	0.4	0.3	1					
Consumer Readiness	Basic Skills	0.9	0.8	0.8	1.0	0.8	0.8	0.6	0.9	0.6	0.8	0.8	0.3	0.3	0.9	1				
Consumer Readiness	Gender Equality	0.7	0.6	0.6	0.9	0.6	0.6	0.5	0.7	0.5	0.6	0.6	0.2	0.1	0.7	0.8	1			
Content and Services	Local relevance	0.9	0.9	0.8	0.9	0.9	0.8	0.7	0.9	0.6	0.8	0.8	0.3	0.3	0.9	0.9	0.7	1		
Content and Services	Availability	0.7	0.6	0.6	0.6	0.9	0.5	0.4	0.6	0.4	0.5	0.7	0.2	0.1	0.6	0.6	0.5	0.7	1	
Content and Services	Online security	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.6	0.5	0.7	0.6	0.3	0.3	0.6	0.6	0.4	0.7	0.4	1

Source: European Commission, Joint Research Centre (2021)

5. Weighting and aggregation

In order to aggregate indicators into the MCI enabler scores (and enabler scores into the overall MCI index score), weights have been assigned to each component of the index. To construct the weights at the dimension, enabler and overall index level, a number of considerations have been taken into account by the developers (statistical relationship between indicators and dimensions, consumer survey responses regarding perceived barriers to mobile internet access, principal component analysis, research results by the GSMA and other organisations on digital inclusion).

The MCI is based on an equal pillar-weighting scheme, all three pillars having 25% weight. Our correlation analysis in the previous section confirms the adequacy of equal weights correlation coefficients between the pillars and the final index score are high and balanced. Weights within the pillars are not very different from equal weights, except for pillar 3 and pillar 4. Becker et al. (2017) suggest three tools, which may give MCI developers considerable insight into the effects of weights and suggest possibilities for refining and simplifying the aggregation.

Table 3: Weighting scheme of the MCI

Enablers	Weight (in index)	Indicator	Weight (in pillar)
Infrastructure	25%	Network coverage	30%
		Network performance	30%
		Other enabling infrastructure	20%
		Spectrum	20%
Affordability	25%	Mobile tariffs	30%
		Handset price	30%
		Taxation	20%
		Inequality	20%
Consumer Readiness	25%	Basic Skills	40%
		Gender Equality	40%
		Mobile ownership	20%
Content and Services	25%	Local relevance	40%
		Availability	40%
		Online security	20%

Source: European Commission, Joint Research Centre (2021)

Two methods of aggregation were considered by the developers, (i) the arithmetic mean and (ii) the geometric mean. The key consideration when choosing between these was in line with the OECD-JRC (2008) recommendations. In dimensions and enablers, which are considered substitutable, arithmetic aggregation formula was applied. At the final aggregation round the non-compensatory approach was taken to aggregate the pillars into the final MCI index.

To check the calculations of the MCI, we rebuilt its four pillars and the index itself from the 14 headline indicators. The recalculation results are in line with the index methodology.

6. Robustness and uncertainty analysis

The development of the MCI, like the construction of any composite indicator, involves assumptions and subjective decisions. This section aims to test the impact of varying some of these assumptions within a range of plausible alternatives in an uncertainty analysis similarly to Papadimitriou et al. (2019), Saisana et al. (2020), Erhart (2021).

Here, the objective is to attempt to quantify the uncertainty in the ranks of the MCI Index, which can demonstrate the extent to which countries can be differentiated by their MCI scores. Although many assumptions made in the development of the MCI Index could be examined, three particular assumptions were examined in this uncertainty analysis (**see Table 5**). These were chosen as plausible alternative pathways in the construction of the MCI Index, which can be relatively easily investigated.

Table 4. Tested assumptions of the CTHI index

Assumption	**Alternatives**
1. Indicator set	A. [Full set] B. [Reduced set]
2. Aggregation method	C. [Arithmetic mean] D. [Geometric mean]
3. Weights	Randomly varied +/-25% from EW

The first tested assumption is the inclusion of indicators. In this statistical audit, the 14 headline indicators were divided into two groups (group 1: Pillar 1 (Infrastructure) & Pillar 4 (Content and services); group 2: Pillar 2 (Affordability) & Pillar 3 (Consumer readiness). All indicators were retained in the final index, but the effect is tested here of removing some indicators simultaneously, resulting in a "reduced set" of indicators (group 1) which can be viewed as an alternative approach to building the index.

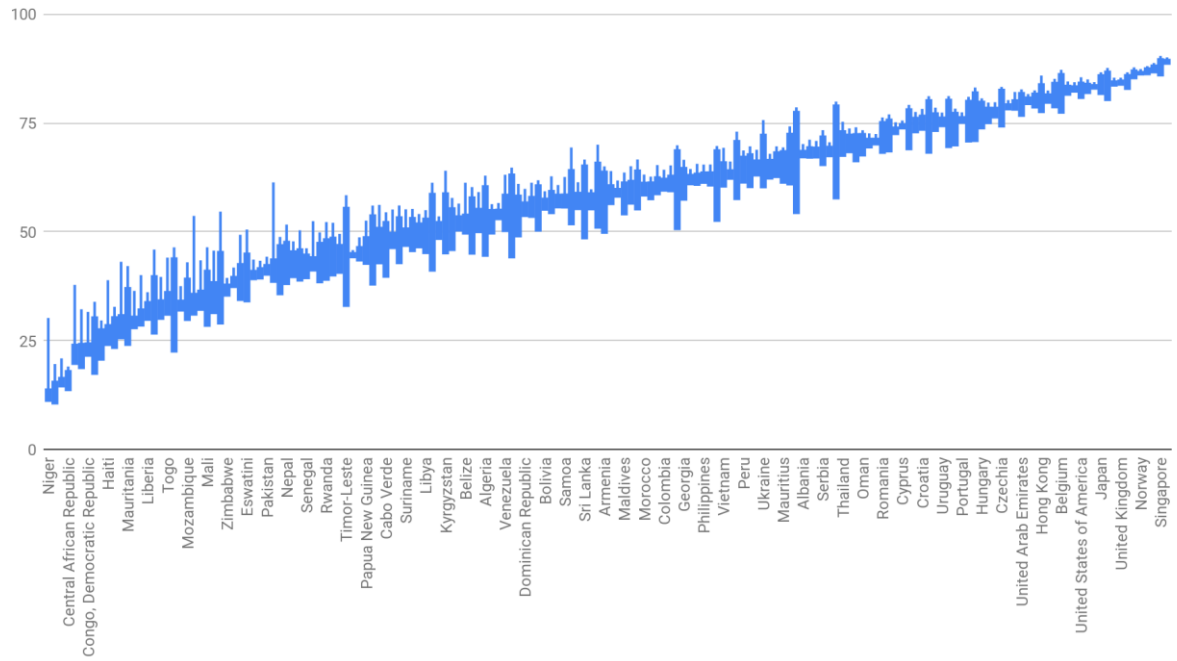
The second assumption which is varied is the aggregation method. In the MCI Index, the scores are aggregated into their pillars using an arithmetic average and then the pillars are aggregated by using the geometric mean formula. An alternative approach would be to use either the arithmetic or the geometric average for the index aggregation randomly to analyse the robustness of the index. To tackle the problem of zeros when using the geometric average formula, zero MCI indicators values have been replaced by 1.

MCI nominal weights assigned at the pillar level are all equal, 25%. The effect of randomly varying indicator weights by +/-25% is also investigated in our simulation, to check modest variations in the importance of individual indicators. Note that the value of the weight was randomly varied, and 25% variation means roughly 7%+/- 2 percentage points at the indicator level weighting when running the simulations with the 14 headline MCI indicators in the four pillars.

To analyse the impact of varying these assumptions, a Monte Carlo experiment was performed, which involved re-building the MCI 4000 times, each time with a randomly selected combination of assumptions 1-3, using the 2019 MCI dataset. The overall results are shown in **Figure 2**.

The uncertainty in the rankings, given the assumptions tested, is mostly quite modest. Country scores can be stated to be within around 13 scores of precision (**Figure 2**), although some countries are especially sensitive to the assumptions made. This information should be also used to guide the kind of conclusions that can be drawn from the index. For example, differences of two or three scores between countries cannot be taken as "significant", whereas differences of 10 score upwards can show a meaningful difference. One can also observe from **Figure 2** that the confidence intervals are generally wider for mid-ranking countries, and narrower for top-ranking countries. The Monte Carlo results can also give an idea of sensitivity to the various assumptions.

Figure 2 Simulated 2019 MCI scores (median values and confidence intervals*)

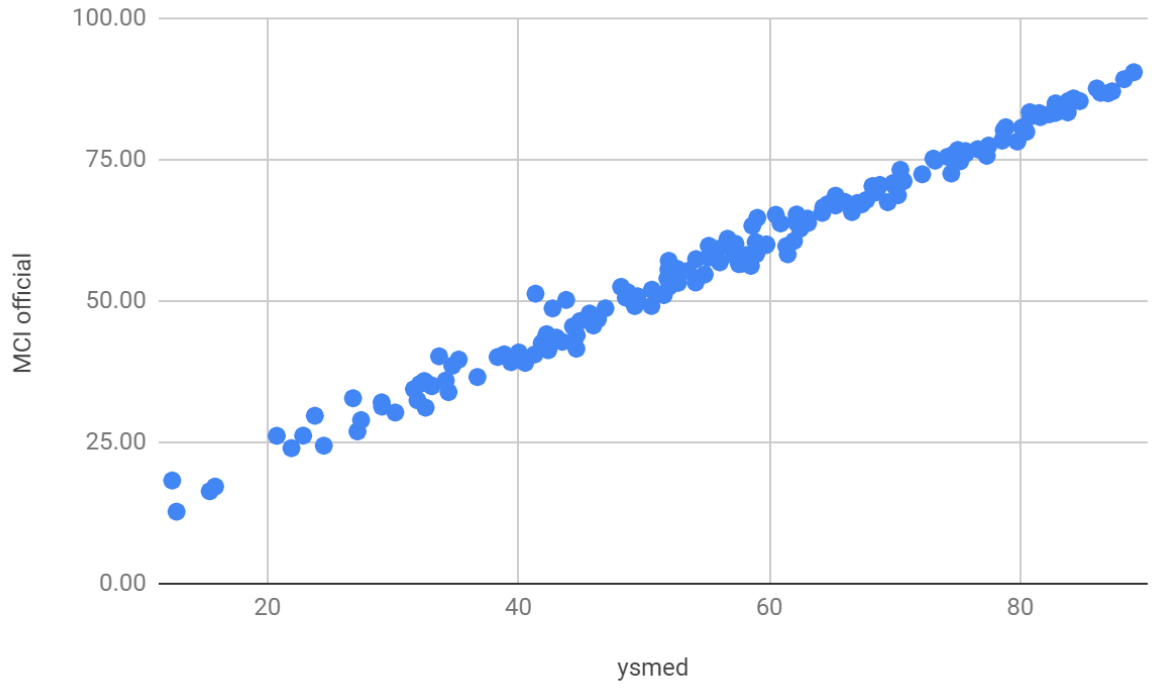


** Confidence intervals show the 30-70% and 5-95% percentiles*

Source: European Commission, Joint Research Centre (2021)

The simulated median MCI scores correlate very well with the 'official' MCI index values (Pearson correlation = 0.99) **Figure 3**, especially in case of above average scoring countries, suggesting that the index can differentiate top performers with high confidence.

Figure 3: Simulated 2019 median scores and the MCI 'official' scores



Source: European Commission, Joint Research Centre (2021)

Figure 4 and **5** show the median ranks of the MCI for simulations with the arithmetic mean against the geometric mean and for simulations with the full set of indicators against those with the reduced set. This gives an idea of sensitivity of the rankings to these assumptions. The plot of the simulation results with the full and reduced indicator set show a noticeable scatter, while the scatter of the aggregation formula is limited. This implies that the selection of indicators may cause greater rank shifts.

To delve slightly further into the possibility of using a geometric mean, **Figure 4** shows the ranks of the arithmetic average plotted against the simulated ranks with a geometric mean. The results show that the impact of changing to a geometric mean is fairly limited and insignificant, with an average rank shift of around one place. However, some countries do shift by a significant amount, including the Republic of Maldives (19 places) and South Africa (17 places).

The overall implications of the uncertainty analysis are that the uncertainty in the rankings is manageable, and allows meaningful conclusions to be drawn from the index, although the set of indicators may cause a contribution to the uncertainty. Further refinement of the MCI indicator set, which has been already on the agenda of the GSMA and the planned replacement of proxies by better indicators can later surely help to improve the statistical qualities and robustness of the MCI in the future, once data availability allows it.

As recommended frequently by the JRC team in its statistical audits, it would be worthwhile to publish confidence intervals alongside the index scores and rankings in case of the MCI.

Figure 4: Simulated 2019 rankings (the arithmetic mean against the geometric mean)

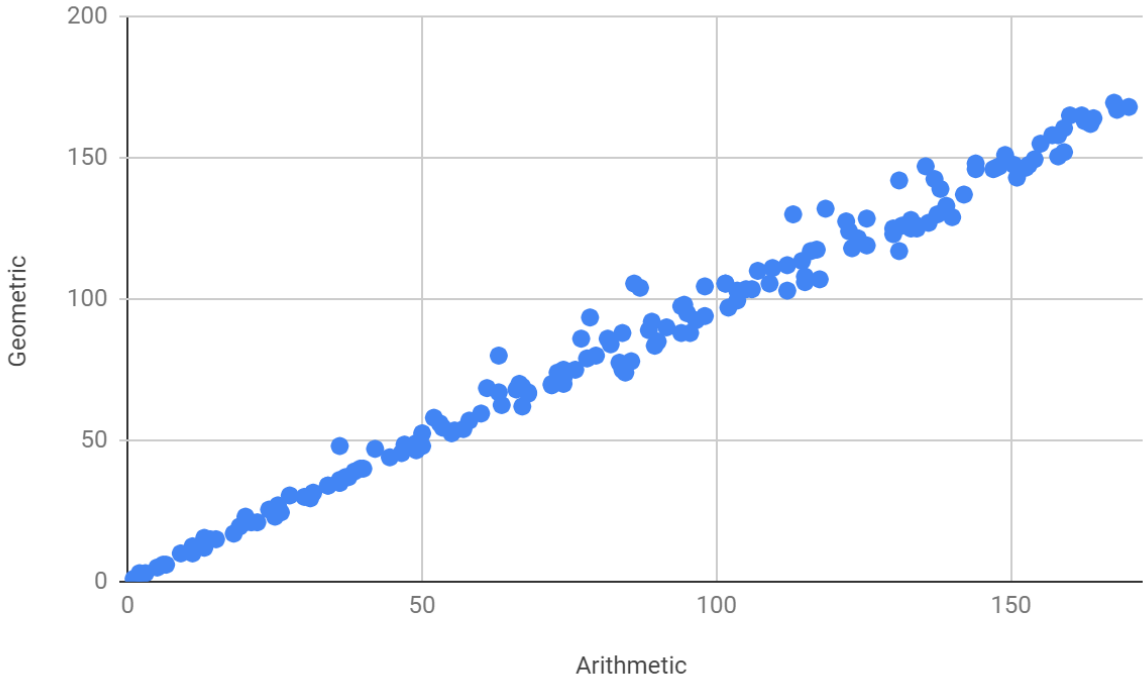
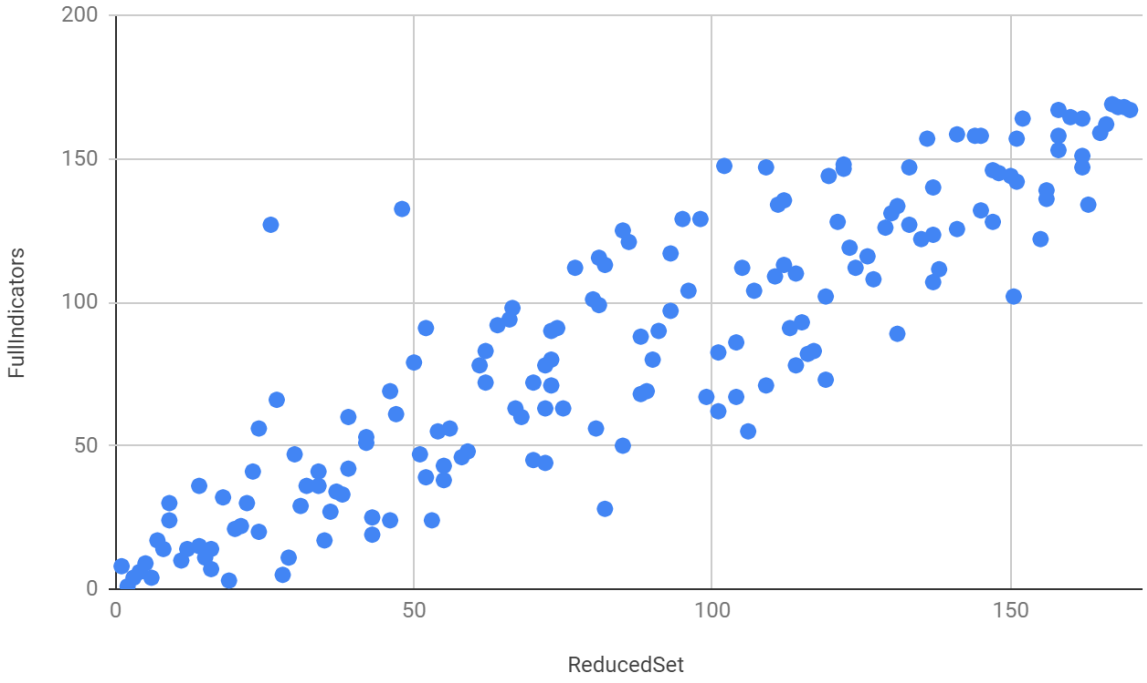


Figure 5: Simulated 2019 rankings (the 'reduced set' of indicators against the 'full set')



7. Conclusions

This technical report details the JRC statistical audit of the Mobile Connectivity Index (MCI) developed by the GSM Association (GSMA).

Overall, the present audit confirms that the MCI meets international quality standards for statistical soundness. The MCI framework is well constructed and robust. The MCI methodology is carefully defined and summarized in the background technical documentation of the index, which is publicly available to users and technical experts in the field. Therefore, the MCI can provide useful answers on why people are using mobile internet connectivity in some countries, and why people are not using mobile internet connectivity in other countries.

The audit conducted herein has shown the potential of the MCI in paving the way towards a monitoring framework that can help to measure the enablers of mobile internet connectivity, ultimately guide policy formulation and action in the EU and elsewhere.

The key findings and recommendations of the JRC statistical audit

- First, the MCI methodology is in general coherent and robust. Pillars of the MCI are positively correlated with the index; correlations of pillars are balanced. The correlation analysis in the audit confirms the adequacy of equal weights of MCI pillars. Weights within the pillars are not very different from equal weights, except for pillar 3 and pillar 4. For the sake of simplicity and communication, equal weights could be considered by the developers at the lower levels of the index too.
- Second, the audit confirms the need for further refinement of the MCI indicator set. This refinement has been already on the agenda of the GSMA and the planned replacement of proxies by better indicators can surely help to improve the statistical qualities of the MCI in the future, once data availability allows.
- Third, and related to the previous point on the possible improvement of background data, the JRC audit recommends publishing the number/share of imputed values alongside the index, its pillars and indicators.
- Fourth, minor changes in the normalisation procedure for all indicators could be considered by the MCI developers, as it may enhance the reliability and integrity of the index.
- Fifth, we recommend adding easy-to-understand formulas of data transformations into the methodology document. This may further transparency and clarity in the current development phase of the MCI.
- Finally, the uncertainty in the rankings is estimated to be manageable, and allows meaningful conclusions to be drawn from the index. An important implication of the JRC uncertainty analysis is that country scores can be stated to be within around 13 scores of precision, although some countries are especially sensitive to the assumptions made. To enhance transparency and accountability of the MCI, it would be worthwhile to publish confidence intervals alongside the MCI scores and rankings.

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Abbreviations

GSMA	GSM Association (GSMA)
MCI	Mobile Connectivity Index
COIN	Competence Centre on Composite Indicators and Scoreboards the JRC
JRC	Joint Research Centre of the European Commission

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